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ORIGINAL ARTICLE

Usage of Bamboo as an Eco-friendly Material in the Freshwater Aquaculture Industry

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ABSTRACT - Freshwater aquaculture consists of a wide diversity of systems across physical and economic scales, infrastructure configurations, species, ownership, and value chains. The present costs of constructing and maintaining the floating rafts for cage culture sheltered inshore water are quite high. As a result only those with big capital investment can afford to get involved in the business while the rural communities staying near the coastal areas are left behind. This paper shows that aquaculture does contribute to the livelihoods of the poor, particularly in areas of Asia where it is a traditional practice, by substituting bamboo for timber structure as well as floats and every floating raft. The usage of bamboo in the aquaculture industry in Malaysia has the potential to be a sustainable and cost-effective solution with a comparison of 12.6% cheaper than conventional materials. It has many applications and adaptable for long service marine uses and has been used in the fishing industry for decades, although no documented information is available.

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INTRODUCTION

The aquaculture industry has grown significantly in recent years as the demand for seafood has increased and wild fish populations have decline. Aquaculture is now more diverse, with 40% more fish, shellfish, aquatic plants, and algal species cultivated globally in various marine, brackish, and freshwater systems [1]. The aquaculture industry serves both domestic and international markets, and seafood produced by aquaculture accounts for a growing share of the world's seafood supply. The aquaculture industry has the potential to provide a sustainable source of seafood for a growing global population. As with any food production, sustainability is an important concern in aquaculture. Sustainable aquaculture practices aim to minimize the environmental impact of fish farming while maximizing production efficiency. Thus, it is important to continue to develop and refine sustainable production methods to ensure that aquaculture can be practiced in an environmentally responsible way.

Global production remains concentrated, however, with only 22 of all 425 species groups farmed in 2017 (5%) accounting for over 75% of global live-weight production. Asia remains the largest aquaculture producer, accounting for 92% of the live-weight volume of animals and seaweeds in 2017. Aquaculture in Asia is also more diverse than in other regions regarding production systems and cultivated species [1]. Aquaculture is an important industry in Malaysia, with a long history of traditional fish farming in freshwater ponds and cages. The industry has expanded to include marine fish and shellfish farming and seaweed cultivation in recent years. The aquaculture industry in Malaysia has been acknowledged as a strategic industry that can accomplish the local demand for high value protein resources as well as demand for fish products for trade purposes. This has facilitated the government to reach its goals in the Ninth Malaysia Plan for food production growth of 33.4% or 1.8 million mt for fisheries and reached 103% self-sufficiency level by 2010 [2].

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Malaysia is the world's third-largest producer of cultured shrimp and the largest producer of pangasius fish outside of Vietnam. Other important aquaculture species produced in Malaysia include tilapia, catfish, and seaweed. Aquaculture production is concentrated in coastal areas and inland freshwater ponds, particularly in Johor, Perak, and Selangor. The Malaysian government has actively supported the growth of the aquaculture industry through initiatives that aim to increase production and improve the industry's competitiveness by introducing Aquaculture Industrial Zones (AIZ). AIZ are designated zones for both lands and water bodies which are granted by the state government for commercial scale aquaculture projects [2]. The Malaysian aquaculture industry has faced challenges related to environmental sustainability, including issues with water quality and disease management. However, efforts are underway to address these challenges by implementing sustainable practices and regulations.

The Lifespan of an Aquaculture System

The lifespan of an aquaculture system can vary depending on several factors, including the materials used, the type of system, and the maintenance practices employed. Concrete ponds and raceways can last for several decades with proper maintenance and upkeep, while polyethylene tanks and pipes may have a shorter lifespan of 10-15 years [3]. Wooden structures such as fish pens and traps may have a shorter lifespan due to the potential for rot and decay, although some species of wood may be more durable and long-lasting than others. Proper maintenance and upkeep are important for prolonging the lifespan of aquaculture systems. Regular cleaning, inspection, and repair of any damage can help prevent minor issues from turning into major problems that could compromise the system's structural integrity.

