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# Understanding issues toward sustainability and innovation adoption in aquaculture: The Malaysian perspective

(Memahami isu kelestarian dan penerimaan inovasi dalam sektor akuakultur: Perspektif Malaysia)

Ahmad Zairy Zainol Abidin[1], Syahrin Suhaimee[1], Mohd Tarmizi Haimid[1], Mohd Hafizudin Zakaria[1] and Aimi Athirah Ahmad[1]

Keywords: aquaculture, sustainability, innovation adoption, fish feed alternatives

**Abstract**

Aquaculture has emerged as a critical sector for Malaysia's food security and rural livelihoods; yet, its growth is constrained by persistent sustainability challenges and lower in innovation adoption. This study examines the key factors influencing sustainability and innovation uptake in the national aquaculture input industry. Employing a mixed-methods approach in 2022, the study triangulated findings from surveys (n = 627 farmers), expert interviews (n = 20), industry engagements and secondary data. The results reveal critical bottlenecks: inconsistent seed quality; high dependency on imported feed ingredients and poor biosecurity practices, with extremely low farmer awareness of Antimicrobial Resistance (AMR) (5%). Furthermore, infrastructure limitations, such as the suboptimal utilisation of Aquaculture Industrial Zones (ZIA) (55% utilised) and high operational costs (particularly utilities), hinder progress. Consequently, the adoption of key innovations in alternative feeds, energy efficiency and digital technologies remains uneven. The paper argues that targeted interventions in policy, infrastructure and research collaboration are essential to advance Malaysia's aquaculture sector towards greater sustainability, competitiveness and resilience.

## Introduction

Aquaculture has emerged as a vital component of Malaysia's agri-food sector, playing a central role in contributing to food security, rural employment and export revenues. With increasing demand for fish protein and stagnation in wild capture fisheries, aquaculture presents a strategic pathway to ensure sustainable seafood production (Chan et al. 2023; Obi et al. 2025). However, this growth is challenged by environmental degradation, biosecurity risks, resource inefficiency and climate change impacts.

The Malaysian aquaculture industry faces critical pressure to balance productivity with sustainability. Poor farm management practices, water pollution, disease outbreaks and over-reliance on natural feedstocks are among the key concerns affecting the industry's ecological footprint (Yusoff 2014; Tan et al. 2024). While policy frameworks such as Good Aquaculture Practices (GAP) and the

[1]Socio-Economy, Market Intelligence and Agribusiness Research Centre, MARDI Headquarters, Persiaran MARDI-UPM, 43400 Serdang, Selangor
e-mail: zairy@mardi.gov.my

promotion of Smart Aquaculture have been introduced (Haimid & Dardak, 2020), their uptake remains fragmented due to a lack of technological literacy, financial constraints and low awareness among small-scale operators (Kamaruddin & Baharuddin 2015).

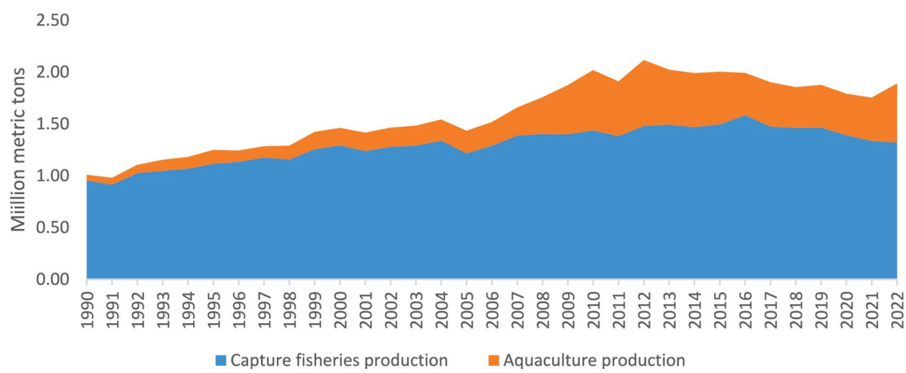
Trends in Malaysia's fisheries sector indicate a clear divergence between marine capture fisheries and aquaculture. As shown in *Figure 1*, capture fisheries have stagnated, mainly since the 1990s, whereas aquaculture production has expanded markedly over the past two decades. This shift highlights the changing dynamics of the sector and raises important considerations regarding sustainability, economic viability and policy interventions. In particular, aquaculture has emerged as a key contributor to Malaysia's fish supply. Between the mid-2000s and 2012, the subsector experienced rapid growth, driven by technological advancements, government support and strong consumer demand (Obi et al. 2025).

In recent years, innovation has been recognised as a key driver in enhancing aquaculture sustainability. From the use of IoT and sensor technologies in water quality monitoring to molecular diagnostics and omics-based disease prevention strategies, innovation holds potential to mitigate risks and enhance efficiency (Lau et al. 2025; Othman et al. 2017). Nevertheless, adoption remains inconsistent across regions and producer groups. Socio-economic barriers, insufficient knowledge transfer and misalignment between research and industry needs hinder the diffusion of such technologies (Rashid et al. 2024; Kamara 2023).

