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Cyber Hasanat: A Service-Learning Approach to Building Digital Citizenship in Education

Sakinah Ali Pitchay

Foreword

Welcome to the October 2025 edition of the *Compilation of Research Papers on STEM (Science, Technology, Engineering & Mathematics)*. This volume highlights innovative and interdisciplinary research addressing real-world environmental, technological, and educational challenges.

The studies range from bioaccumulation of heavy metals in aquatic ecosystems and green water treatment using animal-based coagulants, to robotic technology for sustainability, solar thermal systems in agriculture, and UAV thrust performance. Further contributions explore sustainable aviation fuels, biotechnological advances in Kappaphycus spp., and cybersecurity education through game-based learning and service-learning initiatives.

Together, these works reflect the transformative power of STEM in advancing sustainability, digital resilience, and technological progress. We hope this compilation inspires continued exploration and innovation for a more sustainable and connected future.

Chapter 1
Bioaccumulation of Heavy Metals in Snails and Bivalves as Bioindicators of Aquatic Pollution in Tasik Lindungan Burung, Unisel

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ABSTRACT
The bioaccumulation of heavy metals in aquatic organisms is a critical indicator of environmental pollution and food safety risk. This study quantified copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb) in snails (*Pomacea canaliculate*) and mussels (*Sinanodonta woodiana*) collected from Tasik Lindungan Burung, Malaysia. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was employed following microwave-assisted nitric acid digestion, and results were benchmarked against certified reference material SRM 2976 (Mussels Tissue, NIST). Concentrations in mussels ranged from 0.0012–0.063 ppm (Cu), 0.042–0.064 ppm (Zn), 0.0096–0.018 ppm (Cd), and 0.0012–0.0041 ppm (Pb). Snails exhibited higher values, with 0.024–0.061 ppm (Cu), 0.132–0.250 ppm (Zn), 0.014–0.031 ppm (Cd), and 0.0005–0.0016 ppm (Pb). When compared with the Malaysian Food Regulations 1985, which specify maximum permissible levels of Cd ≤ 1.0 ppm and Pb ≤ 2.0 ppm in molluscs, all measured concentrations were within safe limits. Furthermore, under the Environmental Quality Act 1974, the results suggest low immediate ecological risk, although recovery rates (<5% relative to SRM 2976) highlight methodological limitations in accurately estimating true environmental burdens. The findings confirm the suitability of molluscs as bioindicators while underscoring the need for improved analytical protocols to enhance compliance monitoring under Malaysia's environmental and food safety frameworks.

Keywords: Heavy Metals, Bioaccumulation, Mollusks, Snails, Environmental Monitoring

1. INTRODUCTION

The biomonitoring of heavy metals in mollusks has garnered considerable attention as an effective approach for assessing environmental contamination. Mollusks, including bivalves and gastropods, are well-recognized bioindicators due to their capacity to accumulate heavy metals from their environment (Ozuni et al., 2024). Tasik Lindungan Burung, located within Universiti Selangor (UNISEL), represents a vital aquatic ecosystem that supports a diverse array of aquatic organisms. However, rapid industrialization, urbanization, and anthropogenic activities contribute to heavy metal influx into this aquatic system, posing potential risks to aquatic biota and human health. Previous studies have demonstrated that heavy metal accumulation in mollusks serves as a reliable proxy for pollution levels in aquatic ecosystems (Hamed et al., 2024). Therefore, a comprehensive understanding of heavy metal contamination in mollusks is crucial for evaluating the ecological health of Tasik Lindungan Burung and ensuring the safety of aquatic organisms and human consumers.

The presence of heavy metals in aquatic ecosystems remains a critical environmental issue due to their persistence, bio-accumulative properties, and toxicity (Adesina, 2024). Mollusks, as filter feeders and sediment dwellers, are highly susceptible to heavy metal contamination, making them valuable bioindicators. However, limited research has been conducted to quantify heavy metal accumulation in mollusks inhabiting Tasik Lindungan Burung, UNISEL. The absence of comprehensive biomonitoring data hinders the implementation of mitigation strategies to safeguard the aquatic ecosystem and public health. Previous studies indicate that metal toxicity significantly affects mollusk physiology and reproductive success, potentially disrupting the entire aquatic food web (Almashhadany et al., 2024). Thus, there is an urgent need to determine heavy metal concentrations in mollusks to establish baseline data and guide future conservation measures.

This study aims to quantify heavy metal concentrations in selected mollusk species from Tasik Lindungan Burung, UNISEL, and evaluate their suitability as bioindicators for monitoring heavy metal pollution. Additionally, it seeks to identify potential sources of heavy metal contamination and propose effective management and mitigation strategies. To achieve these objectives, several measures should be implemented. By implementing these measures, this study aims to enhance knowledge on heavy metal pollution in Tasik Lindungan Burung and contribute to the development of effective environmental management policies to protect aquatic ecosystems.

2. METHODOLOGY

2.1. Sampling Area

In this study, bivalve (*S. woodiana*), snail (*P. canaliculata*) samples were sampled from five different stations lake site at Tasik Lindungan Burung, Unisel (Figure 1).

Location	Coordinate
S1(K1/S1)	3°25'42.3"N 101°26'11.0"E
S2(K2/S2)	3°25'41.8"N 101°26'21.2"E
S3(K3/S3)	3°25'41.0"N 101°26'15.1"E
S4(K4/S4)	3°25'30.1"N 101°26'09.5"E
S5(K5/S5)	3°25'54.2"N 101°26'10.3"E

Figure 1. Map and coordinate table of sampling sites at Tasik Lindungan Burung Unisel, Selangor.

2.2. Sample Collection and Preparation

The sample collection and preparation were done according to the method described by Gawad (2018) with modification. The bivalve with same size (ranging from 5 to 11 cm length and 3-7 cm width) and snails with size (ranging from 3-5 cm length and 2 to 5 cm width) were randomly collected from all sites (Figure 2). Samples then were washed with tap water to remove any contaminants before preserved in a freezer.

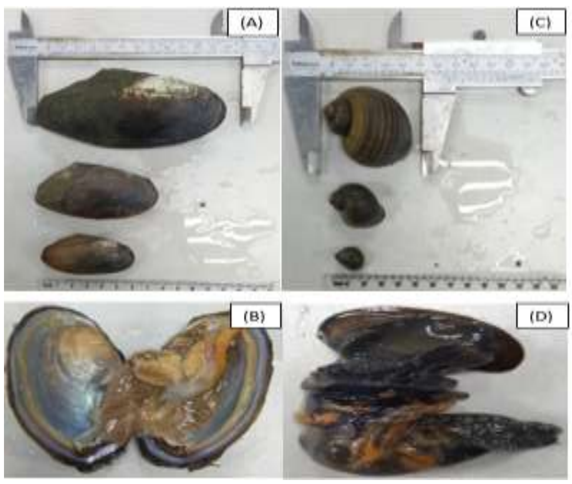

Figure 2. (A) The bivalve of different size and (B) inner shells and flesh of the bivalve. (C) snails with different size and (D) inner flesh of the snail.

2.3 Determination of Heavy Metals

The soft tissues of snail and bivalve were separated from the shell and washed with distilled water. Soft tissues were dried in oven at 60°C until drying completely before powdered in agate mortar. The digestion for soft tissues was carried out using Teflon Bomb nitric acid method with slight modification adopted from Sheng et al, (2021).

The testings were done in triplicate where specifically, 0.05 g dried powder sample was added to 1.5 ml 65% HNO_3 (nitric acid) were placed in Teflon beaker. Teflon beaker then closed tightly and heated in oven at 100°C for 8 hours. Upon cooling, digested sample the transferred into centrifuge tube and topped up to 10 ml with deionized water. The concentration of Cu, Zn, Cd and Pb in all samples were then analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

The experiments were carried out in triplicate. A one-way ANOVA using SPSS version 25 was used to analyzed the experimental data, and a value of $p<0.05$ was considered statistically significant, and the results were expressed as the mean ± SD (standard deviation).

3. RESULT AND DISCUSSION

3.1. Heavy Metal in Molluscs (*S. woodiana*)

The concentrations of Cu, Zn, Cd, and Pb in mussels ranged between 0.0012–0.063 ppm, 0.042–0.064 ppm, 0.0096–0.018 ppm, and 0.0012–0.0041 ppm, respectively (Table 1). The relatively low Cu and Zn levels reflect their essential trace element role, where homeostatic regulation may limit excessive accumulation. The levels detected in all samples are well within acceptable ranges when compared with international dietary intake levels and are considered safe for human consumption. Recent studies in Malaysia, such as those on *Tegillarca granosa* and *Cerithidea obtusa*, similarly report that Cu and Zn concentrations in marine molluscs remain within safe limits and pose negligible risk to human health (Yap et al., 2023, 2024). Eugene Ng et al, (2013) stated that zinc accumulated the fastest in body of bivalve such as mussel and abundant in seafood.

Food Regulations, (1985) stated that Cd and Pb concentrations were consistently below the permissible limits set by the Malaysian Food Regulations 1985 (Cd ≤ 1.0 ppm; Pb ≤ 2.0 ppm). These results are indicative of minimal food safety risk from mussel consumption in the studied lake. This observation aligns with findings from Yap et al., (2024), who reported cadmium concentrations in Malaysian gastropods approaching regulatory thresholds in certain regions. This precaution aligns with recent food safety surveillance efforts in Malaysia that emphasize tracking cumulative exposure to heavy metals over time (Yap et al., 2023).

Table 1 Concentration of heavy metals found in molluscs samples from five sites of Tasik Lindungan Burung Unisel.

Sample	N	Cu (ppm)	Zn (ppm)	Cd (ppm)	Pb (ppm)
C	3	0.0176	0.0174	0.0175	0.0175
K1	3	0.0021	0.0522	0.0149	0.0022
K2	3	0.0012	0.0419	0.0096	0.0012
K3	3	0.0014	0.0458	0.0105	0.0026
K4	3	0.0027	0.0517	0.0144	0.0027
K5	3	0.0024	0.0635	0.0181	0.0041

3.2. Heavy Metal in Snails (*Pomacea canaliculate*)

Snails exhibited higher metal concentrations than mussels, with Cu (0.024–0.061 ppm), Zn (0.132–0.250 ppm), Cd (0.014–0.031 ppm), and Pb (0.0005–0.0016 ppm) (Table 2). The elevated Zn levels are consistent with the species' physiological demand and known bioaccumulation capacity. Although Cd and Pb concentrations were higher in snails compared to mussels, all values remained well within Malaysian Food Regulation limits.

This finding highlights the species' role as a more sensitive bioindicator of environmental metal availability.

Table 2 Concentration of heavy metals found in snail samples from five sites of Tasik Lindungan Burung Unisel

Sample	N	Cu (ppm)	Zn (ppm)	Cd (ppm)	Pb (ppm)
S1	3	0.0423	0.2020	0.0267	0.0013
S2	3	0.0611	0.1530	0.0252	0.0010
S3	3	0.0579	0.2500	0.0240	0.0014
S4	3	0.0241	0.1320	0.0145	0.0005
S5	3	0.0294	0.1790	0.0307	0.0016

A comparison with Malaysian regulatory limits confirms that all measured Cd and Pb concentrations in both taxa were within safe limits (Table 3). Notably, Cu and Zn are not regulated under the Malaysian Food Regulations 1985, although their monitoring is important under the Environmental Quality Act 1974, which governs discharges and aquatic contamination thresholds (Act 127, 1974). The concentrations observed in this study were substantially lower than international food safety benchmarks reported in comparable studies across Southeast Asia.

Despite low absolute values, analytical recoveries against SRM 2976 (Mussels Tissue, NIST) were <5%, indicating systematic underestimation likely due to incomplete digestion or matrix suppression during ICP-MS analysis. This highlights a methodological limitation rather than a true reflection of absence of contamination. Future studies should implement optimized digestion protocols, matrix-matched calibration, and parallel analyses with additional certified reference materials to ensure robust quantification.

Table 3 Comparison of heavy metals concentration found in molluscs and snails samples from five sites of Tasik Lindungan Burung Unisel with Malaysian limits.

Element	Malaysian Limit (ppm)	SRM 2976 Reference (ppm)	Observed Range (ppm)	Compliance
Cd	1.0	0.82 ± 0.16	0.0096–0.031	Within limit
Pb	2.0	1.19 ± 0.18	0.0005–0.0041	Within limit
Cu	n/a	4.16 ± 0.38	0.0012–0.061	n/a
Zn	n/a	137.8 ± 5.1	0.042–0.250	n/a

4. CONCLUSION

This study evaluated the bioaccumulation of copper, zinc, cadmium, and lead in mussels (*S. woodiana*) and snails (*P. canaliculate*) from Tasik Lindungan Burung, Malaysia. The results, expressed in ppm, revealed that snails accumulated higher concentrations of heavy metals than mussels, particularly for Zn and Cu. However, cadmium (0.0096–0.031 ppm) and lead (0.0005–0.0041 ppm) levels in both taxa were far below the maximum permissible limits stipulated under the Malaysian Food Regulations 1985 (Cd ≤ 1.0 ppm; Pb ≤ 2.0 ppm). From a regulatory standpoint, these findings indicate that mollusks from this site do not pose an immediate risk to food safety or exceed environmental quality thresholds under the Environmental Quality Act 1974.

Nevertheless, the consistently low recovery rates (<5% relative to SRM 2976) underscore a methodological limitation that may underestimate true contamination levels. This constraint emphasizes the need for optimized digestion procedures, matrix-matched standards, and routine incorporation of certified reference materials to ensure accurate assessments. Importantly, the study reinforces the utility of mollusks as sentinel organisms for aquatic pollution monitoring and provides baseline data that align with Malaysia's dual regulatory focus on food safety and environmental protection.

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Chapter 2
Emerging Roles of Animal-based Coagulants in Green Water Treatment Technologies

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ABSTRACT
Rapid urbanization and industrial growth have increased the demand for clean water worldwide, which has heightened the need for economical and ecologically friendly treatment solutions. Despite their effectiveness, traditional coagulants like alum and ferric salts increase the creation of sludge, cause secondary pollution, and pose health hazards. The processes, effectiveness, and practicality of animal-based coagulants as sustainable water purification options are examined in this paper. These materials, especially chitosan, gelatin, casein, albumin, and blood proteins, are derived from renewable by-products like crustacean shells, milk, eggs, and animal tissues. They have high molecular weight and amphoteric functional groups that allow for charge neutralization, adsorption, and polymer bridging. Significant decreases in turbidity, suspended solids, organic load, heavy metals, and microbial contaminants have been shown when they are applied to different water matrices. Their physicochemical properties and flocculation efficiency are influenced by extraction and processing techniques such as acid precipitation, enzymatic hydrolysis, and freeze-drying. Through waste valorisation and decreased sludge toxicity, the article also emphasizes environmental and economic sustainability. To enable industrial use, however, issues like regulatory acceptability, restricted standardization, and raw material variability must be resolved. All things considered, coagulants derived from animals are a potential class of bio-coagulant that can aid in the shift to more environmentally friendly and circular water treatment systems.

Keywords: Animal-based coagulants, chitosan, gelatin, water treatment, sustainability

1. INTRODUCTION

One of the 21st century's most pressing environmental issues is still water pollution and scarcity. Climate variability, industrialization, agricultural intensification, and rapid population increase have all had a significant impact on the amount and quality of water supplies worldwide. The World Health Organization (WHO) estimates that by 2050, nearly half of the world's population will reside in water-stressed areas, and that over two billion people lack access to safely regulated drinking water (Kammeyer et al., 2020). The need for efficient and sustainable treatment technologies that can handle contaminants like suspended solids, organic matter, dyes, and heavy metals that typically come from residential, commercial, and agricultural activities has increased due to the growing demand for clean water (Kumar et al., 2023).