In addition to physical wear and tear, aquaculture systems may also be impacted by environmental factors such as weather, water quality, and disease outbreaks. Regular monitoring of these factors and taking appropriate action to mitigate any negative impacts can help extend the lifespan of the aquaculture system. The lifespan of an aquaculture system can vary widely depending on many factors, but with proper maintenance and care, an aquaculture system can last for many years.

Tropical Fish for the Aquaculture Industry

Many types of tropical fish can be used in the aquaculture industry, depending on the specific market demand and production goals. Tilapia is a hardy and fast-growing fish widely cultured in tropical and subtropical regions. It is a popular food fish due to its mild taste and versatility in cooking. Catfish, particularly the channel catfish (Ictalurus punctatus), are another common food fish raised in aquaculture systems. They are hardy and can tolerate a wide range of environmental conditions. Barramundi (Lates calcarifer) is a popular food fish in Asia and Australia. It has a mild flavor and firm texture and is considered a high-value species in aquaculture. Groupers (Epinephelus spp.) are a popular food fish in many parts of the world, including Asia and the Caribbean. They are slow growing but can be raised in aquaculture systems to meet demand. Pangasius, or basa or swai, is a catfish species widely cultured in Southeast Asia. It is a low-cost fish with a mild flavor often used in processed seafood products. Similar to many other nations in the region, Malaysia uses aquaculture to produce high-value fish for export and as a supplement to the nation's food supply. The top species for freshwater or inland aquaculture are tilapia, catfish, clarias, and carps. Giant seabass, grouper, snapper, shrimp/crabs (Penaeus vannamei and P. monodon), bivalves (cockle, mussel, oyster), and seaweed are the primary species for coastal and marine farming [2];[4].

Other tropical fish species that may be raised in aquaculture systems include red snapper, sea bream, cobia, and pompano. The choice of species will depend on factors such as market demand, production goals, and the suitability of the species for the local environment.

Construction of an aquaculture system

The construction of an aquaculture system will depend on several factors, including the species being raised, the production method (ponds, raceways, cages, and recirculating systems), and the materials being used as in Figures 1 and 2. There are a few general procedures that can be used to build an aquaculture system; starting from choosing a location for the aquaculture system that will operate best while taking into account resources like water and electricity availability as well as any possible environmental implications. Then, make an aquaculture system strategy that takes into account the size and layout of the tanks or ponds, water flow, and filtration. Take into account the demands of the raised species as well as any applicable environmental rules. All plants and debris should be removed from the region before level the ground and lay the aquaculture system's foundation such as the tanks or ponds, put in the filters and plumbing, and add apparatus like aerators or pumps. Add any necessary treatments, such as lime or other chemicals to balance the pH or control parasites, to the tanks or ponds after filling them with water. Continually check the water quality, give fish or other animals the proper food, and take care of the equipment and buildings as needed.

Aquaculture systems can be made from various materials depending on the production method and species being raised. Some common materials used in aquaculture systems include concrete, fiberglass, polyethylene, wood, polyvinyl chloride (PVC), and metals. Concrete is a durable and long-lasting material often used to construct aquaculture ponds and raceways. Fiberglass is a lightweight and corrosion-resistant material commonly used in constructing aquaculture tanks and recirculating systems. Polyethylene is a type of plastic resistant to corrosion and can be used to make aquaculture tanks, pipes, and other components. Wood is a traditional material still used to construct small-scale aquaculture systems such as fishponds and cages. PVC is a plastic material used to construct aquaculture pipes, fittings, and other components. Metal materials such as stainless steel and aluminum are sometimes used in the construction of aquaculture tanks, particularly in marine aquaculture operations [5]. The choice of materials will depend on factors such as the type of aquaculture system, the species being raised, and the environmental conditions of the production site. Using sustainable and eco-friendly materials is becoming increasingly important in aquaculture to reduce the environmental impact of production.

It is essential to note that constructing an aquaculture system requires careful planning and attention to detail to ensure its success. Consulting with experts in aquaculture system design and construction can help ensure that the system is built correctly and can meet production goals.