Moreover, Malaysia's aquaculture sector is increasingly affected by climate-related risks such as extreme weather events, temperature fluctuations and salinity changes all of which impact fish health and yield (Abu Samah et al. 2021; Hamdan et al. 2015). The need for climate-resilient strategies, including adaptation frameworks and farm-level risk mitigation, has become more urgent than ever. This paper examines the underlying issues that influence the adoption of sustainability and innovation in Malaysia's aquaculture sector.

**Literature review**

Seed supply and genetics are critical issues in aquaculture sustainability. According to El-Sayed (2006), seed quality determines growth rates, disease resistance and species adaptability to environmental conditions. In Southeast Asia, seed production often faces inconsistent quality due to technological limitations in breeding and the absence of certified hatchery systems (FAO 2024). Malaysia shares these issues, particularly in the production of high-value species such as grouper and mahseer (kelah). Another key challenge concerns the availability of fish feed and the development of alternative sources. Naylor et al. (2021) emphasised that rising global fishmeal prices have driven




Source: Obi et al. 2025.

*Figure 1. Total fishery production in Malaysia (1990 – 2022)*

the search for alternatives such as plant-based proteins, insect meal and microalgae. However, farmer adoption of alternative feed sources is often slow due to cost barriers and reliance on traditional carnivorous species (Kiron et al. 2012). Disease control and antimicrobial resistance (AMR) have been identified by the World Organisation for Animal Health (Mateo 2023) as a global threat. The unregulated use of antibiotics in aquaculture accelerates the development of resistant bacteria. Studies in Vietnam and Thailand show that probiotics, vaccines and phytochemicals are promising alternatives to antibiotics (Defoirdt et al. 2011).

Another main problem related to Malaysia is the issue of inadequate infrastructure within the Aquaculture Industrial Zones (ZIA), which subsequently results in a lack of participants willing to use them. FAO (2017) reported that aquaculture zoning can improve operational efficiency and mitigate environmental impacts. However, the effectiveness of ZIA depends on the availability of basic infrastructure and coordinated management between government agencies and the private sector. Further issues, technology and automation such as Recirculating Aquaculture Systems (RAS), Internet of Things (IoT) applications and biofloc systems have been proven to improve productivity and reduce disease risks (Bostock, J. et al. 2012). However, the main challenges are high capital investment and the need for technical expertise. Boyd et al. (2005) also found that energy and water costs can account for up to 30% of total aquaculture operating expenses. Utility tariff policies that are more supportive of the industry can significantly improve competitiveness.

**Methodology**

This study employed a mixed-methods approach to analyse both quantitative and qualitative aspects of challenges and opportunities within Malaysia's aquaculture input industry in 2022. Quantitative data were analysed using descriptive statistics, while qualitative data were thematically analysed to identify patterns and key issues. The combination of methods allowed for triangulation of data, ensuring that the findings are robust, comprehensive and representative across different stakeholder perspectives.

**Data collection**

Primary data were collected through three approaches: 1) structured interviews, 2) surveys and 3) industry engagement sessions. Structured interviews with key stakeholders with around 20 individuals in each expertise in the aquaculture sector, including the Department of Fisheries (DOF), which oversees national policy and regulation, supported by research from its Fisheries Research Institute (FRI) and researchers from Universiti Malaysia Sabah (UMS). These interviews were crucial in gathering detailed insights on technical issues such as hatchery management, seed quality standards and emerging disease control technologies. Surveys were conducted with 627 aquaculture farmers across Malaysia, using stratified sampling to ensure representation from freshwater and brackish water operators, small-and medium-scale farms and different geographic regions. The survey instrument included both closed-ended and Likert-scale questions, covering farm characteristics and topics such as seed sourcing practices, feed types and costs, disease management strategies, infrastructure availability, technology adoption levels and utility expenses. Industry engagement sessions were conducted with three fish feed manufacturers and selected hatchery operators. These sessions provided market-level perspectives on aquaculture supply chain dependencies, price fluctuations and technological investment constraints, which were seen in the feed and technology.

Secondary data were sourced from DOF Annual Reports (2020 – 2022), Annual Fisheries Statistics, as well as published research and international reports from FAO, OIE and peer-reviewed journals.

**Data analysis**

Quantitative survey data were analysed using Microsoft Excel to generate descriptive statistics. This process identified key trends and distributions, such as the proportion of farms using probiotics, or formalin and the percentage of developed ZIA areas relative to total zoned land.

Qualitative data from interviews and industry engagement sessions were analysed using content analysis. Microsoft Excel was used to organise the data and manage the coding process. A systematic coding process was applied to the transcripts to identify and categorise the main issues discussed. This process revealed several key categories, such as "quality inconsistency in seed supply," "feed price vulnerability" and "AMR awareness gap," which were consistently present in the data and corresponded to the core findings.

While this study's quantitative and qualitative data inform a significant portion of the findings, they do not account for all of the conclusions presented. This primary data is used strategically to highlight specific trends, validate stakeholder perspectives, and provide context to certain issues. The complete analysis also draws upon a wider range of industry knowledge and context, if available.