Coagulation–flocculation is still one of the most popular and dependable primary treatments for water clarifying among the purification technologies now in use. By destabilizing and aggregating suspended materials, it efficiently eliminates turbidity and colloidal particles. Because of their great efficiency and ease of use, chemical coagulants including polyaluminum chloride, ferric chloride, and aluminum sulphate (alum) have been utilized historically. However, widespread usage of these artificial coagulants has led to growing health and environmental issues (Jasim et al., 2022). There have been numerous reports of problems such pH imbalance, increased sludge production, residual metal accumulation, and possible toxicity to aquatic life. Moreover, chemical coagulants require a lot of energy to produce and dispose of, and they frequently conflict with sustainable water management practices (Sudan et al., 2024).

As a result, bio-coagulants have drawn increasing interest as sustainable and environmentally beneficial substitutes. These materials, which come from natural sources like microorganisms, plants, and animals, operate similarly while lowering sludge toxicity and chemical dependency. Animal-based coagulants stand out among the others because of their high molecular weight, amphoteric functional groups, and potent affinity for contaminants. Active biomolecules like chitosan, gelatin, casein, albumin, and plasma proteins, which are mostly derived from crab shells, animal skin, bones, blood, milk, and eggs, display a natural flocculating capacity through charge neutralization, adsorption, and polymer bridging (da Silva et al., 2025; Kristianto et al., 2025).

Animal-based coagulants, as opposed to synthetic ones, are non-toxic, biodegradable, and frequently made from food or industrial waste, which makes them compatible with waste valorisation and the circular economy. By using them, waste is converted into products with additional value for sustainable water treatment, which also lessens the impact on the environment. Notwithstanding these benefits, difficulties with raw material unpredictability, extraction complexity, cost-effectiveness, and public acceptance continue to restrict large scale implementation (da Silva et al., 2025).

This review aims to synthesize current knowledge on the application, mechanisms, performance, and sustainability of animal-based coagulants in water treatment. It highlights their comparative advantages over conventional coagulants, evaluates existing research trends, and identifies key challenges that must be addressed for broader industrial adoption. By consolidating existing evidence, this paper seeks to contribute to the growing discourse on sustainable, nature-based technologies for water purification.

2. OVERVIEW OF ANIMAL-BASED COAGULANTS

2.1. Classification and Sources

Natural macromolecules with coagulation-flocculation characteristics that are obtained from animal tissues or byproducts are referred to as animal-based coagulants. Depending on their origin and molecular makeup, they can be roughly divided into materials based on proteins and polysaccharides (Kristianto et al., 2025; Piazza & Garcia, 2016). Chitosan, which is derived from the deacetylation of chitin, a structural element found in crustacean shells like those of shrimp, crabs, and lobsters, is the main representative of the polysaccharide group. Chitosan has a strong cationic charge in acidic environments because of its linear polymeric chain, which contains hydroxyl and amino groups. Because of this characteristic, it works well to destabilize negatively charged particles in water and create dense flocs with little sludge (Isibor et al., 2023).

Gelatin, casein, albumin, and blood plasma proteins are among the protein-based group; they are derived from animal bones, skin, milk, eggs, and blood. Functional groups like carboxyl (-COOH), amino ($-NH_2$), and hydroxyl (-OH) found in amino acid residues in these materials can ionize at different pH levels, allowing for electrostatic interactions with dissolved contaminants and suspended particles (Lin et al., 2024).

By turning plentiful and underutilized animal by-products into valuable bio-based treatment agents, using these materials also promotes waste valorisation. For instance, the meat and dairy industries produce large amounts of leftover proteins that can be recovered for water treatment, while the seafood business produces thousands of tons of crustacean debris every year. This strategy is in line with the circular economy and sustainable waste management concepts (Zaman et al., 2023).

2.2. Major Types and Characteristics

Because of its potent cationic and antibacterial qualities, chitosan is still the most researched animal-based coagulant. According to studies, under ideal circumstances, chitosan may eliminate up to 90% of heavy metals and more than 95% of turbidity (Kadouche et al., 2012). The degree of deacetylation, solution pH, and molecular weight all affect its effectiveness. Protonated amino groups on the polymer backbone allow negatively charged colloids to bridge and neutralize charges in acidic conditions, which speeds up the development of floc (Roussy et al., 2005).

Gelatin, a hydrolysed collagen derived from animal bones and skin, is amphoteric, meaning it may work in neutral or acidic conditions. Because of its abundance of glycine, proline, and hydroxyproline, it has flexible chains that can bind particles through hydrophobic and hydrogen bonding interactions (Dille et al., 2021; Sarwan et al., 2024).

Near its isoelectric point (pH = 4.6), where its net charge is neutral and encourages the aggregation of suspended solids, casein, the primary protein in milk, demonstrates exceptional coagulation activity. While calcium-precipitated forms of casein increase floc density, casein micelles can trap organic materials and small particles (Huppertz et al., 2018). According to a study, casein-based coagulants were able to remove up to 85% of the turbidity from effluent from food processing (Suman et al., 2018).

Extracted from abattoir waste, blood proteins like albumin and globulin have a high charge density and surface activity. They unfurl and reveal additional binding sites when heated, which improves flocculation efficiency (Zheng, 2023). Proteins like egg albumin and bovine plasma have shown great promise in wastewater treatment for eliminating pollutants like dyes. It has been demonstrated that bovine plasma protein efficiently removes 76% and 68% of the turbidity and colour from synthetic dye effluent, respectively (Ohashi et al., 2012). Similarly, when heat or pH-induced denaturation occurs, the main protein in egg white, egg albumin, exhibits coagulant activity, enabling protein chains to adsorb impurities and create stable flocs (Zahara et al., 2024).

3. MECHANISMS OF COAGULATION

Animal-based materials' complex molecular structures with reactive functional groups that interact with dissolved and suspended pollutants are what give them their high coagulation efficiency. Charge neutralization, adsorptive contact, and polymer bridging are the main ways in which these coagulants work; they frequently cooperate to destabilize colloidal particles and encourage floc formation. The coagulant type, molecular weight, solution chemistry, and operational parameters including pH and mixing intensity all affect each mechanism's relative contribution.

3.1. Charge Neutralization

In natural or wastewater systems, the majority of suspended particles and colloids have a negative surface charge, which causes electrostatic repulsion to inhibit aggregation. When these negatively charged surfaces contact with positively charged sites on the coagulant molecules, charge neutralization takes place, which effectively lowers the zeta potential and destabilizes the suspension(Dawood et al., 2024).

This mechanism makes animal-based coagulants, especially chitosan, very efficient because of their protonated amino groups ($–NH_3^+$) in acidic environments. These cationic sites enable quick particle agglomeration by electrostatically binding to anionic colloids when added to water (Kim et al., 2023). Under ideal circumstances, this procedure, which required charge neutralization, removed 92.54% of the turbidity. Likewise, depending on the pH of the system, blood proteins and gelatin, which have amino acid residues with ionizable side chains, can function as amphoteric polyelectrolytes that neutralize both positively and negatively charged contaminants (Lunkad et al., 2021).

3.2. Adsorptive Interaction

Adsorption contributes significantly to the elimination of pollutants in addition to electrostatic effects. Protein-based coagulants' surfaces have a variety of binding sites that can interact hydrophobically, form hydrogen bonds, and create Van der Waals forces with both organic and inorganic pollutants. For dissolved chemical compounds, dyes, and hydrophobic contaminants that might not react to charge-based coagulation alone, this method works especially well (Liu et al., 2024). The degree of denaturation, molecular flexibility, and availability of exposed functional groups all affect the adsorption capability of coagulants generated from animals. By increasing active site exposure by regulated heating or enzymatic hydrolysis, binding efficiency can be improved (Amesaka et al., 2025).

3.3. Polymer Bridging and Network Formation

When long-chain biopolymers adsorb onto several colloidal particles at once, a three-dimensional network is formed that encourages floc growth and stability. This phenomenon is known as polymer bridging. High-molecular-weight coagulants like gelatin and chitosan have this mechanism. Unoccupied chain segments extend into the solution and cling to nearby particles when partially adsorbed onto particle surfaces, creating sizable, stable flocs that settle well (Liu et al., 2024).

The coagulant molecular weight, dose, and mixing energy are some of the variables that affect polymer bridging efficiency (Alioua & Lapointe, 2023). Research shows that chitosan with a higher molecular weight and degree of deacetylation greatly increases the effectiveness of microalgae removal, with rates above 94% (Rasweefali et al., 2024). In a similar vein, partially denatured gelatin showed improved bridging behavior as a result of polar group exposure and greater chain mobility. But overdosing might cause charge reversal or total surface coverage, which would stop more bridging and cause the particles to stabilize (Tiwari et al., 2024).

4. PERFORMANCE AND SUSTAINABILITY ANALYSIS

4.1. Treatment Performance in Water and Wastewater

Research continuously shows that animal-based coagulants remove pollutants with efficiency that are on par with those of traditional alum or ferric salts. Molecular structure, active functional groups, and operational parameters like pH and dose all affect how successful they are. With a conductivity removal percentage of 73.02%, TSS removal of 98.93%, and COD removal of 33.95%, the study shows that chitosan derived from crustacean shells efficiently eliminates turbidity, indicating its potential as a natural coagulant (Hassan et al., 2022). Chitosan is appropriate for treating drinking water and industrial wastewater because it has antibacterial and heavy-metal binding properties in addition to its physical clarity properties (Coleman et al., 2024).

In wastewaters that are rich in organic matter, gelatin and casein have similar benefits. Glycine and hydroxyproline-rich gelatin work well close to its isoelectric point (pH 4.7–5.2), removing 80–90% of colour (Rigueto et al., 2021). Acid hydrolysis, which denatures proteins and reveals reactive sites, has been shown to remove turbidity from blood plasma-derived coagulants with up to 95% efficiency (Eckert et al., 2025). Despite encouraging lab results, stability and source variability still limit their practical application.

In general, compounds derived from animals work best in mildly acidic environments, producing more compact, readily settleable flocs and needing smaller dosages than inorganic coagulants. They are appropriate for both drinking and wastewater environments due to their multifunctionality, which includes charge neutralization, adsorption, and bridging.

4.2. Sustainability Considerations

Animal-based coagulants have a significant positive impact on environmental sustainability in addition to performance. They support waste valorisation and lessen the pressure on landfills by using by-products from the dairy, meat, and fishery industries. Extracting gelatin from hides or turning shrimp shells into chitosan are two examples of circular economy practices that turn trash into beneficial therapeutic agents (Zulkarnain et al., 2024).

Regarding sludge quality, there are several benefits to treating wastewater with bio-coagulants, especially chitosan. Compared to conventional metal salt coagulants, flocs generated from chitosan are less toxic, lighter, and biodegradable, which lowers disposal costs and environmental hazards. According to research, chitosan-flocculated sludge is safer for the environment since it breaks down more quickly and has fewer residual metals (Ahmed et al., 2024; Coleman et al., 2024).

Economically speaking, lower dosage requirements and less post-treatment handling offset production costs, which range from USD 3 to USD 15 per kilogram. But there are still issues with scalability. If extraction and purification are not optimized, they might be energy-intensive, especially for chitosan. Furthermore, acceptability in applications involving potable water may be constrained by ethical or religious constraints as well as public image. Additionally, bio-coagulant regulatory frameworks are still in their infancy, requiring additional safety testing and quality control (Leon-Pulido et al., 2025).

5. RESEARCH GAPS, FUTURE PERSPECTIVES, AND CONCLUSION

The development and assessment of animal-based coagulants have advanced significantly, but there are still a number of obstacles preventing their widespread use in water treatment. The two biggest obstacles are quality control and uniformity. Raw material variability, which arises from variations in species, food, and extraction techniques, restricts reproducibility and causes uneven performance. To guarantee product consistency and regulatory approval, standard extraction and characterization procedures must be established. These procedures should include determining the ideal molecular weight, degree of deacetylation, and protein purity (AbuAlhaj & Nassar, 2023).

The incomplete mechanistic knowledge of the interactions between certain contaminants and bio-coagulant molecules represents another significant research gap. The relative contributions of charge neutralization, adsorption, and polymer bridging under various circumstances are still unknown, despite their widespread recognition. To clarify these mechanisms and direct the creation of modified or hybrid formulations with improved performance, sophisticated spectroscopic and modelling methods such as FTIR and molecular dynamics simulations should be used (El Ouadrhiri et al., 2025).

Practically speaking, more research is needed to determine scale-up and economic viability. There is little information on operational stability and cost in real-world settings, and the majority of current research is restricted to laboratory or pilot studies. To compare manufacturing costs, energy consumption, and environmental effects to those of traditional coagulants, thorough life-cycle studies and techno-economic analyses are required. Cost-effectiveness and sustainability could be further improved by localized production using seafood or butcher waste, especially in areas with an abundance of raw materials (Leon-Pulido et al., 2025).

Cultural and ethical factors are very significant when it comes to sustainability. Since some communities may find the use of products generated from animals to be sensitive, clear safety messages and the usage of non-edible or discarded waste streams are required to guarantee public approval. Their place in a circular economy model would be strengthened by research into the value-adding potential of sludge generated by animal-based coagulants, such as its potential for reuse as biofertilizers or soil amendments (Zaman et al., 2023).

In the future, combining animal-based coagulants with other synthetic or natural elements presents a viable path. The creation of hybrid bio-coagulants that combine the benefits of gelatin, chitosan, or agents derived from plants may lead to improved performance and wider application in a variety of water matrices. Policymakers, environmental engineers, and material scientists working together will be essential to accelerating industrial acceptance and regulatory approval (Tsoutsa et al., 2024).

In conclusion, animal-based coagulants are a novel class of renewable, biodegradable, and environmentally friendly agents that support international sustainability objectives. These materials have the potential to become a widely used substitute for chemical coagulants by filling up current knowledge gaps, increasing production efficiency, and promoting social acceptance. This would greatly improve the sustainability, safety, and cleanliness of water treatment systems.

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Chapter 3
Robotic Technology as a Determinant of Sustainability-Based Performance: SEM and Focus Group Evidence from Malaysia

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ABSTRACT
This study investigates the influence of robotic technology on sustainability-based performance in Malaysia's food manufacturing sector using a mixed-methods approach that combines Structural Equation Modeling (SEM) and focus group discussions. The SEM analysis of data from 120 manufacturing firms reveals that robotics significantly enhances economic ($\beta = 0.54$), environmental ($\beta = 0.36$), and social performance ($\beta = 0.32$), with an overall strong effect on sustainability-based performance ($\beta = 0.81$). Focus group insights further confirm these results, indicating that robotics improves productivity, energy efficiency, and workplace safety while promoting workforce upskilling. Despite challenges such as high investment costs and limited technical expertise, robotics is shown to be a key enabler of Malaysia's Industry 4.0 goals, driving sustainable development and industrial competitiveness through smarter, cleaner, and safer production systems.

Keywords: Robotics, Sustainability-Based Performance, Structural Equation Modeling, Focus Group, Malaysian Food Manufacturing

1. INTRODUCTION

The integration of robotic technology in manufacturing has become a cornerstone of industrial modernization and sustainable production. Within Malaysia's food manufacturing sector, robotics offers solutions that enhance productivity, precision, and sustainability. Globally, robotics adoption has demonstrated measurable impacts on cost efficiency, process standardization, and workplace safety. Developed economies such as Japan, South Korea, and Germany have integrated robotics into manufacturing ecosystems, creating smart factories with interconnected cyber-physical systems.