Figure 1. Cages in the water-based aquaculture system

Figure 2. Cages in water-based aquaculture system (Binangonan Freshwater Station of South East Asian Fisheries Development Centre)

Usage of bamboo material in the construction of aquaculture system

Bamboo is a highly sustainable and renewable material that can be utilized in constructing eco-friendly aquaculture systems [6]. This material is readily available in many parts of the world, particularly in Southeast Asia, where the aquaculture industry is widespread [7];[8]. Small-scale farmers and fishers in some parts of Asia culture fish in cages made of wood and many bamboo species such as *Bambusa vulgaris* [9], *Gigantochloa scortechinii* [10]; and *Gigantochloa levis* [7]. For example, in Vietnam, grass carp are cultured in bamboo and wood cages in rivers and reservoirs, using grass, maize stalks, cassava leaves, and roots as feed. In Nepal, Chinese carp are cultured using minimal supplementary feed in nylon net cages, bamboo floats, and frames in eutrophic lakes with abundant plankton.

Bamboo has many properties that make it suitable for use in aquaculture systems. It is strong, durable, and lightweight, making it easy to transport and install [11];[12]. It is also resistant to rot and pests, a common problem with other wooden structures [13]. Bamboo can construct various aquaculture structures, including fish cages, pens, and traps. Bamboo may easily replace timber as the primary material in the aquaculture and other fishing industries, according to [14]. Furthermore, compared to lumber, the associated costs are considerably lower [15]. Using bamboo in aquaculture systems can also benefit local communities economically by supporting the development of local industries and employment opportunities. However, it is crucial to note that using bamboo in aquaculture systems should be done sustainably and responsibly. Over-harvesting of bamboo can lead to deforestation and other environmental problems, so it is important to ensure that bamboo is harvested sustainably and that appropriate management practices are in place to ensure the long-term viability of bamboo resources [16].

Other studies have investigated using bamboo as a substrate for biofiltration in aquaculture systems. Bamboo has been shown to be effective in removing nitrogenous compounds from water, maintaining water quality, and reducing the need for water exchange. Bamboo has also been used as a substrate for cultivating beneficial bacteria and other organisms to help maintain water quality [17].

Although bamboo has been a popular building material for maritime environments for many years, little research has been done on protecting it from marine species that can cause damage. Marine wood-boring organisms like mollusks and crustaceans can harm bamboo surfaces when exposed to seawater, but they are not the primary culprits. Studies show that marine borers are attracted to bamboo surfaces superficially degraded by microbes since they are more likely to settle there [18];[14].

Finally, some studies have investigated using bamboo as a feed source for aquaculture species. Bamboo leaves and shoots are a good source of protein and other nutrients and have been shown to be a suitable feed for species such as tilapia and carp. The use of bamboo in the aquaculture industry has the potential to provide sustainable and low-cost solutions for a variety of production challenges. However, further research is needed to fully understand the potential benefits and limitations of using bamboo in aquaculture systems.

Challenges in using bamboo in an aquaculture industry

Although bamboo is a valuable and versatile material for the aquaculture industry, it is important to be aware of some challenges when using it in aquaculture systems. For instance, while bamboo is durable, its lifespan may be shorter than other materials such as steel or plastic. Over time, bamboo may decay, which can lead to structural damage to aquaculture systems. Additionally, bamboo may require more maintenance than other materials used in these systems, such as steel or plastic. For example, bamboo fish pens may need more frequent cleaning to prevent the buildup of algae and other fouling organisms [19]. Moreover, bamboo may be less readily available in certain regions, increasing the cost of using it in aquaculture systems.

Using bamboo may also present some design challenges when constructing aquaculture systems. For instance, bamboo may be more difficult to bend and shape than other materials, which could limit the design options for aquaculture systems. Furthermore, bamboo is a natural material that can vary in quality depending on factors such as bamboo species, age, and growing conditions [9];[12]. This variability could make it more challenging to maintain consistent quality and performance in aquaculture systems.

While bamboo can offer several benefits as a material for aquaculture systems, it is essential to consider its potential challenges and limitations in aquaculture operations. Properly planning and maintaining bamboo aquaculture systems can minimize these challenges, and the benefits of using bamboo can be maximized.

Treatment to increase the durability of bamboo

Bamboo can be vulnerable to micro-organisms and fungal attacks, affecting its durability. The longevity of bamboo can be influenced by the conditions it is exposed to. Treating bamboo with preservatives can extend its service life, as untreated bamboo can last less than a year if exposed to seawater [12]. However, with proper treatment, bamboo can last up to five years, depending on age and species [20].