**Results and discussion**

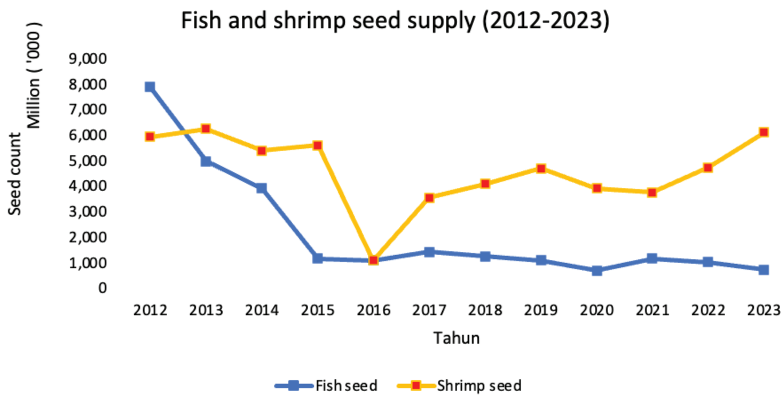
Findings from the structured interviews, surveys and industry engagement sessions highlighted six key areas that influence sustainability and innovation adoption in Malaysia's aquaculture sector: (i) fish and shrimp seed supply, (ii) challenges related to fish feed, (iii) disease control practices and awareness, (iv) utilisation of aquaculture infrastructure, (v) adoption of technology and (vi) the burden of utility costs.

***Fish and shrimp seed supply***

The production of fish and shrimp seed in Malaysia is undertaken by both government and private hatcheries, designed to meet domestic demand. A consistent and high-quality seed supply is paramount, as it directly influences farm productivity and the success of aquaculture operations. The industry can no longer rely on wild-caught seed, as this source is insufficient to meet demand. White shrimp seed dominates the total seed production for aquaculture. The decline in shrimp seed in 2016 was due to an EMS attack. There was a sharp decline in fish seed beginning in 2013 and its production remained flat from 2015 to 2020 (*Figure 2*).

In Malaysia, hatchery facilities producing fish and shrimp seed are operated by both government and private sectors and are found in nearly all states of Peninsular Malaysia, as well as in Sabah and Sarawak. The seed production system can be classified into three categories: freshwater fish seed, marine/brackish water fish seed and shrimp seed. For freshwater species, private hatcheries typically produce catfish (*Clarias* spp.), patin (*Pangasius* spp.), red tilapia (*Oreochromis* spp.), lee koh (carp) and climbing perch (*Anabas testudineus*). Government hatcheries, meanwhile, focus on species such as Java barb (*Barbonymus gonionotus*), river barb, red tilapia, patin, catfish and climbing perch. For marine and brackish water hatchery production, private operators mainly produce oyster, snapper (*Lutjanus* spp.), grouper (*Epinephelus* spp.), seabass (*Lates calcarifer*), red snapper, hybrid grouper and cockle (*Anadara granosa*). Government hatcheries cultivate similar species, adding sea cucumbers (*Holothuria* spp.).

Shrimp hatchery production includes giant freshwater prawn (*Macrobrachium rosenbergii*), black tiger shrimp (*Penaeus monodon*), white shrimp (*Litopenaeus vannamei*) and spiny lobster (*Panulirus* spp.) in private facilities. Government hatcheries also rear these species, with the exception of




Source: Department of Fisheries Malaysia (DOF) Report, 2012 – 2023

*Figure 2. Fish and shrimp seed supply (2012 – 2023)*

spiny lobster. Among these, only the giant freshwater prawn represents the freshwater segment, while the others fall within the marine/brackish water category.

The production of fish and shrimp prior to marketing begins with the stocking of seed or juveniles into a rearing environment that ensures optimal and rapid growth. This process is designed to enable harvesting within the shortest possible time frame. Fish farmers must secure an adequate number of seed or juveniles to meet their production objectives. The seed supply may originate from wild sources or hatchery production. However, wild seed resources are insufficient to meet the growing demand of Malaysia's aquaculture industry. Regardless of their origin whether wild-caught or hatchery-bred, fish and shrimp seed are indispensable to the sector and the means of acquisition directly influence farm productivity. An inconsistent supply can disrupt other farming activities, whereas a stable supply enables maximum production.

However, fluctuations in seed costs significantly affect overall production costs. Hence, the availability of high-quality and consistent fish seed is critical for the success of aquaculture operations. The primary objective of fish and shrimp farmers is to produce marketable stock that fulfils both consumer requirements and market demand. In recent years, artificial breeding technologies have been increasingly adopted, providing farmers with the ability to select for desirable traits such as rapid growth, disease resistance and improved survival rates.

Information from the government agency, indicates that the overall quantity of seed is considered sufficient; there is a significant and persistent issue with the quality and consistency of the supply. Representatives from the Fisheries Research Institute (FRI) highlighted a market deficiency in high-quality fry that exhibit firm survival and growth rates. This quality gap is a critical bottleneck for the industry. Although government bodies like Department of Fisheries (DOF), through its research arm, the Fisheries Research Institute (FRI) are involved in seed production, private hatcheries need to produce the seed to meet national needs, particularly for specialised species like sea bass, kelah and grouper.