Even with rapid technological advancement, the literature still presents an insufficient knowledge of how automation transcribe into measurable sustainability result across industries. Quantitative support from Doran et al., (2025) shows that robot density has a strong positive relationship with Gross Value Added (GVA) in manufacturing, highlighted economic benefits in developed regions. Meanwhile, Almusharraf, (2025) revealed automation's paradoxical effects enhancing productivity and energy efficiency but exacerbating inequality and emissions highlighting global sustainability trade-offs. Together, these studies reveal a major research gap: how robotic integration affects sustainability-based performance in developing-country manufacturing, particularly in sectors like food production, where automation adoption remains limited. To address this, the present study examines the determinant role of robotic technology in driving economic, environmental, and social performance within Malaysia's food manufacturing sector through a mixed-methods approach. This investigation aims to provide empirical insights into the multifaceted impact of robotic technology, thereby contributing to a more nuanced understanding of sustainable industrial development in emerging economies (Rahmat et al., 2022).

2. LITERATURE REVIEW

The integration of robotics in manufacturing is widely recognized as a catalyst for operational excellence, productivity, and sustainability. Robotics, programmable mechanical systems capable of performing complex tasks autonomously or semi-autonomously, has evolved from simple automation to intelligent systems embedded with sensors, vision technologies, and artificial intelligence (AI). According to Bogue (2022), the latest generation of industrial robots is more flexible, adaptable, and energy-efficient, enabling broader use across manufacturing sectors, including food production. In the Malaysian context, Taha et al., (2024) empirically found that the adoption of automated technologies in the food manufacturing industry significantly improves operational efficiency, product quality, and environmental performance, positioning automation as a key driver of sustainability transformation. Moreover, robotics drives sustainable development, enhances healthcare, reduces inequality, and supports economic growth (Almuaythir et al., 2024).

From an economic sustainability perspective, robotics lowers operational costs, increases production speed, and minimizes human error. Lee et al. (2021) and Ahmad et al. (2020) highlighted its ability to sustain continuous production cycles with minimal downtime, improving return on investment (ROI). Additional benefits include waste reduction, inventory control, and consistent product quality. In food manufacturing, robotics supports repetitive and labor-intensive tasks, such as packaging, labeling, palletizing, and quality inspection, enhancing efficiency and cost savings.

In terms of environmental sustainability, robotics improves energy efficiency and resource optimization. Robots integrated with computer vision and AI can precisely manage materials, reducing waste and overproduction. This aligns with circular economy principles, promoting cleaner and more efficient production. Sarkis and Zhu (2020) emphasized that automation technologies support green manufacturing by managing renewable energy and minimizing carbon footprints. In Malaysia, robotics adoption in food processing aligns with Sustainable Development Goal (SDG) 9: Industry, Innovation, and Infrastructure, by promoting cleaner, resource-efficient technologies.

From a social sustainability perspective, robotics enhances workplace safety, reduces physical strain, and transforms the workforce toward higher-skilled roles. By minimizing exposure to hazards and repetitive stress, robotics creates safer, more ergonomic environments. However, Tan and Hashim (2021) stress that digital transformation requires continuous reskilling to equip workers for technological change.

Despite these benefits, Ooi and Rahman (2022) noted persistent barriers in developing countries, including high investment costs, system complexity, and limited expertise. SMEs often lack financial capacity and technical support, while cultural resistance further slows adoption. Overcoming these challenges requires integrated ecosystems involving policy incentives, national training programs, and collaborative R&D among government, academia, and industry to ensure sustainable and inclusive robotics implementation.

3. METHODOLOGY

A mixed-methods research design combining Structural Equation Modeling (SEM) and focus group discussions (FGDs) was employed to validate and contextualize the impact of robotics on SBP.

3.1 Quantitative Phase: SEM Analysis

Data were collected from 120 respondents from medium and large food manufacturing firms across Malaysia. Constructs measured included Robotic Technology (RT), Economic Performance (EP), Environmental Performance (ENP), Social Performance (SP), and Sustainability-Based Performance (SBP). Each construct used a five-point Likert scale, and data were analyzed using AMOS 24.0.
Model Fit Indices: $\chi^2/df = 2.12$, CFI = 0.93, TLI = 0.91, NFI = 0.92, RMSEA = 0.06.
Reliability: CR > 0.85, AVE > 0.50, Cronbach’s Alpha > 0.80.

3.2 Qualitative Phase: Focus Group Discussions

Six focus group sessions were conducted involving 15 participants (managers, engineers, and supervisors) from six different companies. Discussions explored practical experiences, adoption barriers, and sustainability outcomes of robotics implementation. Thematic analysis identified major recurring themes, which were used to complement the SEM findings.

3.3 Ethical Considerations

Ethical approval was obtained from the university ethics committee. All participants provided informed consent, and their responses were anonymized to ensure confidentiality.

4. RESULTS AND DISCUSSION

4.1 SEM Results and Interpretation

The SEM analysis validated the proposed model linking Robotic Technology (RT) to the three sustainability dimensions; Economic Performance (EP), Environmental Performance (ENP), and Social Performance (SP), and the overall Sustainability-Based Performance (SBP) construct. The model achieved excellent fit indices ($\chi^2/df = 2.12$, CFI = 0.93, TLI = 0.91, NFI = 0.92, RMSEA = 0.06, SRMR = 0.04), indicating the hypothesized relationships are statistically valid and the constructs were well specified. Reliability measures also exceeded the threshold (Composite Reliability > 0.85; Average Variance Extracted > 0.50), confirming internal consistency and convergent validity. Table 1 shows the SEM results.

All paths are significant ($p < 0.05$), meaning robotic technology has a strong positive impact on all areas of sustainability-based performance.

Table1 Structural Equation Modeling (SEM) Results for Hypothesized Relationships

Hypothesized Relationship	Coefficient (β)	Significance (p)	Interpretation
RT → Economic Performance	0.54	< 0.01	Robotics enhances productivity, cost efficiency, and product quality.
RT → Environmental Performance	0.36	< 0.01	Robotics reduces waste, energy use, and supports clean production.
RT → Social Performance	0.32	< 0.05	Robotics improves worker safety, reduces physical strain, and increases job satisfaction.
RT → Sustainability-Based Performance	0.81	< 0.01	Robotics is the strongest technological determinant of SBP.

Note. *RT = Robotic Technology; SBP = Sustainability-Based Performance.*
Model fit indices: $\chi^2/df = 2.12$, CFI = 0.93, TLI = 0.91, NFI = 0.92, RMSEA = 0.06, SRMR = 0.04.

These coefficients demonstrate that robotic technology exerts a multidimensional influence on sustainable performance. The economic dimension displayed the strongest link, suggesting that productivity and cost optimization remain the main incentives for robotic investment among Malaysian manufacturers. This is consistent with global findings by Lee et al. (2021) and Ahmad et al. (2020), which emphasize that automation enhances efficiency through precision and process reliability.

The environmental dimension recorded moderate but significant influence ($\beta = 0.36$). Robotic systems contribute to resource optimization, waste minimization, and energy efficiency by controlling material dosage and minimizing production errors. Firms with fully automated processes also reported improved compliance with environmental standards such as ISO 14001 and HACCP, which aligns with sustainable manufacturing principles described by Sarkis and Zhu (2020).

The social dimension, though showing the smallest coefficient ($\beta = 0.32$), remains meaningful. Robotics adoption was found to directly reduce repetitive strain injuries and indirectly promote workforce transformation. This indicates a gradual shift from manual tasks toward supervisory and technical roles, representing the early stages of Industry 4.0-driven upskilling. Such social improvements, although slower to emerge, provide long-term benefits in employee safety and morale.

Mediation analysis further revealed that organizational readiness (training, management commitment, and technical infrastructure) significantly strengthens the RT–SBP relationship. Firms with dedicated robotics teams, in-house maintenance units, and leadership support achieved higher sustainability outcomes ($R^2 = 0.72$ for SBP) than firms lacking structured readiness. This finding underscores the need for managerial involvement and ecosystem maturity in maximizing robotics benefits.

4.2 Focus Group Results and Thematic Insights

The focus group discussions qualitatively validated the SEM findings, revealing four key themes from managers, engineers, and operators across Malaysia’s food manufacturing sector.

(1) Productivity and Operational Efficiency:

Participants from large firms reported major efficiency gains following automation. A packaging manager shared, *"Our ABB robotic arm handles 20 cartons per minute without error, what took three workers now needs one supervisor."* These improvements, consistent with the SEM coefficient ($\beta = 0.54$), reflected 30–50% higher throughput, less downtime, and greater precision in packaging and labeling.

(2) Environmental Optimization:

Respondents linked robotics to cleaner production and measurable waste reduction. A plant engineer noted, *"Before robotics, ingredient losses were 8%; now they're under 2%."* Robotics minimized energy use and material waste while improving hygiene compliance for export standards, supporting a circular production model.

(3) Workforce Transformation:

Robotics redefined rather than replaced jobs. Operators were retrained for system monitoring and data analysis roles. As one supervisor explained, *"We didn't lose jobs; we redefined them."* This aligns with the social performance path ($\beta = 0.32$), showing a shift toward safer, high-skill digital work.

(4) Implementation Barriers:

SMEs cited cost, maintenance, and technical dependence as key challenges. Despite this, most agreed that long-term gains justify the initial investment, especially with training and government support.

4.3 Integrated Discussion and Comparative Analysis

The convergence of quantitative and qualitative findings confirms that robotics serves as a technological and socio-economic catalyst for sustainability. SEM results and focus group insights reveal that robotics enhances efficiency, environmental performance, and workplace well-being. While Malaysia mirrors developed economies in these gains (Bogue, 2022; Lee et al., 2021; Almuaythir et al., 2024), challenges remain in skills and affordability. Organizational culture, leadership, and policy support moderate these impacts. Overall, robotics emerges as a strategic enabler of Industry 4.0 and circular economy goals, where economic gains fuel environmental innovation and social improvement, aligning with Malaysia's National Robotics Roadmap, Industry4WRD, and SDGs 9 and 12.

5. CONCLUSION AND RECOMMENDATIONS

This study concludes that robotics significantly improves sustainability performance in Malaysia's food manufacturing sector, enhancing economic efficiency, environmental outcomes, and worker well-being. To accelerate adoption, Malaysia should introduce policy incentives, invest in workforce upskilling, promote R&D collaboration, and align robotics with circular economy and carbon reduction goals. Sharing success stories can also increase awareness and acceptance among SMEs. Embedding robotics within sustainability strategies will drive balanced growth and position Malaysia as a leader in sustainable Industry 4.0 transformation.

The transition toward sustainable robotics adoption mirrors national efforts in other sectors, such as the defense food supply chain. Hashim et al. (2025) demonstrated how integrating sustainability principles into operational systems can enhance both efficiency and resilience, reinforcing the role of robotics as a strategic enabler for Malaysia's Industry 4.0 and sustainability transformation.

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Chapter 4
Solar Thermal Systems for Agricultural Applications in Malaysia: A Case Study Using SHIP Tools

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ABSTRACT
This manuscript examines the benefits of implementing solar thermal systems for agricultural applications in Malaysia, with a case study on a solar drying system for coffee beans utilising Solar Heat for Industrial Processes (SHIP) tools. The study evaluates four configurations of solar thermal collectors to identify the most cost-effective and energy-efficient design. Scenario 1 emerged as the optimal configuration, offering the shortest payback period (3.4 years), high energy savings (87,600 MYR/year), and a low Levelized Cost of Heat (LCOH) of 60 MYR/MWh. The findings emphasise the potential of solar thermal technologies to enhance agricultural productivity while reducing environmental impact and reliance on fossil fuels. The integration of such systems can promote sustainability, improve energy efficiency, and strengthen Malaysia's transition toward renewable energy in agriculture.

Keywords: Solar thermal system, SHIP tools, coffee bean drying, renewable energy, techno-economic analysis.

1. INTRODUCTION

Agriculture has always played a critical role in Malaysia’s economic and social development, serving as a foundation for food security, employment, and rural prosperity. Agriculture and food systems rely on a diverse range of energy sources, including both renewable and non-renewable resources like fossil fuels. Energy is essential across all stages of the agri-food sector, from production to processing, distribution, retail, preparation, and cooking. Food production is a highly energy-intensive process, requiring energy both on-farm and off-farm (Bundschuh et al., 2017). As one of the key sectors under Malaysia’s sustainable growth agenda, agriculture contributes significantly to the national GDP and the livelihood of millions. However, the sector faces growing challenges, including climate change, rising energy costs, and the need for environmentally friendly technologies.

1.1. The Importance of Renewable Energy in Agriculture

Energy consumption in the agricultural sector is primarily linked to mechanisation, irrigation, processing, and preservation activities. Traditional reliance on fossil fuels has led to increased operational costs and environmental degradation. Renewable energy technologies, especially solar energy, provide a sustainable alternative to meet these energy demands. Malaysia, with its tropical climate and abundant solar irradiance averaging 4.5–6.5 kWh/m² per day, presents an ideal environment for solar energy integration.

Solar thermal systems can be employed in numerous agricultural processes such as crop drying, heating, and sterilisation. The adoption of solar drying systems, in particular, has gained attention due to their efficiency in maintaining product quality and reducing dependency on conventional energy sources. In Malaysia, various organisations have explored the development and application of solar drying systems, including the Malaysian Agricultural Research and Development Institute (MARDI), the Standard and Industrial Research Institute of Malaysia (SIRIM), New England Biolabs (NEB), and the Forest Research Institute of Malaysia (FRIM) (Fudholi et al., 2015).

1.2. Coffee Bean Drying and Its Energy Demands

Coffee is one of the most widely traded commodities in the world, and its post-harvest processing directly influences product quality and market value. The drying stage, which reduces the moisture content of coffee beans to about 11–12%, is crucial for preserving aroma, flavour, and preventing microbial growth. Conventional drying methods, such as open-sun and mechanical drying, are often inconsistent and energy-intensive.

In tropical countries like Malaysia, where humidity levels are high, traditional drying methods result in uneven drying and product spoilage. Mechanical dryers, though efficient, depend on fossil fuels and electricity, leading to high operational costs. Thus, solar-assisted drying presents a sustainable solution that harnesses abundant sunlight while minimising environmental impact.

1.3. Solar Thermal Technology for Agricultural Applications

Solar thermal technology involves capturing solar radiation and converting it into thermal energy for heating or drying processes. This system typically includes solar collectors, heat exchangers, and thermal storage components that enable continuous operation, even under variable weather conditions.

The implementation of solar thermal systems in agriculture enhances process efficiency, ensures uniform drying, and reduces emissions. Moreover, the integration of thermal storage allows for energy use during cloudy conditions, increasing the reliability of the system (Singh et al. 2025).

1.4. The Role of SHIP Tools in System Design and Optimisation

To ensure technical and financial feasibility, simulation tools such as Solar Heat for Industrial Processes (SHIP) are used for system design and optimisation. The SHIP tool evaluates different configurations of solar collectors and assesses system performance under various climatic and operational scenarios. By analysing parameters like collector area, efficiency, and investment cost, SHIP assists in determining the most cost-effective design.

This study focuses on the design and optimization of a solar thermal drying system for coffee beans in Malaysia using SHIP tools. Through detailed analysis of system performance and techno-economic evaluation, the study identifies the most efficient and financially viable configuration suitable for local agricultural applications..

2. METHODOLOGY

The methodology integrates simulation and economic analysis using SHIP tools. Four solar collector configurations—Arcon HT-A 28/10, Arcon HT-SA 28/10, Ritter XL Solar CPC 45 XL, and Ritter XL Solar Aqua Plasma 19/50—were evaluated under Malaysia's climatic conditions. The analysis covered solar yield, collector efficiency, installation cost, payback period, and levelized cost of heat (LCOH).