When used in aquaculture, the lifespan of bamboo can depend on several factors, such as species, conditions, and maintenance. Properly treated bamboo can be highly durable and long-lasting in the right conditions, lasting several years in aquaculture applications. To enhance its resistance to decay and pests, bamboo can be treated with preservatives like borates. Environmental factors such as water quality, weather, and pests can impact the lifespan of bamboo in an aquaculture system. Regular monitoring and maintenance can help address any issues and prolong the lifespan of the bamboo structure.

According to Bui et al. [21], various treatment circumstances were put to the test, including treatment at 100 °C or 180 °C; with flax oil, sunflower oil, or without oil; for durations of 1 h, 2 h, or 3 h; and, various cooling techniques and durations. Then, uniaxial compression tests, three-point bending tests, water immersion tests, and humidity testing were performed on both untreated and treated bamboo. The findings demonstrated that, as compared to untreated bamboo, some of the studied treatment procedures could increase the specimens' compressive strength and durability [21].

The use of a heat treatment process is another alternative that is highly recommended here to enhance the bamboo's durability. Furthermore, this technique is eco-friendly and does not threaten the environment [12]. Oil heat treatment refers to the heat treatment with a vegetable oil such as tung oil, linseed oil, palm oil, coconut oil [12];[22];[23] or mineral oil (methyl silicone oil) [24] as the heat transfer medium, which has the advantages of high heat transfer efficiency, uniform heating, and accurate temperature control. For example, in the study by Wahab *et al.* [12], tropical bamboo (*Gigantochloa scortechinii, 4 years old)* were harvested and subjected to high-temperature condition using palm oil as a heating media at 120-220 °C for 30-90 minutes exposure. The results show that the heat-treated bamboo retained most of its original physical and strength properties after the heat-treatment process.

Construction of bamboo floating rafts and cage

Aquaculture production requires cages for various stages, such as rearing fry and fingerlings, holding broodstock, spawning, and foodfish production. The size of the cage mesh is determined by the size of the fish at stocking, with larger mesh sizes used as the fish grow. It is recommended to stock fish in the largest mesh size that will retain them. Bamboo is a viable material for floating structures in different aquaculture systems such as crab culture, penaeid or marine prawn culture, and coastal finfish culture in brackish water or net cages. Table 2 and 3 provides a comparison of the cost of using bamboo versus timber.

1) Frame of raft
The raft's bamboo frame floats on the water by employing the material as flotation. bamboo species having a service life of 18 to 36 months (after heat treatment, chemical treatment, or marine paint application)):

a. *Bambusa vulgaris* (buluh minyak),
b. *Bambusa blumeana* (buluh duri),
c. *Gigantochloa levis* (buluh beting)
d. *Gigantochloa scortechinii* (buluh semantan).

Materials for frame:

a. Bamboo for the frame (20' length),
b. Floor planks (20' length),
c. Side planks (20' length),
d. Nails (2 kg),
e. Bolts and nuts (36 pieces),
f. Nylon strings.

2) Floatation
Bamboo is employed for floating due to its durability and ease in maintenance and replacement. Currently, the bamboo poles cost between RM8.00 and RM10.00 per culm (15 m).

3) Cages
This section deals with the cutting and shaping the netting to form four net cages, each 3 x 3 x 3 m. It is advised to use knotted polyethylene for netting, and the following measurements of the ply and mesh size are equivalent to different sizes of fry stockings (Table 1). For a stocking size of 10 – 22 cm, a polyethylene net with a 2.5 cm mesh and a ply of 21 is suggested. For one raftwith 4 cages, 30 m of netting with a width of 300 mesh is required.

Table 1. Specification of the ply and mesh size with fry stocking sizes

Size for fry (cm)	Mesh size(cm)	Ply
09-12	2.5	18
10-22	2.5	21
25-32	3.8	30
More than 32	6.3	48

4) Anchorage
To maintain the raft and the nets in position, anchorage is necessary. For this purpose, concrete weights are used. Figures 3 and 4 show a single bamboo fish floating cage. Table 2 and 3 provides the cost of constructing a single fish floating cage.