Currently, there are 398 hatchery operators producing fish and shrimp seed in Malaysia. Out of this number, only 41 operators (10.3%) were certified under the Malaysian Good Agricultural Practice (myGAP) scheme. The ratio of certified to uncertified operators remains uneven at approximately 1:10, as shown in *Table 1*. This imbalance reflects both the challenges of certification adoption and the need for greater efforts to align hatchery practices with sustainable aquaculture standards.

A survey of 627 aquaculture entrepreneurs revealed that 35% face challenges in securing experts for fish breeding, particularly for key freshwater species such as tilapia, keli and patin. This study also identified a structural weakness that is the lack of a formal recognition system for hatcheries or a centralised database of breeding specialists. The proposal to create such a database received overwhelming support (96%) from potential users, indicating a clear demand for a system to connect farmers with verified experts.

Table 1. The number of hatcheries for myGAP and non-myGAP holders

| Type | Number of hatcheries | Ratio between myGAP and non-myGAP |
|---|---|---|
| myGAP | 41 | 10 : 1 |
| Non-myGAP | 357 | |

Source: Engagement with DOF officials

***The challenges related to fish feed***

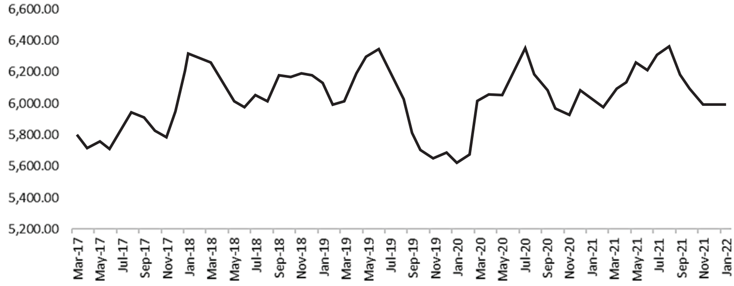
The prices of fish feed ingredients, particularly fishmeal and soybean meal, have shown a global upward trend from 2017 – 2022 (*Figure 3*). Although Malaysia has domestic pellet producers, the country remains dependent on raw material imports from Vietnam, China and the Netherlands. Rising prices exert significant pressure on farmers' operational costs, as feed can represent 50 – 70% of production costs (Naylor et al. 2021).

Global fishmeal production is highly dependent on a limited number of countries that serve as the primary suppliers to the international market. As illustrated in *Figure 4*, Peru has consistently maintained the largest share of global fishmeal exports over the past decade, positioning the country as the world's leading exporter of fishmeal for animal feed.

On the demand side, China has emerged as the dominant global importer of fishmeal, holding the largest share of global imports for almost ten consecutive years (*Figure 5*). This reflects China's expanding aquaculture and livestock industries, which drive a substantial portion of the worldwide demand for fishmeal.

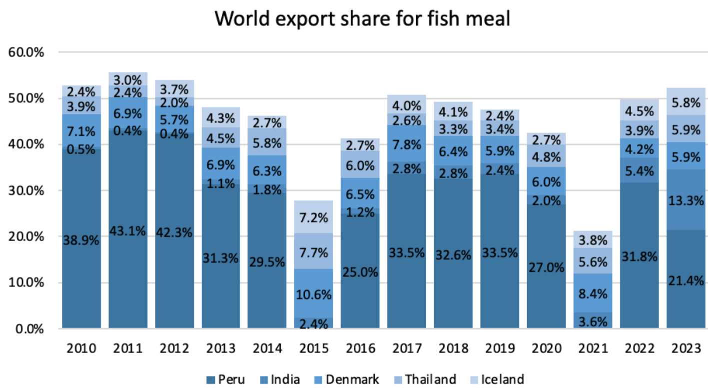
In the case of Malaysia, the domestic market remains largely dependent on imports. The country primarily imports fishmeal from Vietnam, followed by China and the Netherlands, to meet its local requirements. However, Malaysia is also active in the export market, particularly to Indonesia and China. This dual role occurs because market actors often operate simultaneously as both importers and exporters, engaging in trade to optimise their commercial positions (*Figure 6*).

Engagement with three fish feed manufacturers in Malaysia, revealed that, in terms of raw material supply, particularly fishmeal and soybean meal, no significant supply disruptions were reported.



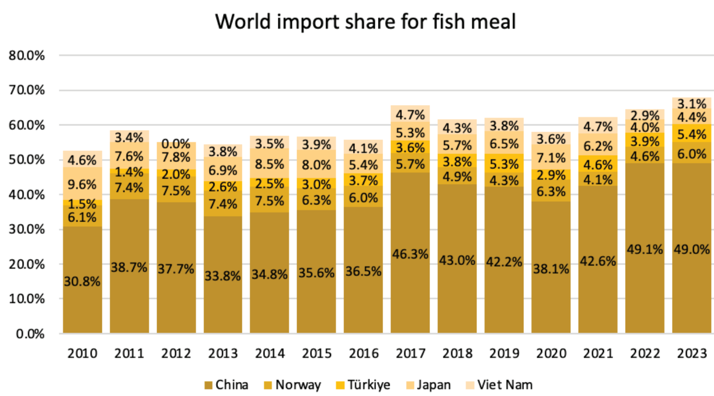

Source: Index Mundi. Fishmeal, Peru Fish meal/pellets 65% protein, CIF, Malaysian Ringgit per Metric Ton. Note: Fishmeal, Peru Fish meal/pellets 65% protein, CIF