The methodology involves using SHIP (Solar Heat for Industrial Processes) tools to design and analyze a solar thermal drying system for coffee beans, as shown in Figure 1. It includes defining solar input parameters, assessing collector types, simulating system operation, and performing a techno-economic analysis. The process load parameters are listed in Table 1.

The SHIP simulation uses meteorological data from Malaysia to determine optimal collector configurations. The hydraulic concept ensures continuous heat delivery to the drying system using a closed-loop circulation with a thermal storage tank and heat exchanger. The specific heat capacity of air, the primary working fluid in the drying process, was utilised for subsequently calculations. The drying process was conducted at a target temperature of 60°C, with the inlet air temperature set at 25 °C. Soeswanto et al. (2021) conducted at a target temperature of 60 °C reduces drying time by approximately 65% compared to 45°C. Nevertheless, excessively high drying temperatures may result in undesirable effects, such as hardening or scorching of the coffee beans.

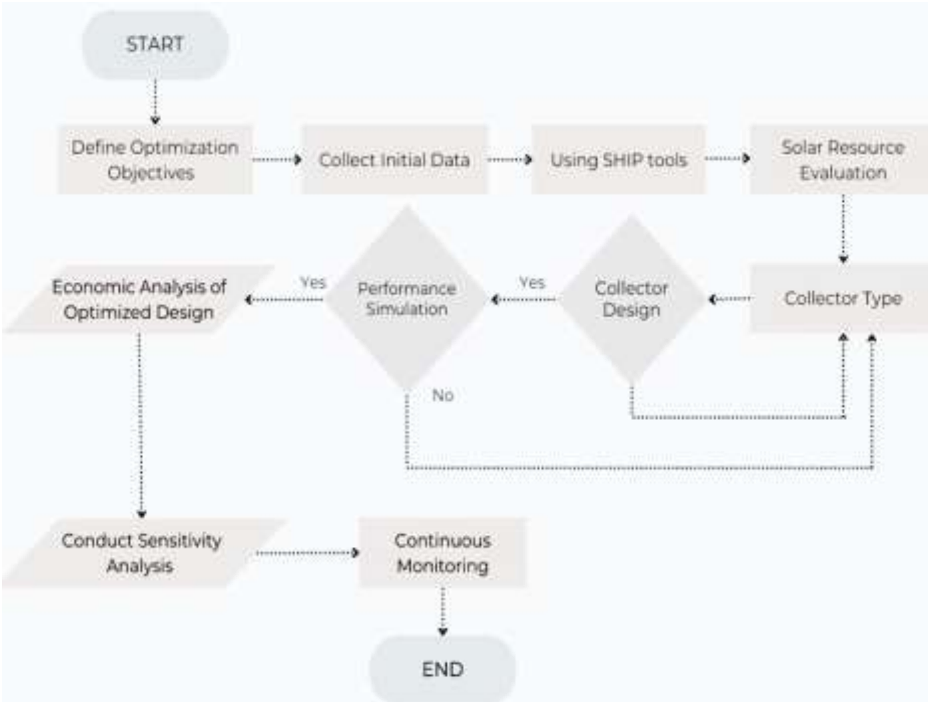

Figure 1: Flow Diagram of Method Using SHIP Tool

Table 1 Process Load Parameters

Parameter	Values
Mass Flow (kg/s)	3.95
Specific Heat Capacity (kJ/kg. K)	1.01
Start Temperature (°C)	25.00
Final Temperature (°C)	60.00

Economic evaluation was based on specific parameters such as discount rate, investment subsidy, residual value, operation and maintenance costs, and cost of substituted final energy. These parameters are summarised in Table 2.

Table 2 Main Parameters for Economic Evaluation

Solar Collector Types	Value (MYR/m^2)
Arcon HT-A 28/10	1,512
Arcon HT-SA 28/10	1,612.80
Ritter XL Solar - CPC 45 XL	2,016
Ritter XL Solar - Aqua Plasma 19/50	2,184

3. RESULTS AND DISCUSSION

Simulation results from SHIP tools demonstrate the performance of four collector configurations under Malaysian conditions. Scenario 1 (Table 3) achieved an annual solar yield of 274 MWh/a using 18 collectors (244 m² total area), balancing efficiency and space utilisation. It demonstrated the shortest payback period of 3.4 years and the lowest LCOH (60 MYR/MWh). Larger systems (Scenarios 3 and 4) offered higher yields but required higher investment costs, lowering cost-effectiveness.

Table 3 Optimal Sizing for Scenario 1

Item	Unit	Value
Investment Costs	MYR	355,093
Annual final energy savings	MYR/a	84,165
Simple Payback	Years	3.3
Levelized cost of heat (LCOH)	MYR/MWh	59

Comparative analysis of all four scenarios reveals that while larger collectors yield more energy, their higher investment cost reduces economic attractiveness. Scenario 1 offers the lowest Levelized Cost of Heat (LCOH = 60 MYR/MWh) and a Net Present Value (NPV) of MYR 1,128,145. Scenario 2 produced a slightly higher NPV of MYR 1,165,469, but with a longer payback period, making it more suitable for medium to large-scale operations.

4. CONCLUSION

The study confirms the feasibility and benefits of implementing solar thermal drying systems in Malaysia’s agricultural sector. Scenario 1 demonstrates superior cost-effectiveness, short payback period, and energy efficiency. Future research should explore hybrid solar-biomass designs and system scalability for multi-crop applications.

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Chapter 5
UAV Motor and Propeller Thrust Performance: A Static and Dynamic Assessment

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ABSTRACT
The paper investigates the optimal pairing of electric motors and propellers to maximize thrust efficiency for UAVs. It emphasizes the importance of both static and dynamic thrust tests to measure the performance of various motor and propeller combinations. The study highlights that wind velocity significantly affects propeller efficiency, impacting energy consumption and flight duration during real-world conditions. To ensure reliable results, the entire propulsion system, including the propeller, motor, electronic speed controller (ESC), power supply, and battery, is bench-tested. The research utilizes subsonic open loop wind tunnels to examine 15 different small-scaled propellers at varying wind speeds, ranging from 0 to 12 meters per second. The findings will be analyzed to determine the most efficient motor and propeller combination, addressing the challenges in selecting the ideal setup due to a lack of trustworthy data. The study aims to provide insights into the relationship between thrust and UAV performance, which is often poorly understood. Ultimately, the goal is to identify a combination that produces significant thrust while minimizing power consumption.

Keywords: *UAV, Dynamic Thrust, Wind Tunnel, Propulsive Efficiency. Coefficient Thrust*

1. INTRODUCTION

These days, propellers are frequently used for UAVs propulsion (Deters *et al*., 2014). The effectiveness of the aircraft's operation is influenced by the electric motor, Electronic Speed Control (ESC), and propeller in addition to the power source and by surrounding nature, such as wind, that can cause a lot of resistance and force towards an aircraft. Reliable results can only be obtained by bench testing the entire propulsion system, which includes the propeller, electric motor, ESC, power supply, and battery (Hitchens, 2015). The UAV propeller's basic function is to transmit torque (rotational force) from the engine, which creates axial thrust, to the propeller. A propeller creates forward thrust by pushing back on the air (Lowry, 2001). Basic components like the blade, leading edge, trailing edge, and tip are shared by all propellers (RoboticsDNA, 2022). A blade station, in other words, is a reference position on a blade that is a certain distance from the hub's center (Pauliny, 2012). Figure 1 shows an example of a propeller structure.

Figure 1: Example of propeller structure (Aircraft Systems, 2022)

In comparison to increasing the blade's breadth or chord, adding more blades to make them more robust has less negative impact (Rajeevalochanam *et al*., 2016). The uniform distribution of thrust and power will rise with additional blades on the propeller, but efficiency will only slightly improve (Ghoddoussi *et al*., 2016). With the same forward speed, rpm, and engine shaft power, the blade length can be slightly decreased since three or more blades have a larger lifting area than two blades of the same size (Garner, 2009). Since each blade must cut through more turbulent air than the previous blade, adding additional propeller blades reduces the propeller's total efficiency. Air will accelerate through the propeller blades and produce a significant pressure differential to propel the aircraft forward (Anderson,2010). The drag load will also rise as you accelerate. As a result, more power is needed for acceleration at higher airspeed.

The ratio of output power to input power can be used to describe propelling efficiency (McCoy, 2016). The propeller's propulsive efficiency, which results from its rotation in the air, is one of its keys defining parameters (Borges, 2015). The more engine thrust that can be harnessed, the greater lift the aircraft will be able to achieve (Tomas, 2022).

The UAV battery must be lighter and provide enough power to the system, due to the predominating benefits, Lithium Polymer batteries are frequently employed in UAVs. Figure 2 shows a comparison of energy densities for various chemistries.

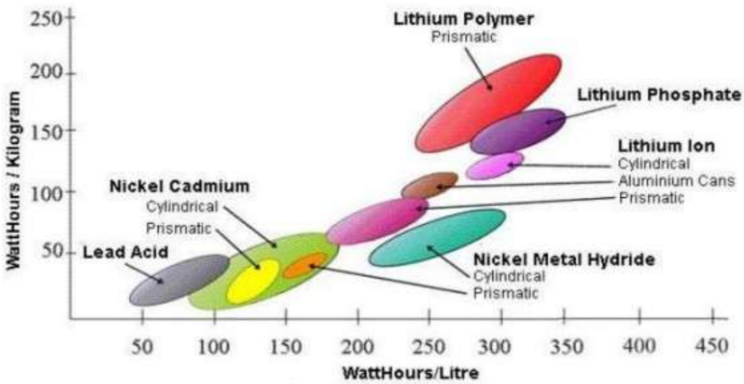

Figure 2: Comparison of energy densities for various chemistries (Reid, 2004)

2. METHODOLOGY

The main components of this project are the RCBenchmark 1520 thrust stand, Propeller, Brushless outrunner motor, Lithium polymer (LiPo) battery, Electronic Speed Controller (ESC) and Open Loop Wind Tunnel.

2.1 RCbenchmark 1520 thrust stand

This experiment utilized the RCbenchmark 1520 thrust stand for data collection and visualization. The RCbenchmark thrust stand was created to cut down on the time and expense involved in creating a unique test rig. Figure 3 shows the RCbenchmark 1520 Thrust Stand.

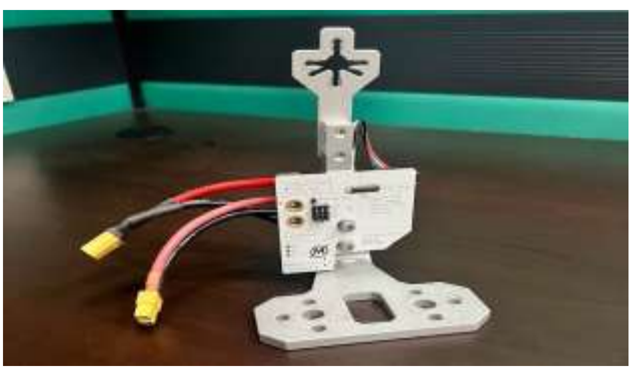

Figure 3: RCbenchmark 1520 thrust stand

All required parameters can be measured while the ESC signal is controlled by the tool, and the data is recorded in a Comma-Separated Values Comma-Separated Value (CSV) file for data analysis. The accuracy of data measurement and ongoing data logging are benefits of employing this thrust stand (in the spreadsheet). The capability of calibration is crucial to guarantee the consistency of test results. Table 1 shows the specifications of the RCbenchmarak 1520 thrust stand.

Table 1: Specification of RCBenchmark 1520 thrust stand

Specification	Minimum	Maximum	Tolerance	Unit
Thrust	-5	5	0.5%	Kgf
Voltage	0	35	0.5%	V
Current	0	40	1%	A
Angular Speed	0	190k	-	RPM

2.2 Brushless Outrunner Motor

The brushless motor for the thrust testing will be using brushless outrunner motors of three different types: T-Motor, NTM 910 KV Motor, and SunnySky Motor. Figure 4 and Table 2 show three different types of motor and its specification.

Figure 4: From left to right, NTM motor, T-Motor, SunnySky motor

Table 2: Specification of Three motors used in this experiment

Brand	SunnySky	NTM	T-Motor
Model	SunnySky X2814-7	NTM Prop Drive Series 35-36A 910Kv / 350W	T-Motor AS2814 Long Shaft
Weight	108 g	117 g	112 g
Motor KV	1100	910	1050
Max LiPo Cell	3-4S	3S	3-4S
Maximum Power	600 Watt	350 Watt	553 Watt

2.3 Wind Tunnel

The test portion and the wind speed capability were taken into consideration when choosing the wind tunnel. The test portion must be large enough to accommodate the installation of the thrust stand and propeller. The open-loop subsonic low-speed wind tunnel at MIAT was used to produce the requisite wind speed for the experiment. Figure 5 shows a subsonic low-speed wind tunnel. The subsonic low-speed wind tunnel was used to conduct the static and dynamic thrust experiment. The tests were run at several air speed settings, including 0 m/s (Static), 2 m/s, 4 m/s, 6 m/s, 8 m/s, 10 m/s, and 12 m/s.


Figure 5: Subsonic low-speed wind tunnel and test position.

3. RESULTS AND DISCUSSION

The primary goal of the analysis is to determine the efficiency of the propeller, power coefficient, and thrust coefficient formulae from the RCbenchmark output data with references.

3.1 Static Test Results

From the graph Figure 6, the most efficient combination of motor and propeller on static tests is the T-Motor and fixed 14x7 propeller which produce 6.68 efficiencies that have been calculated by dividing thrust by energy consumption. Table 3 shows the overall efficiency of static test data.

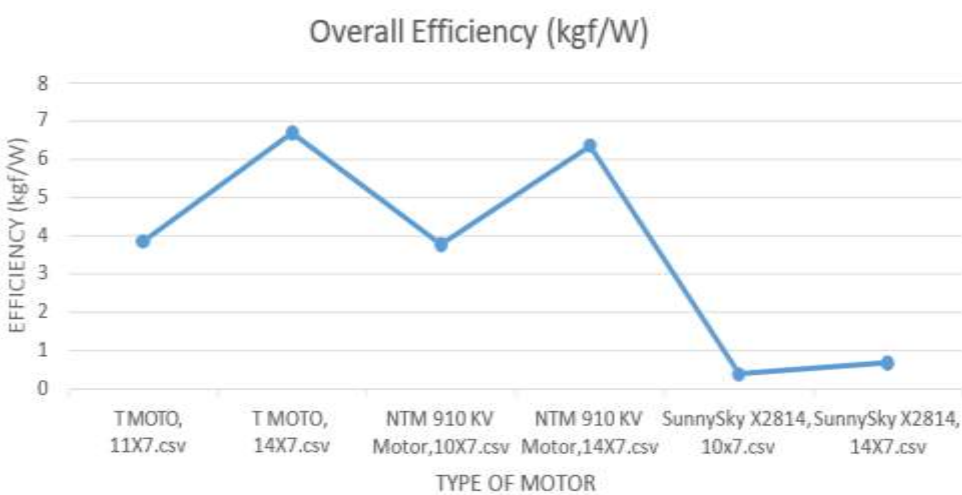

Figure 6: Overall efficiency for static test graph.

Table 3: Overall efficiency for static test data.