Table 2. The cost of using timber in constructing a single fish floating cage [14]

Materials/Service	Price (RM)
Timber (*Dryobalanops* spp.) 2" x 3" x 20' x 12 pieces - 0.2 ton x RM10000 / ton	2000.00
Timber (*Dryobalanops* spp.) 2" x 2" x 20' x 3 pieces - 0.03 ton x RM10000/ ton	300.00
Timber (*Dryobalanops* spp.) 1" x 6" x 20' x 12 pieces - 0.2 ton x RM10000/ ton	2000.00
A complete set of net (3 x 10 meter x 4 pieces)	240.00
Floatation (plastic drum) 8 unit x RM 60 / unit	480.00
Nails 3", (3 kg), bolts and nuts (5 kg)	100.00
Labor (RM 50 X 2 person x 10 days)	1000.00
Total	6120.00

Table 3. The cost of using bamboo in constructing a single fish floating cage [14]

Materials/Service	Price (RM)
Timber (*Dryobalanops* spp.) 1" x 6" x 20' x 12 pieces – 0.2 ton x RM4800 / ton	2000.00
Bamboo pole 20' in length – 32 pieces x RM12 / pole	384.00
Bamboo for floatation 4' – 288 pieces x RM2.40 / piece	691.20
Bamboo heat treatment (10 kg palm oil)	1000.00
A complete set of net (3 x 10 meter x 4 pieces)	240.00
Nail 3" (1 kg)	8.70
Nylon rope (1kg, 14 mm)	23.00
Labor (RM 50 X 2 person x 10 days)	1000.00
Total	5346.90

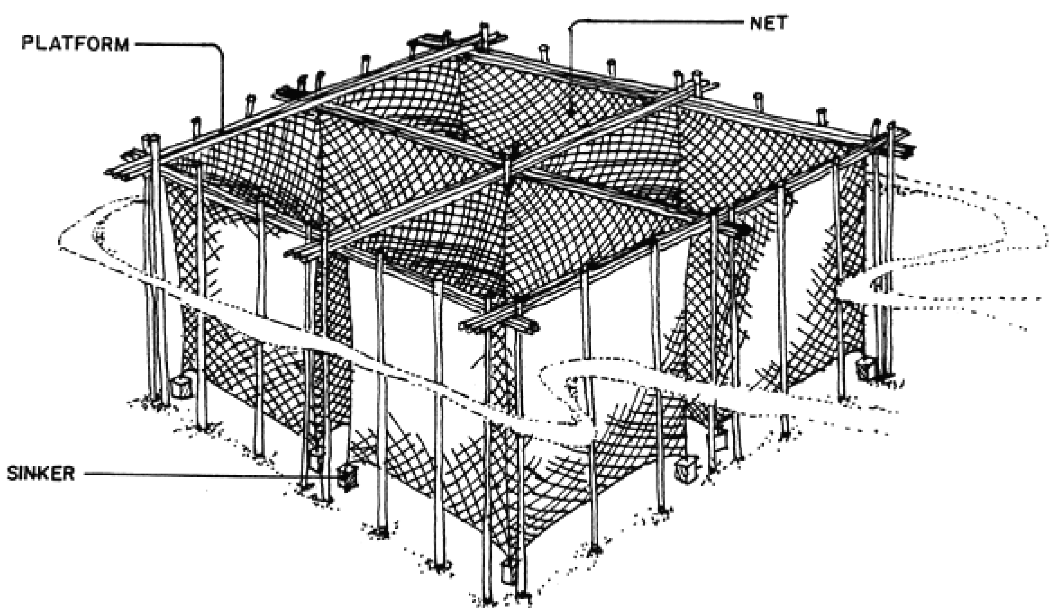

Figure 3. The plan (top) and side (bottom) elevation of bamboo fishing cages.