*Figure 3. World fish meal price in pallet form 2017 – 2022 (RM/mt)*



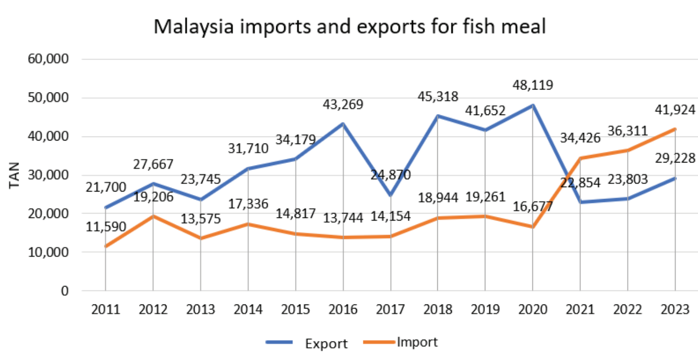

Source: UN Comtrade Data. HS230120 (Flours, meals and pellets; of fish or of crustaceans, molluscs or other aquatic invertebrates, unfit for human consumption). Note: Peru is not listed for 2015 and 2021

*Figure 4. World export share for fish meal*




Source: UN Comtrade Data. HS230120 (Flours, meals and pellets; of fish or of crustaceans, molluscs or other aquatic invertebrates, unfit for human consumption)

*Figure 5. World import share for fish meal*




Source: UN Comtrade Data. HS230120 (Flours, meals and pellets; of fish or of crustaceans, molluscs or other aquatic invertebrates, unfit for human consumption)

*Figure 6. Malaysia imports and exports for fish meal*

However, the companies highlighted the persistent issue of rising raw material costs. Despite these increases, the manufacturers indicated that they were still able to absorb the higher costs without passing them directly on to customers, thus maintaining stable retail prices for feed pellets. But for domestic fishmeal producers, we are unable to engage with any company that is related to fishmeal; thus, the status of fishmeal supply, particularly low-value fish (trash fish) used in fishmeal production, could not be obtained.

For the pellet feed industry, no major production disruptions were identified. Consequently, the search for alternative raw material sources was not considered a priority by manufacturers. The production of fish feed pellets within Malaysia is regarded as sufficient to meet national demand, supported by the presence of multiple local and foreign-owned companies operating domestically. These companies possess substantial production capacity and are well-equipped to meet the needs of the aquaculture industry, particularly in tailoring feed formulations to suit the specific requirements of local farmers.

Nevertheless, some local companies continue exploring alternative substitutes, such as microalgae. Microalgae as a substitute for fishmeal has been increasingly highlighted as a promising alternative in aquaculture nutrition. A review of recent studies suggests that microalgae, when used in photobioreactor systems, have the potential to replace up to 15% of fishmeal in aquafeed formulations. However, further economic feasibility assessments are necessary to determine its viability at a commercial scale. Microalgae are recognized as an important nutritional source in aquaculture, particularly due to their high protein content, essential fatty acids and bioactive compounds beneficial for aquatic species.

However, several risks may hinder wider adoption. Market acceptance remains limited due to low awareness of their benefits, while competition from conventional feeds such as soybean poses significant economic challenges. Photobioreactor systems are costly and sensitive to environmental fluctuations, raising concerns about production stability. In addition, regulatory and policy uncertainties constrain large-scale investment, meaning that without targeted interventions, commercialisation may be delayed and dependence on imported feed ingredients sustained.

***Disease control and prevention practices and awareness***

The use of disease control measures in aquaculture is a global issue and has shown significant growth, particularly in Asian countries, due to the rapid expansion of the aquaculture industry. This trend is linked to limited regulatory enforcement, restricted access to alternative treatment methods and inadequate incentives for farmers to adopt improved practices. Addressing this issue requires coordinated global efforts. While antimicrobial agents are commonly applied to control diseases and parasites in cultured fish and other aquatic species, their excessive use can lead to the development of antimicrobial-resistant bacteria, posing risks to aquaculture sustainability, human health and the environment. Consequently, there have been increasing initiatives worldwide to reduce and ultimately eliminate the reliance on chemical disease control in aquaculture. This can be achieved through regulatory interventions, awareness-building on associated risks and the adoption of alternative disease management strategies such as vaccination, probiotics, phytogenic additives and good aquaculture practices (GAP). Many countries have already established maximum residue limits (MRLs) for veterinary drugs in seafood to ensure food safety and certification schemes have been introduced to recognise aquaculture operations that minimise or eliminate the use of chemical disease control.