Type of Motor	Time (s)	ESC signal (µs)	Thrust (kgf)	Electrical Power (W)	Overall Efficiency (kgf/W)
T-MOTOR, 11X7	64.21424	1500	0.961960101	251.1040875	3.830921712
T-MOTOR, 14X7	38.35808	1340	0.937668792	140.3538223	6.680749956
NTM 910 KV Motor, 10X7	89.58031	1660	0.950567677	252.7530262	3.76085577
NTM 910 KV Motor,14X7	63.66204	1500	1.120578369	176.7922412	6.338391106
SunnySky X2814, 10x7	64.52495	1500	0.909602688	244.3449401	0.372261725
SunnySky X2814, 14X7	38.73353	1340	0.93259769	140.5037399	0.66375293

3.2 Dynamics Test Results

The data from the experiment was directly gathered and plotted in the graph below using the RCbenchmark for the dynamic test based on the figure below we can see that T-Motor with an 11x7 propeller is the best combo among all other combos. Figure 7 shows the overall efficiency for Dynamic test all motor and propeller combo. Table 4 shows the overall efficiency of the dynamics test.

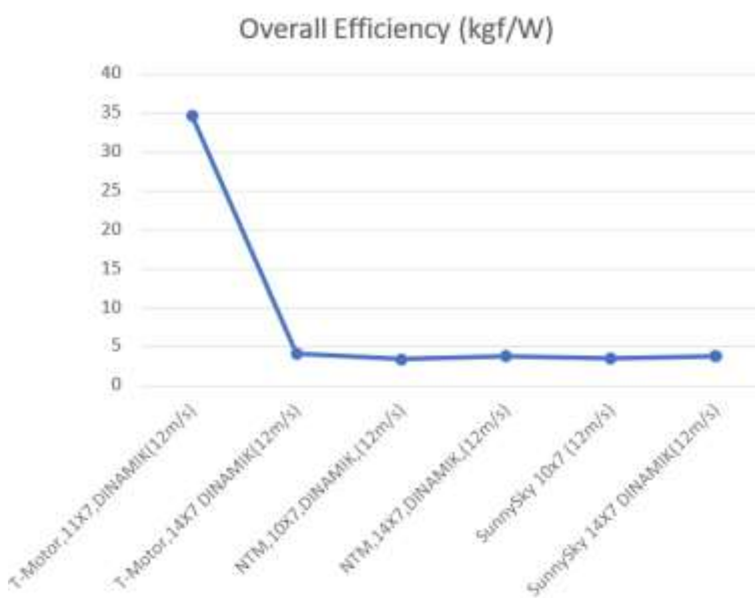

Figure 7: Overall comparison efficiency among all motor and propeller combinations.

Table 4: Overall efficiency for dynamics test data.

Type of motor (12 m/s)	Thrust (kgf)	Electrical Power (W)	Overall Efficiency (kgf/W)
T-Motor,14X7 DYNAMIC	0.960126801	241.0353188	3.98334487
T-Motor,11X7, DYNAMIC	0.86421	249.5562	34.62988
NTM,10X7, DYNAMIC	0.948884679	287.001261	3.306203868
NTM,14X7, DYNAMIC,	1.053293255	288.2371826	3.654258781
SUNNY SKY 10x7	0.872806521	258.8765727	3.371516054
SUNNY SKY 14X7	0.933987	255.1348	3.660759

4. CONCLUSIONS

Three different motors were successfully tested in a wind tunnel to measure the dynamic thrust of 15 propellers that were both fixed and folded. These tests were carried out to quantify the dynamic thrust generated by varying the airspeed in the wind tunnel from 0 m/s to 12 m/s. The coefficient of thrust, coefficient of power, and propulsive efficiency are used to evaluate the propeller's performance characteristics. For further recommendations, this project needs a lot of motors and propellers of different sizes to make sure to obtain more precise data that can be used for commercial and industry and an extra backup set for the testing cause the testing required a lot of time to be done due to battery that always needs to be charged and the ESC that always overheat cause of multiple tests during the testing.

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Chapter 6
Sustainable Aviation Fuel in Malaysia: A Comparative Study of Palm Oil and Lignocellulosic Biomass Pathways

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ABSTRACT
Sustainable Aviation Fuel (SAF) provides a lower-carbon alternative to conventional jet fuel. This study compares two major SAF pathways—Hydroprocessed Esters and Fatty Acids (HEFA) from palm oil and Ethanol-to-Jet (ETJ) from lignocellulosic biomass—using Life Cycle Assessment (LCA). Data from the GREET 2023 .Net model were analysed for greenhouse gas (GHG) emissions, energy consumption, and resource utilisation. ETJ shows 58.96% lower GHG emissions (126,852 tonnes) compared to HEFA (309,060 tonnes) and a higher renewable energy contribution (94.3% vs. 76.7%). However, ETJ requires more water (6.9 million m³ vs. 0.5 million m³) and higher total energy input. HEFA remains a short-term SAF option due to mature infrastructure, but ETJ represents a long-term, sustainable pathway, provided process efficiency and water management are improved. This study supports Malaysia's SAF transition strategy from palm oil to biomass feedstocks.

Keywords: Sustainable Aviation Fuel, Palm Oil, Lignocellulosic Biomass, Life Cycle Assessment, Malaysia

1. INTRODUCTION

The aviation sector is a vital driver of global connectivity and economic development but contributes about 2–3% of global CO_2 emissions (Bilal & Iqbal, 2020). With air traffic projected to rise in the coming decades, the industry faces increasing pressure to align with international climate targets such as CORSIA and the IATA Net Zero 2050 roadmap.

In this context, Sustainable Aviation Fuel (SAF) has emerged as the most promising near-term decarbonization option, capable of achieving up to 80% lifecycle GHG reduction depending on the feedstock and conversion route (Kargbo et al., 2021). SAFs are "drop-in" fuels compatible with existing aircraft engines and fueling infrastructure. Among the technologies certified by ASTM International, two pathways dominate global deployment:

- Hydroprocessed Esters and Fatty Acids (HEFA) – produced from lipid-based feedstocks such as palm oil, waste cooking oil, or animal fats.

- Ethanol-to-Jet (ETJ) – derived from lignocellulosic biomass, including agricultural residues, forestry waste, and energy crops.

Malaysia offers unique potential for SAF development because of its dual-feedstock advantage. As one of the world’s leading palm oil producers, it has a mature infrastructure suitable for HEFA, while its abundance of lignocellulosic residues — such as oil-palm fronds, empty fruit bunches, and rice husks — provides opportunities for ETJ production (Arshad et al., 2019; Chen et al., 2023). The HEFA route, though technologically established, faces sustainability challenges related to deforestation and indirect land-use change, whereas ETJ utilises non-edible waste biomass but demands higher energy and water inputs and involves more complex pre-treatment steps (Phuang et al., 2021).

Therefore, this study performs a comparative Life Cycle Assessment (LCA) of both HEFA- and ETJ-based SAF pathways using the GREET 2023 .Net model (Wang et al., 2020). The assessment focuses on key environmental indicators — GHG emissions, fossil fuel dependency, renewable energy contribution, and water consumption — to determine the most sustainable production route for Malaysia’s aviation decarbonization strategy.

2. METHODOLOGY

A comparative Life Cycle Assessment (LCA) was conducted following ISO 14040/14044 standards to evaluate the environmental performance of HEFA and ETJ SAF pathways. The analysis utilized the GREET 2023 .Net model (Wang et al., 2020) and adopted a Well to-Pump (WTP) boundary covering all upstream stages from feedstock cultivation to fuel production. Figure 1 above illustrates the general flow of the production of Sustainable Aviation Fuel (SAF) within a Life Cycle Assessment (LCA) framework. It outlines the key stages involved in SAF production from feedstock acquisition to final fuel distribution, highlighting the processes and outputs assessed in this study. This is a conceptual overview of the SAF production lifecycle and is not related to any experimental work conducted in this study.

For the HEFA pathway, the system boundary includes palm cultivation, oil extraction, refining, hydrotreating, and isomerization, with emissions from land-use change and hydrogen production incorporated. For the ETJ pathway, the boundary encompasses feedstock collection, pre-treatment, hydrolysis, fermentation, and catalytic upgrading to jet fuel (Bilal & Iqbal, 2020; Vásquez et al., 2019). Energy allocation was applied to co-products such as low-sulphur diesel and gasoline blendstock to ensure consistent comparison.

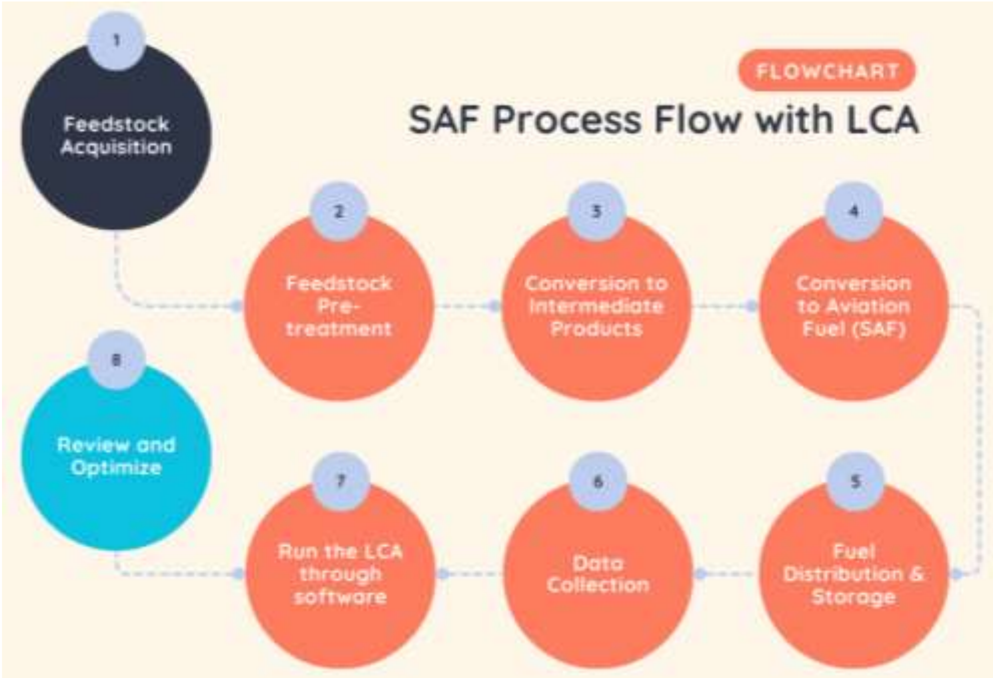

Figure 1 Flow chart comparing different feedstocks for SAF using LCA

2.1. LCA Framework and Boundary

A Well-to-Pump (WTP) boundary was adopted, covering all upstream stages from feedstock cultivation or collection to SAF production and storage. HEFA pathway: Includes oil palm cultivation, crude palm oil extraction, refining, hydrotreating, and isomerisation. Land-use change and hydrogen production emissions were considered. ETJ pathway: Includes biomass collection, pre-treatment, enzymatic hydrolysis, fermentation to ethanol, catalytic upgrading, and product refining. Energy allocation was applied to co-products such as low-sulphur diesel and gasoline blendstock. This boundary allows for consistent comparison of environmental performance between both pathways.

2.2. Functional Unit

The functional unit was defined as the production of 220,000 tonnes of SAF per year, representing Malaysia's projected industrial capacity (EcoCeres Bioenergy, 2024). Data inputs were sourced from R&D GREET® 2023 .Net and supplemented with Malaysian regional data on palm-oil yields, fertilizer use, and biomass transport. Hydrogen was assumed to be derived from natural gas for HEFA and 30% renewable hydrogen for ETJ, while Malaysia's grid electricity mix (45% natural gas, 35% coal, 20% renewables) was applied.

2.3. Data Sources and Assumptions

All life-cycle data were sourced from the R&D GREET® 2023 .Net model, which provides verified datasets for feedstock cultivation, processing, and transport. For the HEFA pathway, Malaysian palm oil yield, fertilizer, and milling data were applied, while the ETJ pathway used agricultural and forestry residues with average local transport distances. Hydrogen was assumed to come from natural gas for HEFA and 30% renewable sources for ETJ. Malaysia’s electricity mix (45% natural gas, 35% coal, 20% renewables) was used, and default GREET parameters were retained where local data were unavailable.

2.4. Environmental Indicators

The LCA evaluated both pathways using four main environmental indicators: greenhouse gas (GHG) emissions expressed as CO_2-equivalents, fossil fuel dependency measured by total fossil-based energy use (MJ), renewable energy contribution as a percentage of total energy input, and water consumption in cubic meters. These indicators were selected for their direct relevance to assessing the sustainability of SAF production and their alignment with international aviation decarbonization targets.

2.5. Analytical Approach

Each pathway was simulated under identical conditions in GREET. Outputs were normalised per functional unit, and major emission “hotspots” were identified for each process stage. The results were then compared to evaluate environmental performance and trade-offs between the HEFA and ETJ systems.

2.6. Limitations

The study relied on secondary model data, which may not fully represent Malaysian-specific process efficiencies. Economic and social aspects were excluded to maintain environmental focus.

3. RESULTS AND DISCUSSION

The comparative Life Cycle Assessment (LCA) highlights clear differences in environmental performance between the Ethanol-to-Jet (ETJ) and Hydroprocessed Esters and Fatty Acids (HEFA) pathways. Using the GREET 2023 .Net model, the study compared greenhouse gas (GHG) emissions, air pollutants, resource use, and energy efficiency, revealing important trade-offs between both routes.

The ETJ pathway records a total of 126,852 t CO_2-eq, nearly 59% lower than HEFA’s 309,060 t CO_2-eq, due to the absence of land-use change and greater renewable energy integration. ETJ also exhibits lower air pollutants, including NO_x (345.6 t vs. 758.6 t) and SO_x (189.1 t vs. 407.8 t), attributed to its cleaner feedstocks. ETJ requires more water (6.9 million m³) than HEFA (0.5 million m³) because of fermentation stages, but this can be mitigated through water recycling. Although ETJ demands higher total energy input (28.68×10^9 MJ) compared to HEFA (11.76×10^9 MJ), it relies heavily on renewable energy (94% vs. 77%), resulting in lower fossil dependency (1.90×10^9 MJ vs. 2.67×10^9 MJ). Overall, ETJ outperforms HEFA in most indicators except water use, confirming its long-term sustainability advantage for Malaysia’s SAF roadmap.

Table 1 Summary of Comparative Results for ETJ and HEFA Pathways

Sustainability Indicator	ETJ (Lignocellulosic Biomass)	HEFA (Palm Oil)	Remarks / Implications
Total GHG Emissions (t CO_2-eq)	126,852	309,060	ETJ produces ~59% lower emissions due to renewable feedstock.
NO_x Emissions (t)	345.63	758.64	Lower nitrogen-related emissions in ETJ.
SO_x Emissions (t)	189.14	407.83	HEFA emits more sulphur from hydrogenation and refining.
Water Consumption (m^3)	6,906,441	513,490	ETJ more water-intensive due to fermentation stages.
Total Energy Input (MJ)	28.68×10^9	11.76×10^9	ETJ requires higher process energy but mostly renewable.
Renewable Energy Share (%)	94.3%	76.7%	ETJ relies more on renewables, lowering fossil dependence.
Fossil Fuel Dependency (MJ)	1.90×10^9	2.67×10^9	ETJ shows lower fossil input and better sustainability.

4. CONCLUSION

The comparative Life Cycle Assessment (LCA) results demonstrate that both HEFA and ETJ pathways offer significant potential to reduce greenhouse gas emissions compared to conventional jet fuel. However, the ETJ pathway achieves a substantially lower carbon footprint, reduced air pollutant emissions, and higher renewable energy utilization. Despite its higher energy and water demands, ETJ aligns more closely with Malaysia’s long-term sustainability and decarbonization objectives. HEFA remains an important transitional option due to its existing industrial readiness and compatibility with current refining infrastructure.