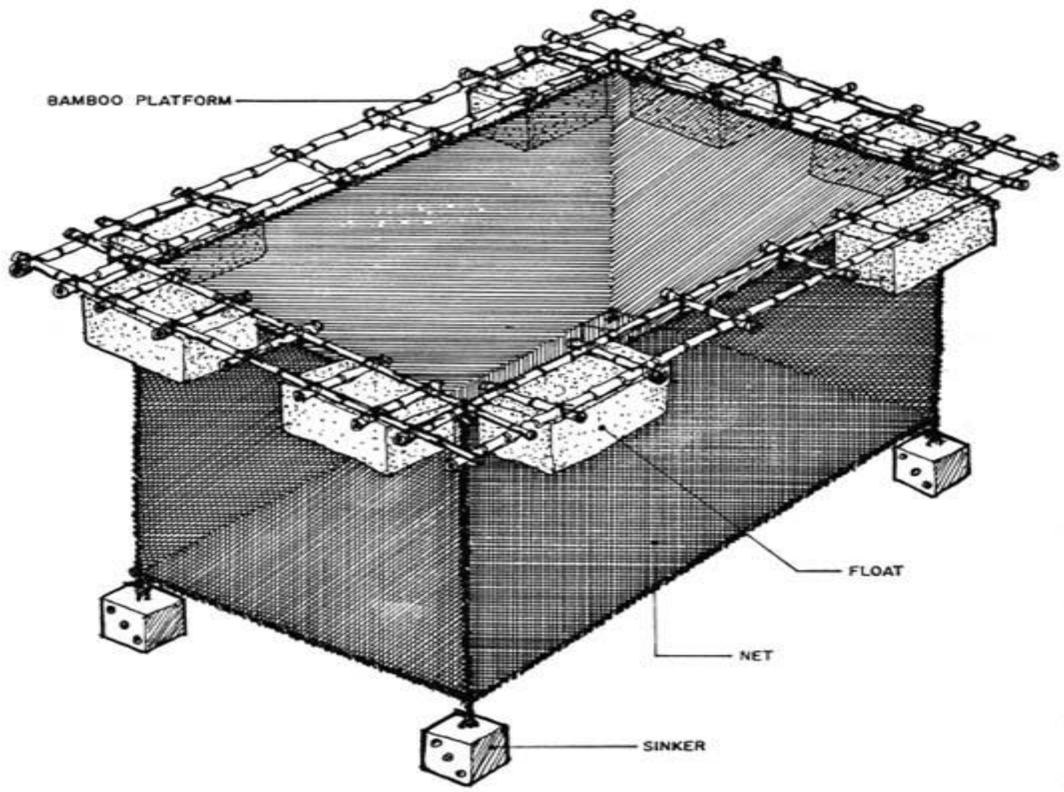

Figure 4. Fishing cage with bamboo used as floatation materials

Differences in economic aspects between fresh water and salt water aquaculture system

Freshwater aquaculture offers a diverse range of systems that vary in physical and economic scales, infrastructure configurations, species, ownership, and value chains [1]. The most popular freshwater species for export and national consumption are tilapia and striped catfish, which are mainly produced in earthen ponds. Freshwater and brackish-water crustaceans are also cultivated, either in monoculture or in polyculture systems with other fish, mollusks, and aquatic plants.

The profitability of freshwater versus saltwater aquaculture systems will depend on various factors, such as the species being cultured, the cost of production inputs, market demand, and price, and the availability of suitable production sites. Freshwater aquaculture is generally cheaper to set up and operate, as it requires less expensive equipment and infrastructure. Freshwater species like tilapia and catfish are also easier to raise than saltwater species, making them more cost-effective to produce. On the other hand, saltwater aquaculture systems can offer higher profit margins due to the higher market demand and price for certain species, such as shrimp, sea bass, and tuna. However, these species often require specialized facilities and equipment, making them more expensive to produce than freshwater species.

Choosing between freshwater and saltwater aquaculture systems will depend on various factors and vary depending on specific production goals and market conditions. It is essential to carefully evaluate the costs and benefits of each type of system and select the one that best fits the producer's needs and available resources.

Feasibility of small-scale aquaculture industry

Small-scale aquaculture enterprises have been successfully implemented in various parts of the world, demonstrating that aquaculture can be practiced on a small scale. This approach can have several benefits, such as providing a source of food and income for individuals or communities while improving nutrition and food security [25]. The scale of small-scale aquaculture operations can vary, depending on the production objectives and available resources, from private ponds to small-scale commercial operations. Popular species for small-scale aquaculture include tilapia, catfish, and carp.