In Malaysia, the use of antimicrobials in aquaculture is overseen and regulated by the Department of Fisheries (DOF). The department discourages routine antimicrobial use and promotes alternative measures, including GAP, proper nutrition and vaccination. The DOF has also set MRL standards for veterinary drugs in seafood to ensure consumer safety. Nevertheless, survey results show that farmers prefer to use antimicrobials. Key factors driving this include limited awareness, the high cost of alternatives and the easy availability of unprescribed antimicrobials in the market. Survey data revealed that the majority of farmers were unaware of the risks associated with antimicrobial resistance (AMR). Only 5% of respondents were familiar with AMR and its consequences. Survey results indicated widespread use of antimicrobials and chemicals in aquaculture farms, with antibiotics such as enrofloxacin and oxytetracycline being commonly reported. This knowledge gap helps explain why the use of controlled substances persists despite being discouraged by the DOF. Antimicrobial are used frequently for treatment (46%), prevention (32%) and as a routine practice (22%).

The Department of Fisheries (DOF) and its research division, the Fisheries Research Institute (FRI), are actively promoting alternatives, including good aquaculture practices, vaccination and probiotics. Notable locally developed alternatives include the probiotic SitroPro, the herbal extract Sirehmax and the oral vaccine StrepToVax. These products offer a path towards reducing chemical dependency, improving sustainability and mitigating the risk of AMR. The most commonly used substances are probiotics/EM (37.31%), followed by chemicals like formalin (22.39%). Use of herbal extracts was very low (0.68%), likely due to limited commercial development and variability in effectiveness. Unlike conventional antimicrobials, phytogenic extracts lack standardised dosages and regulatory approval, making their adoption slower (*Table 2*).

Table 2. Use of disease control agents and drugs among aquaculture farmers

| Disease control agents and drugs | Percentage (%) |
|---|---|
| Probiotics/EM | 37.31 |
| Formalin | 22.39 |
| Coarse salt | 16.69 |
| Iodine | 8.96 |
| Methylene blue | 6.65 |
| PondDtox and lime | 5.56 |
| Herbal extracts | 0.68 |
| Others | 1.76 |

Source: Survey Data 2022

***The utilisation of aquaculture infrastructure***

The development of aquaculture infrastructure in Malaysia has been primarily concentrated within the Aquaculture Industrial Zones (ZIA), as in 2023, it covered a total of 19,327 ha nationwide, of which only 10,598 ha (55%) were actively utilised. At the initial stage, the Department of Fisheries (DOF) provides basic infrastructure such as farm access roads, domestic water supply, electricity and irrigation/drainage systems, depending on available government allocations.

The National Agrofood Policy 2.0 (NAP 2.0) set a target to increase aquaculture production from 400 thousand mt in 2020 to 520 thousand mt in 2025, representing a 30% growth. Based on the 2021 production baseline, the projected contribution from ZIA was estimated to increase by 9,866 mt by 2025.

However, the latest data from DOF (2023) indicate that total ZIA production reached 9,663 mt, which is only 2% below the projected 2025 target (*Table 3*). This suggests that ZIA production is on track and is likely to surpass the policy target before 2025.

Table 3. Aquaculture production by state at ZIA, 2021 – 2023 (mt)

| State | 2021 | 2022 | 2023 |
|---|---|---|---|
| Kedah | 336.54 | 1,791.70 | 1,081.00 |
| Pulau Pinang | 839.36 | 799.06 | 1,086.89 |
| Perak | 2,648.43 | 3,218.97 | 2,749.64 |
| Selangor | 1,398.80 | 713.47 | 932.68 |
| Negeri Sembilan | 3.13 | 4.33 | 5.03 |
| Melaka | 273.07 | 408.91 | 309.30 |
| Pahang | 1,281.80 | 1,419.29 | 2,557.79 |
| Kelantan | 37.65 | 41.07 | 53.19 |
| Terengganu | 123.96 | 147.23 | 124.77 |
| Sarawak | 474.38 | 753.62 | 614.33 |
| Sabah | 172.08 | 276.96 | 148.06 |
| Total | 7,589.19 | 9,574.61 | 9,662.68 |

Source: Department of Fisheries Malaysia (DOF), 2023

***The adoption of technology***

The adoption of technology has become increasingly critical in strengthening aquaculture practices, particularly in addressing the dual challenge of increasing production while maintaining product quality. Farmers are progressively exploring diverse technological solutions such as solar-powered systems, marine cage culture, locally developed Recirculating Aquaculture Systems (RAS) and smart Internet of Things (IoT) applications in hatchery and grow-out operations. In addition, innovations such as floating tank nurseries, automated feeding devices, biofloc systems and feed barges have been introduced to enhance efficiency and sustainability.

Although these technologies present promising alternatives for improving productivity, the relatively high costs associated with their adoption remain a major barrier, particularly for small-scale producers. Findings from surveys indicate that the majority of farmers (47%) continue to rely on traditional systems, which are less capital-intensive but comparatively less efficient. Meanwhile, only a small proportion (3%) has shifted towards super-intensive systems, which, despite offering higher yields, demand significant financial investment and technical expertise.

This distribution underscores the uneven pace of technological transition within the aquaculture sector, where the adoption of advanced systems remains limited to specific groups of farmers with greater access to resources. Consequently, while technological innovation is recognised as a driver of productivity, its widespread application is dependent upon the economic and structural constraints faced by farmers.