In conclusion, Malaysia should pursue a dual-phase strategy: implementing HEFA in the short term using waste-based feedstocks, while progressively investing in ETJ technologies for future large-scale deployment. Continued research in biomass pre-treatment efficiency, renewable hydrogen production, and process water recovery will be crucial to enhance the overall sustainability and economic feasibility of SAF production in the country.

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Chapter 7
Comparative Study Between Submerged Fermentation and Solid-state Fermentation for the Enhancement of Phenolic Content in *Kappaphycus* spp.

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ABSTRACT
This study evaluates the potential of microbial fermentation using *Aspergillus oryzae* to enhance total phenolic content and investigate physicochemical changes in *Kappaphycus alvarezii* and *Kappaphycus striatum*. Both submerged fermentation (SmF) and solid-state fermentation (SSF) were employed to compare their effectiveness. SSF was further divided into two conditions: SSF[NS], where seaweed was the sole carbon source, and SSF[S], where sucrose and yeast extract were supplemented as additional carbon and nitrogen sources, respectively. The seaweed varieties used were *K. alvarezii* var. Giant (white), *K. alvarezii* var. Giant (purple), and *K. striatum* var. Green Flower. pH was monitored every two days throughout the fermentation process. Results showed that SSF[S] significantly enhanced total phenolic content compared to SmF and SSF[NS] across all seaweed types. The highest phenolic content (10.022 mg GAE/g) and soluble protein concentration (0.225 mg/mL) were observed on the fourth day of SSF[S] in *K. striatum* var. Green Flower. Reducing sugar levels were generally low, attributed to carbohydrate utilization during fermentation. These findings suggest that SSF with supplemented nutrients is a more effective strategy for enhancing the functional properties of seaweed. The application of microbial fermentation, particularly SSF[S], holds promise in the development of value-added food ingredients derived from seaweed biomass.

Keywords: Solid state fermentation, submerged fermentation, *Kappaphycus* spp., total phenolic content

1. INTRODUCTION

Food is increasingly recognized for its role in promoting health through bioactive compounds such as phenolics, which possess strong antioxidant properties and are linked to the prevention of chronic diseases. Malaysia's extensive marine environment provides suitable habitats for seaweed cultivation, particularly *Kappaphycus alvarezii* and *Kappaphycus striatum*, which are commercially farmed in Sabah. In 2023, Malaysia produced 225,048 metric tonnes of wet weight seaweed worth an estimated RM100 million (Bernama, 2024). These macroalgae are promising sources of bioactive compounds because of their rapid growth, high yield, and CO_2 capture efficiency (Rodríguez-Martínez et al., 2016). Conventional extraction of phenolics often relies on organic solvents such as acetone, ethyl acetate, hexane, and methanol, but these methods raise environmental and safety concerns (Buenrostro-Figueroa et al., 2017). Hot water extraction can also lead to nutrient degradation due to high temperatures, further highlighting the need for more sustainable approaches.

Microbial fermentation has emerged as a cost-effective and eco-friendly alternative for phenolic extraction. Unlike solvent extraction, fermentation can release bound phenolics through enzymatic action or generate new phenolics through microbial secondary metabolism (Bhanja Dey et al., 2016). Two main fermentation approaches are commonly used: submerged fermentation (SmF), which involves microbial growth in liquid media with controlled parameters, and solid-state fermentation (SSF), which occurs on moist solid substrates with little or no free-flowing water. SmF offers advantages in process monitoring and scalability (Farinas, 2015), while SSF better mimics natural microbial habitats, allows the use of agro-industrial waste, reduces contamination risks, minimizes wastewater generation, and can enhance enzyme productivity.

Studies have demonstrated that fermentation increases the recovery of phenolics from lignocellulosic and agricultural residues. White rot fungi degrade lignin via ligninolytic enzymes such as lignin peroxidase, manganese peroxidase, and laccase, enabling access to energy-rich polysaccharides (Sharma and Arora, 2015). Other GRAS molds such as *Aspergillus niger* have shown high antioxidant activity when fermenting rice residues under SmF (Tian et al., 2012). Similarly, SSF has enhanced extractable phenolics in apple, grape, and pitahaya residues (Zambrano et al., 2018), rice bran (Abd Razak et al., 2015), plum fruit (Dulf et al., 2016), pearl millet (Salar et al., 2017), and brown seaweed (Suraiya et al., 2018). Fermentation technology therefore offers significant potential for producing phenolic-rich functional ingredients for the food industry. Nonetheless, further in vivo and toxicological studies are essential to ensure the safety and efficacy of these antioxidant-enriched fermented products.

2. MATERIALS AND METHOD

2.1 Sample Preparation

The dried seaweed was purchased from Semporna, Sabah. In this study, three samples were used; *K. alvarezii* var. Giant, locally known as white seaweed (WG), K. *alvarezii* var. Giant locally known as purple seaweed (PG) and *K. striatum* var. Green flower (GF). Sample preparation was adapted from Tan and Lee (2014).

2.2 Cultivation of *Aspergillus oryzae* and Inoculum Preparation

The fungi used this study, *Aspergillus oryzae* was obtained from MARDI culture collection, Serdang, Selangor. The strain was cultured on potato dextrose agar (PDA) plates for 4 days in the incubator at 30°C. Inoculum preparation was done according to (Lee, Hung, and Chou, 2008). The amount of distilled water was measured at 100 mL in a graduated cylinder and poured evenly on four PDA plates which contain the 4 days old culture. A hockey stick was used to collect the spores. Then the suspended fungal cultures were filtered using Whatman filter paper No. 1 into a shake flask. The filtrate was used as inoculum. All flask, funnel, filter paper, distilled water was sterilized prior to use.

2.3 Solid State Fermentation

The experiment was conducted in 250 mL Erlenmeyer flasks with 10 g working volume according to the method described by Zambare, (2010). Two types of SSF was conducted in this study; one used the seaweed only as the sole carbon source for the microbes and termed as non-supplemented solid state fermentation SSF[NS], while the other one used 0.03 g sucrose as supplementary carbon source and 0.03 g of yeast extract as supplementary nitrogen source, and therefore termed as supplemented solid state fermentation, SSF[S]. Distilled water was added in such a way that the final substrate moisture content is 70 %. After sterilization at 121°C, 15 psi for 15 min and cooled, the flask was inoculated with 10% of inoculum and was incubated at 30°C for 2 to 6 days. At the end of fermentation, the biomass was treated with 100 mL of distilled water and was agitated thoroughly on a rotary shaker for 1 hour at 180 rpm. The whole content was centrifuged at 8000 rpm for 10 minutes and the supernatant obtained was further filtered by using Whatman filter paper no. 1. The clear supernatant was used as the crude fermented seaweed extract and was stored at -20°C for further analysis.

2.4 Submerged Fermentation

Seaweeds were extracted by using ultrasound assisted extraction (UAE) at room temperature for 30 min by using distilled water as solvent. Ratio sample to distilled water used was 1:20 (5g samples in 100 mL of distilled water). The extract was centrifuged at 3500 rpm for 20 minutes and then was filtered by using muslin cloth to remove the residue. The filtrate obtained was used as the substrate for submerged fermentation (SmF). Fermentation was performed in a 250 mL conical flask containing 100 mL of seaweed extracts according to the method by Eom et al. (2011). Sterilized medium was inoculated with 3% of *A. oryzae* spore suspension. Aerobic fermentation was performed at 30°C with agitation at 120 rpm. Sampling was done every two days intervals. Samples were centrifuged at 8000 rpm for 10 min and the supernatant obtained was filtered by using Whatman filter paper no 1. The filtrate obtained was stored at -20°C for further analysis.

2.5 Physico-Chemical Analysis of Fermented Seaweed Extracts:

2.5.1 pH

pH of samples was determined after centrifugation and filtration by using a pH meter according to method described by Bae and Kim (2010).

2.5.2 Total Phenolic Content

Total phenolic content of samples was determined based on the method of Ganesan et al. (2008). Sample (0.1 mL) was mixed with 2 mL of 2% sodium carbonate (Na_2CO_3) and the mixture was allowed to stand at room temperature for 2 minutes followed by the addition of 0.1 mL of 50% Folin-Ciocalteu's reagent. The reaction mixture was mixed thoroughly and allowed to stand at room temperature for 30 minutes in the dark. Absorbance of sample was measured at 720 nm using spectrophotometer. Total phenolic content was expressed as Gallic acid equivalent per gram (GAE/g) of dry samples.

2.5.3 Reducing Sugar Content

Reducing sugar content of fermented seaweed was determined by using the method of (Trivedi et al., 2015). One mL of DNS reagent was added to 1 mL of samples and 2 mL of distilled water in a test tube. The mixture was mixed and then heated in boiling water bath (100^{o}C) for 5 minutes to develop the color. The mixture was cooled immediately by using ice cubes. Samples were analysed for reducing sugar content by using spectrophotometer at 540 nm. Standard curve of glucose with concentration ranged from 0 - 0.8 mg/mL was plotted based on absorbance against concentration.

2.5.4 Protein Content

Estimation of soluble protein content was determined by using the method of Lowry et al., (1951). Sample (0.2 mL) was taken into a test tube and made to 1 mL by using distilled water. An amount of 4.5 mL of Reagent I (48 mL of 2% Na_2CO_3) in 0.1 N NaOH, 1 mL of sodium potassium tartrate ($C_4H_4O_6KNa{\cdot}4H_2O$) in water and 1 mL of 0.5% copper sulphate pentahydrate ($CuSO_4.5H_2O$) in water) was added and the mixture was incubated for 10 min. Then, 0.5 mL of Reagent II (Folin’s Ciocalteu reagent 1:1) was added and incubated in the dark for 30 min. The absorbance of samples was read at 660 nm in UV-Vis spectrophotometer. Bovine serum albumin (BSA) was used as standard solution.

2.5.5 Statistical Anaysis

Analyses were performed in triplicates and data were expressed as an average of the replicates ± standard deviation. The significant differences between the independent variables were analysed by one-way analysis of variance (ANOVA) test followed by the Tukey's Multiple Comparison Test.

3. RESULTS AND DISCUSSION

3.1 pH Changes during Fermentation

pH of samples was determined every two days interval during fermentation process. As a general practice, the pH in SSF is almost never controlled during fermentation; only the initial pH of the substrate can be adjusted before inoculation. In this study, initial pH was not adjusted before inoculation. The initial pH during fermentation plays an important role during germination of spores and enzyme activities. It was reported that higher pH can increase the rates of metabolic flow, which can be achieved by the mycelium growth of spores, whereas low pH can inhibit the germination of spores (Sohail et al., 2009). Table 1 shows the pH of samples at different fermentation process.

Table 1: pH of Samples at Different Fermentation Processes.

Fermentation	Day	GF	WG	PG
		pH	**pH**	**pH**
SmF	0	7.11^{c} ± 0.13	6.95^{c} ± 0.01	6.77^{d} ± 0.01
	2	7.50^{b} ± 0.09	7.08^{b} ± 0.02	7.10^{c} ± 0.01
	4	7.79^{a} ± 0.02	7.09^{b} ± 0.01	7.87^{a} ± 0.02
	6	7.95^{a} ± 0.03	7.18^{a} ± 0.01	7.76^{b} ± 0.02
SSF [S]	0	7.50^{d} ± 0.03	7.50^{b} ± 0.01	7.25^{c} ± 0.01
	2	7.75^{c} ± 0.03	7.55^{b} ± 0.01	7.30^{c} ± 0.01
	4	7.97^{b} ± 0.03	7.64^{b} ± 0.03	7.65^{b} ± 0.03
	6	8.26^{a} ± 0.05	7.90^{a} ± 0.06	8.03^{a} ± 0.08
SSF[NS]	0	7.21^{c} ± 0.16	6.99^{a} ± 0.12	6.56^{b} ± 0.01
	2	7.87^{b} ± 0.07	6.22^{c} ± 0.08	6.58^{b} ± 0.01
	4	8.13^{a} ± 0.02	6.52^{b} ± 0.02	7.28^{a} ± 0.01
	6	8.32^{a} ± 0.13	5.74^{d} ± 0.04	7.21^{a} ± 0.01

pH of samples was expressed as mean of three replications + standard deviation. Mean with different letter for each column indicates significantly different at $p < 0.05$.
*Note: GF – *K.striatum* var. Green flower; WG – *K.alvarezii* var. Giant (white seaweed); PG – *K.alvarezii* var. Giant (purple seaweed)

Most of the samples at different fermentation processed showed an increase in pH reading as the fermentation progressed, except for PG fermented through SmF and SSF[NS] and WG fermented through SSF[NS]. The reason for this finding was unclear, since *A.oryzae* has been previously shown to generate organic acids during the fermentation of carbohydrates. Bae and Kim (2010) reported that pH of fermented sea tangle extract also increased as the fermentation progressed and they assumed that *A.oryzae* may generate basic compounds during the fermentation of sea tangle extract. The similar findings was reported by (Chancharoonpong et al.,2012), where pH of soybean koji fermented with *A.oryzae* was decreased after 24h of cultivation but it further increased until the end of cultivation. Liang et al., (2009) suggested that pH of fermented matter was increasing due to the microbial metabolic activities especially various extracellular protein production. In this study, the pH increased during SmF and SSF might be due to the increase of basic amino acid such as histidine after fermentation.

3.2 Total Phenolic Content

This study was performed with the aim to identify fermentation method that produces the highest free polyphenols. Previous researchers reported that total phenolic content was enhanced by fermentation in pineapple waste (Correia et al., 2004), choberry pomace (Dulf et al., 2018), grape, apple and pitahaya residues (Zambrano et al., 2018), fig by-products (Buenrostro-Figueroa et al., 2017), cereal and legumes (Sadh et al., 2017), brown seaweed (Eom et al., 2011) and many more. Table 2 shows the total phenolic content of seaweed samples at different fermentation process.

Table 2: Total Phenolic Content (mg GAE/g) of Seaweed Samples at Different Fermentation Processes.