Small-scale aquaculture systems can be tailored to meet the specific needs of the producer and the available resources, as well as the local environment and climate. In many poor countries, low-tech, low-cost techniques that utilize locally available materials and resources are commonly used in small-scale aquaculture. It can have numerous benefits, including the provision of food, income generation, and opportunities for community development and education. It is a sustainable and economically viable way for individuals or communities to produce food while also improving environmental and social outcomes.

The cost of setting up a small-scale aquaculture operation can vary depending on several factors, such as the type of fish or aquatic organism being cultured, the size and location of the operation, the equipment and infrastructure needed, and the regulatory requirements in the local area. However, with careful planning, small-scale aquaculture operations can be established with an initial investment ranging from a few thousand to tens of thousands of dollars.

There are costs associated with running a small-scale aquaculture enterprise, such as the construction of fish ponds, tanks, or cages, as well as the purchase of necessary machinery like pumps, filters, and aeration systems. Fish feeding expenses can also be high, but using locally produced or on-site-grown feed can reduce these costs. Additional costs may include labor, permits, and licenses, as well as marketing and distribution once the fish are ready for sale [26].

It is important to carefully evaluate the costs and potential benefits before investing in a small-scale aquaculture operation. The return on investment (ROI) can vary, but with proper management and market demand, a well-managed operation can generate a reasonable ROI ranging from 10% to 30%. By carefully managing factors like water quality, feed and feeding, and disease prevention, small-scale operators can improve the growth and survival rates of their fish or aquatic organisms, maximizing their ROI potential (Aquaculture Business Plan Development).

Aquaculture industry for rural community

Aquaculture has contributed to poverty reduction in poor societies in the few areas of the world in which it is a traditional practice, for example, China, Indonesia, and Vietnam, and it continues to do so today through benefits, employment, and income.

An aquaculture industry can be beneficial for rural communities in tropical regions for several reasons. Aquaculture can provide a source of income for rural communities by producing fish or aquatic organisms for local or regional markets. This can help to diversify the local economy and provide an additional source of income for local households. Aquaculture can also help to improve food security by producing fish or aquatic organisms for local consumption. In areas where access to protein-rich foods is limited, aquaculture can provide a valuable source of nutrition. Aquaculture can be designed to be environmentally sustainable by using low-impact production methods, such as recirculating systems, and by minimizing the use of antibiotics and other chemicals. This can help to protect the natural resources on which rural communities rely. Establishing an aquaculture industry in a rural community can provide opportunities for technology transfer and skills development. This can include training in fish production techniques, fish health management, and marketing and sales skills [27].

Although there are a lot of barriers preventing its spread, aquaculture helps help the impoverished by providing them with a means of subsistence, especially in regions of Asia where it is a traditional practice. Aquaculture could significantly contribute to rural development in nations where it is neither a traditional nor common practice, according to the recent adoption of new technology. For rural populations in tropical areas, an aquaculture business can be a useful and long-term source of nourishment and revenue. It can also boost regional economic growth and environmental sustainability, as discussed by Belton [28] and Allison [29].

CONCLUSION

Based on the available information, using bamboo in the aquaculture industry in Malaysia has the potential to be a sustainable and cost-effective solution with a comparison of 12.6% cheaper than conventional materials. Bamboo is a renewable resource widely available in Malaysia, and its use in aquaculture systems has been shown to be effective in providing structural support and as a natural filtration system. Additionally, bamboo has the potential to provide a source of income for local communities through the production and sale of bamboo-based aquaculture products. There are also potential challenges associated with using bamboo in aquaculture, such as durability and susceptibility to pests and decay. Additionally, there may be technical and regulatory hurdles to overcome in designing and constructing bamboo-based aquaculture systems that meet safety and environmental standards. The application of bamboo in the aquaculture industry in Malaysia has the potential to be a viable and sustainable option, but careful planning, research, and monitoring will be necessary to ensure success. Further research and development may also be needed from both government and the private sectors to optimize the use of bamboo in aquaculture systems and to address any challenges that may arise.

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