***The burden of utility costs***

Electricity and water costs are major components of farm operating expenses. Aquaculture farmers in Malaysia show a high dependence on electricity and water for their daily operations. The issue of rising operational costs, largely attributed to utility usage, has been widely raised among producers. However, efforts to mitigate this challenge remain limited, as the supply of electricity and water is governed by national policies and institutional frameworks.

There is no special electricity tariff for aquaculture, despite its strategic role in the agricultural and food sector. Information obtained from Tenaga Nasional Berhad (TNB) confirms that no preferential tariff scheme is currently in place for aquaculture operators. During a briefing at the Malaysia Agriculture, Horticulture and Agrotourism Exhibition (MAHA) 2022, representatives from the Sustainable Energy Development Authority (SEDA) and the Energy Commission highlighted that, based on 2021 data, electricity consumption by the agricultural sector, particularly fisheries, remains relatively low compared to other national sectors. Consequently, the introduction of a sector-specific tariff for fisheries has not been prioritised. Nevertheless, electricity tariff reviews are undertaken every three years, with the upcoming revision scheduled for 2025. TNB reaffirmed that aquaculture operators will continue to be subjected to the prevailing standard tariffs across the country.

Raw water charges also vary by state (RM0.04 – RM0.10/$m^3$), creating cost disparities among producers. Charges for water abstraction, defined as the pumping of freshwater or seawater into aquaculture ponds from natural sources, remain inconsistent across states and are only enforced in selected regions. In addition, charges for the discharge of pond effluents are imposed under the authority of the Department of Environment. However, following the Menteri Besar and Chief Ministers' Meeting on 28 June 2022, the Prime Minister announced a national initiative to introduce lower abstraction charges for both freshwater and seawater utilisation within the agri-food sector. As of 2022, raw water tariffs ranged from RM0.04 – RM 0.10/$m^3$, depending on state regulations (*Table 4*).

Table 4. Raw water tariff rates in selected state in Malaysia (2022)

| State | Raw water tariff type | Rate (RM/$m^3$) |
|---|---|---|
| Johor | None | None |
| Negeri Sembilan | None | None |
| Melaka | Applicable | 0.08 |
| Perak | Non-domestic | 0.04 |
| Selangor | Commercial | 0.05 |
| Kedah | Commercial | 0.05 |
| Kelantan | Non-domestic | 0.06 |
| Pahang | Non-domestic | 0.08 |
| Terengganu | Non-domestic | 0.10 |

Malaysia needs uniform tariff policies and incentives for energy efficiency, including the use of green technologies such as solar power or aquavoltaics to reduce grid dependency. Without policy intervention, utility costs will continue to be a major barrier to the financial sustainability of aquaculture farms.

**Recommendations**

The Malaysian aquaculture sector is at a critical juncture where the convergence of sustainability and innovation adoption is essential to ensure long-term resilience. A key issue hindering progress is the quality and availability of aquaculture seeds. Despite adequate production capacity, inconsistencies in seed quality undermine productivity and farmer confidence. Addressing this challenge requires the certification of hatcheries and the establishment of a national database of breeding experts, which would enhance both reliability and credibility within the sector.

Feed dependency represents another pressing concern. The Malaysian aquaculture industry remains highly reliant on imported feed ingredients, exposing farmers to global market volatility and rising production costs. Innovation in this area must focus on alternative feed resources such as insect-based proteins, microalgae, and plant-derived formulations, which not only promote self-sufficiency but also align with the global sustainability agenda.

Disease management, particularly the escalating challenge of antimicrobial resistance (AMR), highlights another area of vulnerability. Current practices have raised concerns about public health and the credibility of international trade. Sustainable solutions require systemic interventions, including the promotion of vaccines, probiotics and phytogenic additives, supported by government-led awareness and incentive programs. This aligns with the broader sustainability principle of reducing ecological and health risks associated with conventional aquaculture practices.

The underutilisation of Aquaculture Industrial Zones (ZIA) limits opportunities for innovation-driven growth and sustainability. Upgrading these zones with modern facilities and improved management systems could transform them into growth clusters for innovation-driven aquaculture. Simultaneously, the adoption of advanced systems such as biofloc, recirculating aquaculture systems (RAS) and renewable energy-based solutions is crucial. However, the uptake of these technologies is often constrained by high capital costs. Policymakers should therefore expand financial mechanisms such as soft loans and targeted subsidies to enable wider adoption, in line with innovation diffusion theory which stresses affordability as a key determinant of technological acceptance.

High utility costs further undermine sustainability and hinder the adoption of energy-efficient innovations. Electricity remains governed by standardised tariffs across all sectors, with no preferential rates for aquaculture. Similarly, water abstraction charges vary across states and are inconsistently applied. These factors inflate production costs and weaken the industry's regional competitiveness. A reform of tariff structures that recognises aquaculture as part of the national food security agenda would create a more enabling environment for innovation and sustainability.