Fermentation	Day	Total phenolic content (mg GAE/g)*		
		GF	**WG**	**PG**
SmF	0	$1.06^{c} \pm 0.01$	$1.44^{a} \pm 0.21$	$1.62^{b} \pm 0.17$
	2	$1.12^{a} \pm 0.10$	$1.80^{a} \pm 0.27$	$2.07^{a} \pm 0.10$
	4	$1.51^{b} \pm 0.01$	$0.32^{c} \pm 0.00$	$2.73^{a} \pm 0.20$
	6	$2.41^{a} \pm 0.03$	$0.37^{b} \pm 0.04$	$1.57^{b} \pm 0.04$
SSF [S]	0	$2.39^{c} \pm 0.10$	$2.44^{c} \pm 0.16$	$1.52^{c} \pm 0.05$
	2	$7.35^{b} \pm 0.11$	$3.61^{b} \pm 0.02$	$2.98^{b} \pm 0.06$
	4	$10.02^{a} \pm 0.09$	$3.59^{b} \pm 0.06$	$4.04^{a} \pm 0.30$
	6	$7.67^{b} \pm 0.05$	$4.48^{a} \pm 0.29$	$3.52^{b} \pm 0.05$
SSF[NS]	0	$2.16^{c} \pm 0.01$	$0.87^{c} \pm 0.19$	$1.72^{b} \pm 0.10$
	2	$6.61^{b} \pm 0.10$	$1.08^{c} \pm 0.02$	$1.24^{c} \pm 0.03$
	4	$7.22^{b} \pm 0.01$	$1.78^{b} \pm 0.22$	$2.34^{a} \pm 0.10$
	6	$8.63^{a} \pm 0.03$	$2.30^{a} \pm 0.30$	$1.93^{b} \pm 0.05$

*TPC of samples was expressed as mean of three replications + standard deviation. Mean with different letter for each column are significantly different at $p < 0.05$.
*Note: GF – *K.striatum* var. Green flower; WG – *K.alvarezii* var. Giant (white seaweed); PG – *K.alvarezii* var. Giant (purple seaweed)

In general total phenolic content produced in SSF[S] were higher compared to SmF and SSF[NS] for all seaweed samples. Total phenolic content for WG was increased from day 0 to day 2 of SmF and then decreased until day 6 of fermentation. PG sample also showed a similar trend where it increased up to day 4 and then decreased at day 6 of fermentation. Only GF sample showed the increase of TPC as SmF progressed. It is noted that the highest total phenolic content (10.02 mg GAE/g) was found on the fourth day of SSF[S] for GF samples. The same finding was also observed for PG, where the highest phenolic content was on the day 4 of SSF[S]. However, for WG, the highest phenolic content was on the day 6 of fermentation. Overall results obtained suggested that the highest phenolic content was produced through SSF[S] compared to SmF. SSF[S] suplemented with sucrose and yeast extract as additional carbon and nitrogen sources respectively also shows higher content of phenolic compounds compared to SSF[NS] which utilized seaweed as a sole nutrient source for the growth of *A.oryzae.* According to Wiratno et al., (2014), nitrogen is a major nutrient that influence fermentation efficiency and at the same time also become a limiting factor to fermentation process. Limitations of nitrogen will cause a decrease in sugar transport activities in the stationary phase resulting in a reduced fermentation rate. Papagianni (2004) reported that deficiency of nitrogen sources in the medium greatly affects fungal growth and metabolite production. Yeast extract as nitrogen sources used in this study was proved to be very efficient in improving fermentation rate (Jørgensen, 2009). However, it was one of the most expensive nutrients. Therefore, it should be added in smallest possible amounts to make the process economical viable. The use of supplementary yeast extract in this study showed that it may help in increasing the yield of phenolic content due to efficient fermentation process as compared to fermentation without the addition of supplementary nutrients. During SSF process, the concomitant production of amylases, pectinases, xylanases, proteases, β-glucosidase, tannase and ellagitannase enzymes and their synergic activity increase the TPC release and enhance antioxidant activity (Vattem and Shetty, 2003).

3.3. Reducing Sugar Content

The analysis of reducing sugar content will indicate that the carbohydrates was used during fermentation and the reducing sugar content shows the residual nutrients left as a result of microbial degradation. Table 3 shows the reducing sugar content of seaweed samples at different fermentation process. In general, reducing sugar content was higher in SmF compared to SSF[S] and SSF[NS]. Low reducing content in seaweed extracts suggested that carbohydrates are used as substrate for growth.

Table 3: Reducing Sugar Content (mg/ml) of Samples at Different Fermentation Processes.

Fermentation	**Day**	**Reducing sugar content (mg/ml)***		
		GF	**WG**	**PG**
SmF	0	0.17^{a} ± 0.03	0.19^{a} ± 0.02	0.12^{c} ± 0.01
	2	0.16^{a} ± 0.03	0.16^{b} ± 0.00	0.17^{a} ± 0.02
	4	0.13^{b} ± 0.00	0.21^{a} ± 0.00	0.14^{b} ± 0.03
	6	0.12^{b} ± 0.02	0.21^{a} ± 0.00	0.14^{b} ± 0.00
SSF [S]	0	0.09^{a} ± 0.02	0.13^{c} ± 0.00	0.14^{b} ± 0.00
	2	0.10^{a} ± 0.01	0.25^{a} ± 0.01	0.12^{c} ± 0.00
	4	0.10^{a} ± 0.00	0.15^{b} ± 0.00	0.13^{b} ± 0.00
	6	0.11^{a} ± 0.01	0.15^{b} ± 0.00	0.14^{a} ± 0.00
SSF[NS]	0	0.10^{b} ± 0.01	0.12^{c} + 0.00	0.14^{a} ± 0.00
	2	0.13^{a} ± 0.02	0.14^{b} ± 0.03	0.14^{a} ± 0.02
	4	0.10^{b} ± 0.01	0.16^{a} ± 0.00	0.13^{b} ± 0.00
	6	0.09^{b} + 0.00	0.15^{a} ± 0.00	0.15^{a} ± 0.00

*Results are expressed as mean of three replications + standard deviation. Mean with different letters for each column are significantly different at $p < 0.05$.
*Note: GF – *K.striatum* var. Green flower; WG – *K.alvarezii* var. Giant (white seaweed); PG – *K.alvarezii* var. Giant (purple seaweed)

3.4 Soluble Protein Content

The effect of different fermentation methods and times on soluble protein content is tabulated in Table 4. In general, it can be seen that soluble protein content increases significantly during fermentation by using *A.oryzae*. The results obtained showed that soluble protein content in WG fermented through SmF was the highest on the sixth day of fermentation (0.17 mg/ml). The highest protein content for the same samples undergo SSF[S] was also on the sixth day of fermentation (0.16 mg/ml). However, soluble protein content undergoes SSF[NS] shows the highest on the fourth day of fermentation (0.06 mg/ml). For GF, the highest soluble protein (0.16 mg/ml) was observed on the sixth day of SmF. For SSF[S] and SSF[NS] the highest soluble protein content was found on day 4 respectively. Comparing the soluble protein content in GF for all fermentation process, SSF[S] produced the highest soluble protein content on the fourth day (0.23 mg/ml). Meanwhile, for PG, the highest soluble protein was observed at day 4 of all fermentation process. Total soluble protein produced from SSF[S] shows the highest (0.13 mg/ml) compared to SmF and SSF[NS].

Table 4: Soluble Protein Content (mg/ml) of Samples at Different Fermentation Processes.

Fermentation	Day	Soluble protein content (mg/ml)*		
		GF	WG	PG
SmF	0	0.01^{d} ± 0.00	0.01^{d} ± 0.00	0.034^{c} ± 0.003
	2	0.07^{c} ± 0.01	0.04^{c} ± 0.00	0.057^{b} ± 0.005
	4	0.13^{b} ± 0.00	0.07^{b} ± 0.06	0.101^{a} ± 0.026
	6	0.16^{a} ± 0.00	0.17^{a} ± 0.01	0.044^{b,c} ± 0.005
SSF [S]	0	0.01^{d} ± 0.00	0.07^{d} ± 0.01	0.031^{c} ± 0.013
	2	0.17^{b} ± 0.01	0.10^{c} ± 0.00	0.072^{b} ± 0.005
	4	0.23^{a} ± 0.02	0.12^{b} ± 0.00	0.126^{a} ± 0.003
	6	0.13^{c} ± 0.01	0.16^{a} ± 0.00	0.066^{b} ± 0.001
SSF[NS]	0	0.01^{c} ± 0.00	0.00^{c} ± 0.00	0.01^{b} ± 0.00
	2	0.03^{b} ± 0.01	0.01^{b} ± 0.00	0.01^{b} ± 0.00
	4	0.06^{a} ± 0.02	0.06^{a} ± 0.02	0.09^{a} ± 0.01
	6	0.04^{b} ± 0.00	0.05^{a} ± 0.01	0.01^{b} ± 0.00

*Results are expressed as mean of three replications + standard deviation. Mean with different letters for each column are significantly different at $p < 0.05$.
*Note: GF – *K.striatum* var. Green flower; WG – *K.alvarezii* var. Giant (white seaweed); PG – *K.alvarezii* var. Giant (purple seaweed)

4. CONCLUSION

K.alvarezii and *K.striatum* has excellent potential to be valorised as a nutrient source for the release of phenolic compounds by fungal strains in SSF. Based on the results obtained, solid state fermentation with nutrient supplementation (SSF[S]) was chosen as the method of choice for the next processing step due to the high total phenolic content released. These findings are the first step towards the applications of fermented seaweed extracts enrich in phenolics in either food or pharmaceutical products.

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Chapter 8
Game-Based Cybersecurity Learning: Integrating Naqli and Aqli for Resilient Digital Citizens

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ABSTRACT
The growing incidence of cyber threats poses significant risks to individuals, particularly young digital natives who often lack the awareness and skills to navigate online environments safely. Traditional approaches to cybersecurity education, while informative, frequently fail to sustain learner engagement or address the ethical dimensions of digital behavior. This chapter introduces Secure Cybercitizenship (SET), a board game designed as an innovative game-based learning (GBL) tool that integrates Naqli (revealed knowledge) and Aqli (rational knowledge) to promote both technical literacy and ethical responsibility in cybersecurity awareness. Building upon the earlier mobile-based innovation CYBERPOLY (Beyond the Board: CYBERPOLY as a Multidimensional Gamified Learning Tool for Cybersecurity Awareness), SET extends the gamification approach into a physical, offline, and collaborative format that is accessible to a wider range of learners. The objectives of this study are fourfold, which are (i) to identify the social need for early-age cybersecurity education, (ii) to analyze potential threats and suitable game-based solutions, (iii) to design a culturally relevant board game that integrates Naqli and Aqli knowledge, and (iv) to evaluate its effectiveness as an edutainment tool. Methodologically, the research employed an Agile-based iterative design process encompassing needs analysis, game development, pilot testing with 100 school students in Negeri Sembilan and Selangor, and evaluation through pre- and post-game surveys. Findings indicate that SET significantly enhances cybersecurity literacy, fosters ethical reflection, and sustains learner motivation through interactive play. The integration of Naqli and Aqli knowledge proved particularly effective in bridging technical competence with moral responsibility, thereby cultivating more resilient digital citizens. This chapter argues that the SET framework provides a scalable and contextually relevant model for cybersecurity education, aligning with Malaysia's 10-10 MySTIE Framework and the National Cyber Security Agency's goal of fostering well-informed netizens. By integrating pedagogical innovation with ethical considerations, SET highlights the potential of game-based learning to tackle significant societal challenges and contribute to the cultivation of a cyber-literate and ethically aware society.

Keywords: Cybersecurity Awareness, Game-Based Learning, Naqli And Aqli Integration, Digital Citizenship, Educational Gamification

1. INTRODUCTION

The digital transformation of society has created both opportunities and vulnerabilities. While online platforms enable unprecedented access to information, communication, and innovation, they also expose individuals to various cyber threats, including phishing, malware, identity theft, and social engineering. In Malaysia, CyberSecurity Malaysia has reported a 21.22% increase in cybercrime cases over the past five years, underscoring the need to equip citizens with cybersecurity awareness from an early age.

Traditional didactic methods of teaching cybersecurity often fail to engage digital natives, who are accustomed to interactive, technology-driven learning environments. Game-based learning has emerged as a promising pedagogical approach that combines entertainment with education, fostering deeper engagement, motivation, and knowledge retention. This integration ensures that learners not only acquire technical literacy but also develop ethical reasoning, cultivating responsible and resilient digital citizens. This research builds upon the earlier innovation, CYBERPOLY, a mobile gamification tool for cybersecurity awareness (Ali Pitchay et al., 2022; Ali Pitchay et al., 2025). While CYBERPOLY successfully demonstrated the potential of gamification in cybersecurity education, its scope was extended in SET to include offline accessibility, broader player engagement, and the integration of Naqli and Aqli knowledge. The Secure Cybercitizenship (SET) board game was developed as a localized, culturally relevant intervention that integrates Naqli (revealed knowledge) and Aqli (rational knowledge).

The development of SET was guided by four key objectives. First, it required identifying the social need for educating young citizens, particularly school and university students, about cybersecurity awareness at an early stage. Second, it aimed to analyze potential cybersecurity threats and design suitable solutions that could be delivered through a game-based learning format. Third, the project focused on designing a board game that integrates Naqli and Aqli knowledge, thereby promoting both technical literacy and ethical reasoning. Ultimately, the study aimed to assess the effectiveness of the board game in engaging students and increasing their awareness of cybersecurity issues. These objectives collectively reflect the dual emphasis on knowledge acquisition and ethical formation, positioning SET as a holistic educational tool.

2. LITERATURE REVIEW

Game-based learning has been widely recognized as an effective approach to enhance student engagement, motivation, and knowledge retention (Kim & Lee, 2023). Research indicates that games foster active learning by encouraging problem-solving, collaboration, and critical thinking (Hamari et al., 2020). In the field of cybersecurity, several educational games have been developed, such as Hacker: The Cyber Security Logic Board Game and Android: Netrunner (Prensky, 2022). While these games provide valuable insights into hacking scenarios and cyber defense strategies, they are often limited by accessibility, static content, and a lack of ethical integration (Connolly et. al., 2022). Moreover, many of these products are international in origin, expensive, and not tailored to the Malaysian context.

The SET board game addresses these limitations by offering localized content that is relevant to Malaysian learners and by embedding ethical dimensions through the Ta’alim iNAQ cards. Unlike existing games that focus primarily on technical aspects, SET emphasizes both awareness and ethics, ensuring that players understand not only how to protect themselves but also why responsible digital behavior is crucial. The inclusion of two levels of quizzes, which are beginner and intermediate, further scaffolds learning, allowing students to progress at their own pace. This approach aligns with recent scholarship that emphasizes the importance of contextualized and culturally relevant cybersecurity education (Ali Pitchay et al., 2022; Azahar et al., 2025; Gee, 2021).

While CYBERPOLY successfully demonstrated the potential of gamification in cybersecurity education, SET extends this innovation by incorporating offline accessibility, broader player engagement, and the integration of Naqli and Aqli knowledge.

Table 1 Comparison of CYBERPOLY and SET

FEATURE / DIMENSION	**CYBERPOLY (FORMER PRODUCT)**	**SET: SECURE CYBERCITIZENSHIP (CURRENT PRODUCT)**
Platform	Mobile application (digital gamification)	Physical board game (offline, portable)
Learning Focus	Cybersecurity awareness through mobile-based quizzes and scenarios	Cybersecurity awareness with added integration of Naqli & Aqli (iNAQ) knowledge for ethical grounding
Target Audience	University students and young adults	School and university students (early-age education focus)
Game Mechanics	Quiz-based progression, earning points and rewards in-app	Board game with two quiz levels (beginner & intermediate), badges, and a salary-based reward system
Accessibility	Requires a mobile device and Internet access	Offline, anytime-anywhere play; accessible without technology
Ethical Integration	Primarily technical literacy	Combines technical literacy + ethical reasoning via Ta'alim iNAQ cards
Player Mode	Individual or small group (mobile-based)	2–6 players, collaborative and competitive board play
Limitations	Dependent on device availability and connectivity	Static questions, physical board size, potential loss of cards
Recognition	Recognized as an innovative mobile gamification tool (*Beyond the Board: CYBERPOLY as a Multidimensional Gamified Learning Tool for Cybersecurity Awareness*)	Awarded Gold Medal at Malaysia Technology Exposition (MTE) 2023
Continuity	Established a foundation for gamified cybersecurity learning	Expanded into a social innovation tool aligned with Malaysia's 10-10 MySTIE Framework and NACSA's vision

To fully appreciate the innovation represented by the Secure Cybercitizenship (SET) board game, it is important to situate it within the trajectory of earlier gamified cybersecurity tools. The development of SET builds directly upon the success of CYBERPOLY, a mobile-based application introduced as a multidimensional gamified learning tool for cybersecurity awareness (Beyond the Board: CYBERPOLY as a Multidimensional Gamified Learning Tool for Cybersecurity Awareness). CYBERPOLY demonstrated the potential of gamification to enhance digital literacy and engage learners through interactive quizzes and reward systems. However, its reliance on mobile devices and internet connectivity limited its accessibility, particularly in contexts where offline learning was needed. SET extends this foundation by transforming the digital experience into a physical board game that is portable, collaborative, and enriched with the integration of Naqli and Aqli knowledge. The following table highlights the key differences and continuities between CYBERPOLY and SET, illustrating how the latter represents a significant evolution in both pedagogical design and ethical integration.

The comparison between CYBERPOLY and SET in Table 1 highlights a clear path of innovation, transitioning from a mobile-based gamification tool to a more inclusive, offline board game that incorporates ethical principles. While CYBERPOLY laid the groundwork for gamified cybersecurity awareness, SET broadens its scope by integrating both Naqli and Aqli knowledge, enhancing accessibility, and promoting collaborative learning. This progression not only addresses the limitations of the earlier product but also aligns with national educational and cybersecurity strategies, positioning SET as a more holistic and impactful tool for cultivating resilient digital citizens.

3. METHODOLOGY

The research employed an Agile-based iterative design process, which allowed for flexibility and continuous improvement throughout the development of the board game. The process was divided into four phases.

- Phase 1: Needs Analysis – Surveys and focus groups with students identified gaps in cybersecurity awareness and informed the design of the game.
- Phase 2: Game Design and Development – The board game was developed with Naqli and Aqli integration, quiz booklets, and a reward system linking knowledge acquisition to gameplay.
- Phase 3: Pilot Testing – The game was tested with 100 participants from primary and secondary schools in Negeri Sembilan and Selangor.
- Phase 4: Evaluation and Feedback – Pre- and post-game surveys measured knowledge gains, motivation, and ethical reasoning.

The first phase involved a needs analysis, during which surveys and focus groups were conducted with students to identify gaps in their cybersecurity awareness. The second phase focused on game design and development, incorporating both Naqli and Aqli integration, quiz booklets, and a reward system that linked knowledge acquisition to gameplay. The third phase involved pilot testing with 100 participants from primary and secondary schools in Negeri Sembilan and Selangor. Finally, the fourth phase focused on evaluation and feedback, utilizing pre- and post-game surveys to assess knowledge gains, motivation, and ethical reasoning.

Reliability and validity were ensured through expert validation by information security lecturers, while external recognition, such as the Gold Award at the Malaysia Technology Exposition 2023, affirmed the innovation and impact of the product. This iterative methodology ensured that the game was not only pedagogically sound but also engaging and relevant to its target audience.

4. RESULTS

Preliminary findings suggest that SET substantially enhances cybersecurity literacy among students. Participants exhibited increased awareness of common threats and were more capable of articulating prevention strategies. Notably, the integration of Naqli and Aqli knowledge deepened ethical awareness, prompting students to consider the moral implications of their online behavior.

The interactive nature of the game enhanced engagement compared to traditional lecture-based methods. Students reported higher levels of motivation and enjoyment, which contributed to sustained learning momentum. The portability and offline accessibility of the board game further support its use as a lifelong learning tool, making it suitable for diverse educational contexts. These findings suggest that SET board game has the potential to serve as a scalable model for cybersecurity education, particularly in regions where digital literacy and ethical awareness are pressing concerns.

5. DISCUSSION AND CONCLUSION

The SET board game aligns with Malaysia's 10-10 MySTIE Framework, which emphasizes education and digital literacy, as well as the National Cyber Security Agency's (NACSA, 2023) vision of developing better-informed netizens. By integrating ethical and technical knowledge, SET serves as a model for other educational interventions that aim to balance cognitive and moral development.

For policymakers, SET illustrates the importance of investing in localized and culturally relevant educational tools. For educators, it offers a practical, engaging resource that can be integrated into school curricula and university courses. For researchers, it highlights the importance of interdisciplinary approaches that combine pedagogy, technology, and ethics.

The SET board game effectively addresses gaps in cybersecurity awareness while promoting ethical values through game-based learning. By integrating both Naqli (transmitted) and Aqli (rational) knowledge, the game offers a comprehensive approach that balances technical skills with moral responsibility. Its recognition at national innovation competitions highlights its potential for wider adoption.

6. RECOMMENDATION

Future research should examine digital adaptations of SET, the long-term effects on behavior, and its relevance across different cultures. By integrating pedagogical innovations with ethical considerations, SET aids in fostering a resilient, cyber-aware society equipped to navigate the complexities of the digital era.

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Chapter 9
Cyber Hasanat: A Service-Learning Approach to Building Digital Citizenship in Education

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ABSTRACT
This study explores the first initiative of Cyber Hasanat: Protecting Our Digital Community project, which serves the university and community engagement involvement under Malaysia's Service-Learning Malaysia (SULAM) framework. The Cyber Hasanat project, carried out at *Taman Tasik Jaya Primary School (STAJA)* in Seremban, was developed to promote cybersecurity awareness and ethical digital practices among primary school pupils. At the same time, it provided an opportunity for university students to strengthen their leadership, communication, and facilitation abilities through active engagement and community-based learning. Seventy-five undergraduates from the Bachelor of Computer Science (Information Security & Assurance) programme at Universiti Sains Islam Malaysia (USIM) designed and facilitated interactive activities, most notably the Secure Cybercitizenship (SET) board games, during the ExploreSTREAM SULAM USIM–STAJA Carnival 2023. Adopting a qualitative case-study approach, the project integrated observation, reflective journaling, and stakeholder feedback to assess its educational impact. Quantitative findings from the Cyber Hasanat 2023 survey involving 150 respondents aged 15–16 revealed a moderate to high level of cybersecurity awareness, with the highest competency in creating strong passwords (mean = 3.73, 74.6%) and lower awareness in maintaining account privacy (mean = 3.37, 67.4%). These results show that participants have a strong conceptual understanding of cybersecurity; however, practical application and consistent behavioral reinforcement require improvement. Qualitative feedback supported these findings, showing increased digital literacy, improved recognition of threats such as phishing and data theft, and positive behavioural shifts in online safety practices. Beyond cognitive outcomes, the initiative also enhanced interpersonal collaboration, problem-solving, and adaptability among facilitators, which are core attributes aligned with Malaysia's *Ekonomi MADANI* and SDG 4 (Quality Education). The *Cyber Hasanat* project demonstrates that experiential, game-based service-learning effectively bridges academic theory and social responsibility, offering a scalable model for fostering inclusive digital citizenship across ASEAN educational contexts.

Keywords: Cybersecurity Awareness, Game-Based Learning, Naqli And Aqli Integration, Digital Citizenship, Educational Gamification

1. INTRODUCTION

As digital connectivity expands globally, young learners are increasingly exposed to online risks such as phishing, data breaches, and misinformation. Early cybersecurity education plays a vital role in shaping responsible digital citizens who can navigate technology ethically and safely (Ahmad et al., 2023). The term Hasanat originates from the Arabic word meaning “good deeds,” which, in this context, refers to ethical and responsible actions in cyberspace. In the context of this project, Hasanat signifies virtuous and ethical actions within digital spaces, emphasizing integrity, empathy, and accountability online. It reflects the belief that good deeds extend beyond physical interactions to include responsible and moral conduct in cyberspace, aligning with the project’s vision to cultivate secure and ethical digital citizens through community engagement and education.

This Cyber Hasanat project is designed under the SULAM framework to combine academic learning with civic engagement, empowering university students to transfer their knowledge of cybersecurity to the community. Implemented at primary school at Taman Tasik Jaya, Seremban and the public hall nearby in mid-2023, this project utilized gamified learning through the Secure Cybercitizenship (SET) board games to cultivate cyber awareness and inclusiveness among primary school students.

2. LITERATURE REVIEW

Service-learning integrates classroom knowledge with community-based action, enhancing students’ ethical, civic, and professional competencies (Holmes & Albritton, 2022). Gamified education, including serious games, has gained recognition for increasing motivation and retention in complex topics such as cybersecurity (Sodikin & Hikmawan, 2023; Ng & Hasan, 2025). Research by Bello and Oyelere (2022) highlights that interactive game-based learning fosters digital literacy and awareness of online safety issues among children. In Malaysia, studies emphasize the urgent need to embed cyber ethics and digital citizenship in early education to prepare future generations for an increasingly digital society (Ahmad et al., 2023; Manganello et al., 2024). The Cyber Hasanat initiative aligns with UNESCO’s (2023) call for integrating digital citizenship into school curricula and Manganello et al. (2024), who argue that cybersecurity education must address behaviour as much as technical knowledge.

3. METHODOLOGY

This study employed a qualitative case-study design to examine the implementation and impact of the Cyber Hasanat project. The project involved 75 USIM undergraduates and approximately 1,100 primary school pupils over a four-month period. However, only 150 students were involved in this project, as there are many other programmes occurring at the same time, and the students were split into several activities. Data were gathered through observation, reflective journals, and teacher feedback to assess cognitive, behavioural, and affective outcomes. Activities included SET board games, guess the IP address, password guessing, and broken telephone, each of which emphasised teamwork, communication, and cybersecurity comprehension. Data were thematically coded into domains of knowledge, skill development, ethical awareness, and community impact.

4. RESULTS

The Cyber Hasanat 2023 Survey involved a total of 150 respondents within the age range of 15 to 16 years old. The objective of this survey was to evaluate students' understanding of cybersecurity awareness and ethical online behaviour, aligned with the goals of the Cyber Hasanat initiative under the Secure Cybercitizenship (SET) learning framework. The survey instrument comprised eight closed-ended questions based on a five-point Likert scale and two open-ended questions designed to capture qualitative insights into participants' understanding of cybersecurity awareness and ethical online behaviour. For data interpretation, a descriptive statistical analysis was employed to summarize central tendencies such as mean scores, while mean score visualization through graphical representation was utilized to provide a clearer overview of participants' response patterns and overall levels of cybersecurity awareness.

Table 2 Statistical summary of preliminary survey

Metric	Mean	Standard Deviation
I know how to stay safe online	3.61	1.15
I do not share my personal information	3.49	1.12
I know how to create a strong password	3.73	1.16
I am familiar with cyberbullying	3.50	1.12
I know what to do if I see cyberbullying	3.49	1.16
I keep my account private	3.37	1.17
I don't click unfamiliar links	3.40	1.18
I know the importance of antivirus software	3.41	1.08

Based on Table 1, the overall mean scores indicate that respondents aged 15–16 years demonstrated a moderate to high level of cybersecurity awareness. The highest-rated aspect, "I know how to create a strong password" (mean = 3.73), shows that students have a fairly good understanding of password security. This may be attributed to exposure to common digital safety campaigns or classroom emphasis on password protection.

Conversely, the lowest-rated statement: "I know the importance of keeping my account and password private" (mean = 3.37), suggests a gap in the practical application of security habits, particularly in maintaining confidentiality and avoiding password sharing. This implies that while students may conceptually understand online risks, they still need reinforcement in consistent personal data protection practices.

The responses to the open-ended questions revealed several recurring themes that provide deeper insight into participants' understanding of safe and ethical online behaviour. Many respondents emphasized the importance of practicing ethical digital conduct, such as avoiding the spread of false information, communicating politely, and showing respect toward others in online spaces. Another common theme involved recognizing and verifying secure websites, where participants mentioned looking for trusted indicators such as the padlock icon in the browser or using verification tools like VirusTotal to ensure the authenticity and safety of websites before engaging with them. These responses demonstrate a growing awareness among students of both technical cybersecurity practices and responsible digital citizenship.

Overall, students exhibit strong conceptual awareness but require continuous experiential learning through gamification and scenario-based engagement to internalize safe digital habits.

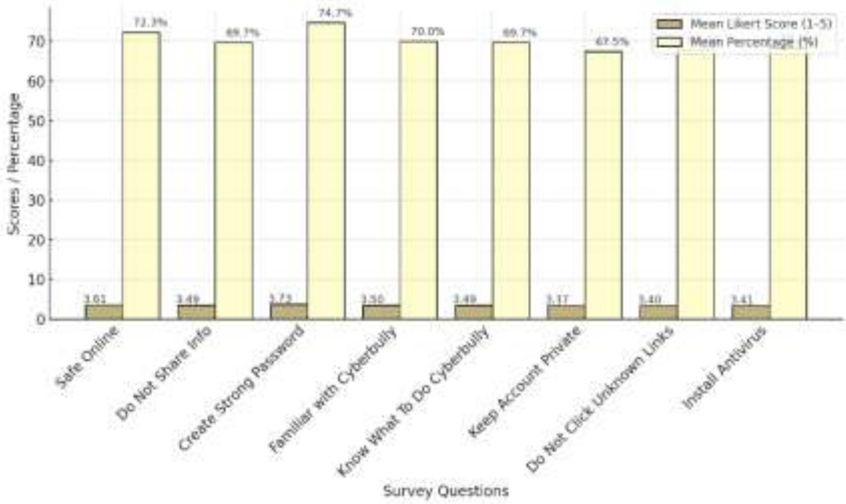

Figure 1: Cybersecurity awareness score for 150 respondents of primary school students

The comparative analysis in Figure 1 between the mean Likert scores and their corresponding percentages reveals a consistent trend of moderate to high cybersecurity awareness among respondents. The highest performance was recorded in the domain of creating strong passwords, reflecting effective cognitive understanding of personal data protection practices. In contrast, slightly lower scores in areas such as maintaining account privacy and avoiding unfamiliar links suggest the need for deeper behavioural reinforcement through experiential learning. Overall, the results highlight that while participants possess foundational cybersecurity knowledge, sustained engagement through gamified and ethics-based learning interventions is essential to translate awareness into long-term digital resilience.

The integration of gamified activities contributed to greater engagement and enjoyment, consistent with earlier research emphasizing the value of play-based digital literacy education (Bello & Oyelere, 2022).

5. DISCUSSION

The findings affirm that gamified service-learning enhances both cognitive and affective dimensions of cybersecurity education. The Cyber Hasanat project effectively combined theoretical concepts of cybersecurity with practical, hands-on experiences through board games, echoing Chia et al. (2021) and Manganello et al. (2024). Students not only acquired technical understanding but also developed civic-mindedness and digital empathy (Kim & Ko, 2022). Such community-based projects reinforce the integration of digital ethics and inclusivity, supporting UNESCO's (2023) digital citizenship framework. Overall, the program's success underscores the potential of SULAM initiatives in creating sustainable digital education models that empower both learners and facilitators.

6. CONCLUSION AND RECOMMENDATION

The Cyber Hasanat initiative exemplifies how experiential, gamified learning can nurture ethical, responsible, and digitally literate citizens from an early age while aligning with the national aspirations of Malaysia's Ekonomi MADANI and SDG 4 (Quality Education). By embedding cybersecurity awareness within community engagement, the project successfully bridged the gap between academic theory and real-world practice, demonstrating that inclusive digital education can simultaneously build technical competence and moral integrity.

The findings from the Cyber Hasanat survey reinforce the importance of adopting a more engaging and sustained approach to cybersecurity education. Integrating practical learning modules such as password-strength testing, phishing detection, and simulated cyber challenges can enhance students' ability to apply theoretical knowledge in authentic contexts. Equally, embedding digital ethics and moral responsibility across all learning activities, including Cyber Hasanat talks and the Secure Cybercitizenship (SET) board games, can strengthen values-based online behaviour. The use of gamified analytics and AI-driven dashboards is recommended to monitor learners' progress in cyber hygiene awareness and provide personalized feedback. Strengthening school and parent collaboration will also ensure that cybersecurity habits are reinforced beyond the classroom.

In the long term, a longitudinal impact evaluation is vital to measure behavioural change and the enduring effects of Cyber Hasanat's interventions. Collectively, these strategies not only sustain the project's educational impact but also position Cyber Hasanat as a model for advancing digital inclusiveness, ethical awareness, and national resilience are core pillars of a prosperous, compassionate, and knowledge-driven MADANI society.

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