**Summary**

Overall, the Malaysian aquaculture input industry demonstrates strengths such as established feed production, seed capacity, and locally developed disease management techniques. Nonetheless, weaknesses persist, notably in seed quality assurance, feed import dependency, disease management, uneven water tariff structures and limited uptake of innovative technologies. These weaknesses are further exacerbated by external threats including global price volatility, climate variability and increasing competition from regional producers.

Yet, these challenges also present opportunities. By strategically investing in certified hatcheries, alternative feed sources, sustainable disease control methods, modern aquaculture systems and supportive utility policies, Malaysia can reposition its aquaculture sector on a more sustainable trajectory. Such interventions could facilitate the broader adoption of innovation, thereby strengthening sectoral competitiveness and resilience.

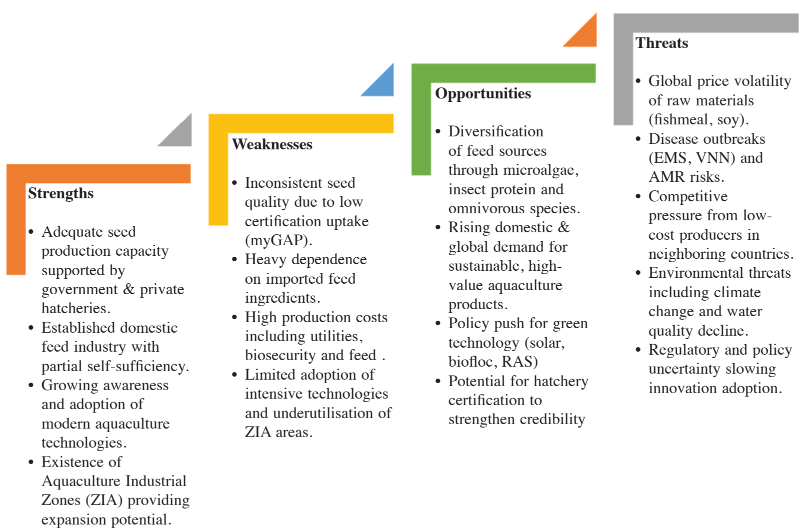



*Figure 7. SWOT analysis of sustainability and innovation adoption in Malaysia's aquaculture sector*

In conclusion, understanding the interplay between sustainability concerns and the adoption of innovation is essential for Malaysia to secure its place in the regional aquaculture landscape. The industry's future lies in striking a balance between environmental responsibility and technological advancement, thereby ensuring long-term food security, economic viability and environmental stewardship.

Future research should focus on several critical dimensions to advance the sustainability and innovation agenda. First, in-depth studies are needed on the socio-economic factors that influence farmers' readiness to adopt innovative aquaculture technologies, particularly among small- and medium-scale operators. Second, comprehensive life-cycle assessments (LCAs) of emerging systems such as biofloc and recirculating aquaculture systems (RAS) should be conducted to evaluate their environmental and economic trade-offs within the Malaysian context. Third, further investigations into the feasibility of alternative feed ingredients including insect-based proteins, microalgae and agricultural by-products could provide pathways to reduce import dependency. Additionally, research into water and energy optimisation strategies, as well as disease management and AMR issues, tailored to aquaculture operations, may offer insights into reducing production costs while supporting sustainability goals.

Finally, policy-oriented studies that assess the effectiveness of current utility tariffs, financial incentives and regulatory frameworks will be vital to inform evidence-based interventions. Such efforts would not only strengthen Malaysia's aquaculture sustainability agenda but also accelerate the adoption of innovations, ensuring the sector remains competitive in the rapidly evolving global food system.

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**Abstrak**
Akuakultur telah muncul sebagai sektor kritikal untuk jaminan makanan dan kelangsungan hidup luar bandar di Malaysia, namun pertumbuhannya dikekang oleh cabaran kelestarian yang berterusan dan penerimaan inovasi yang perlahan. Kajian ini meneliti faktor-faktor utama yang mempengaruhi kelestarian dan penerimaan inovasi dalam industri input akuakultur negara. Menggunakan pendekatan kaedah campuran (*mixed-methods*) pada tahun 2022, kajian ini melakukan triangulasi dapatan daripada tinjauan (n = 627 pengusaha), temu bual pakar (n = 20), libat urus industri dan data sekunder. Hasil kajian mendedahkan kekangan yang kritikal: kualiti benih yang tidak konsisten; kebergantungan tinggi terhadap bahan makanan import dan amalan biosekuriti yang lemah, dengan kesedaran peladang yang sangat rendah terhadap Rintangan Antimikrob (AMR) (5%). Tambahan pula, had infrastruktur seperti penggunaan Zon Industri Akuakultur (ZIA) yang suboptimal (55% digunakan) dan kos operasi yang tinggi (terutamanya utiliti) membantutkan kemajuan. Akibatnya, penerimaan inovasi utama dalam makanan alternatif, kecekapan tenaga dan teknologi digital masih tidak sekata. Kajian ini menegaskan bahawa intervensi bersasar dalam dasar, infrastruktur dan kerjasama penyelidikan adalah penting untuk memajukan sektor akuakultur Malaysia ke arah kelestarian, daya saing dan daya tahan yang lebih tinggi.