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Benefits, Challenges, and Strategies of Integrated Wheat-Fish Farming Practices in Egypt

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ABSTRACT

Recent fluctuations in global and local wheat prices have sparked a growing interest in reducing the importation of this essential crop. The primary goal of this study was to assess the technical and economic aspects of wheat cultivation in integrated aquaculture-agriculture systems, as well as identifying farmer challenges and proposing strategies to address these challenges. Following the 2023 wheat harvest season, a survey was administered to wheat farmers in Kafr El-Sheikh, El-Sharqia, and El-Buhaira Governorates, with 32 respondents. The wheat production function was developed using the Cobb-Douglas production function after analyzing the data using cost-benefit analysis. The results indicate that farmers prefer cultivating winter wheat to mitigate the risks associated with the cold tolerance of the Nile tilapia and reduce their dependence on irrigation. The average cost per hectare is around USD 49, yielding a total return of USD 1,752, a net profit of USD 1,402, and an impressive return on investment of 401%. Furthermore, the production function analysis highlighted the impact of fertilizers and pest control management on wheat productivity, with seed selection playing a significant role. Labor and location, on the other hand, did not show statistically significant relationships. Despite these promising results, wheat farmers in fish ponds face several challenges hindering the expansion and improvement of this practice. These challenges include the absence of a unified fertilization program, pest-related issues, a lack of agricultural guidance, government-imposed price constraints, difficulties in balancing fish and wheat farming, high groundwater levels, and legal issues related to wheat cultivation in integrated aquaculture-agriculture systems. The study's findings provided a comprehensive set of strategies to address these challenges, aiming to promote the broader adoption of these sustainable practices to maximize returns from land and water with minimal environmental impact and contribute to food security.

INTRODUCTION

Wheat is considered by the Egyptian government as a critical strategic commodity for ensuring political stability **(Abdalla *et al.*, 2022; Helmy, 2023)**. However, the government's efforts to achieve self-sufficiency have fallen short. Wheat self-sufficiency decreased from 56 to 48% between 2012 and 2021 despite an increase in cultivated land from 1.344 to 1.428 million hectares and an increase in production from 8.8 to 9.8 million tons **(CAPMAS, 2023)**. Hence, Egypt has become the world's largest importer of wheat, largely from Russia and Ukraine (**Zyukin *et al.*, 2020; Svanidze & Durić, 2021; Abdalla *et al.*, 2022; Abay *et al.*, 2023; Halawa, 2023; Helmy, 2023)**. Ongoing conflicts disrupt the supply chain, leading to global price spikes, exacerbating local food prices, and further endangering Egypt's already precarious food security situation **(Abdalla *et al.*, 2022; Abay *et al.*, 2023)**. As a result, low-income groups' food intake has decreased, while their dependency on subsidized items such as bread has remained constant **(Abay *et al.*, 2023)**. According to projections, Egypt's wheat demand would increase more than treble by the year 2025 **(Abdalla *et al.*, 2022)**. Given these obstacles, **Gaafar (2018)** proposed a solution to combat Egypt's wheat consumption-production imbalance by following the integrated wheat-fish farming (IWFF) .

Historically, aquaculture and horticulture were separate agricultural enterprises. Nonetheless, integrating these disparate systems can result in various benefits, such as increased productivity, improved resource utilization efficiency, and reduced environmental impact **(Goda *et al.*, 2024)**. Moreover, integrated aquaculture/ horticulture systems can establish a more dependable and robust food production system, capable of adapting effectively to evolving climate conditions (**Nenciu *et al.*, 2022**). Therefore, there is an increasing need to develop integrated strategies that can aid aquaculture/horticulture industries in adapting to the changing environment, while also enhancing the efficiency of resource utilization **(Nguyen *et al.*, 2020)**.

The basic idea behind any system of integration is that the outputs or products of one organism or system serve as inputs or resources for another organism or system **(Elewa & Nasr-Allah, 2023)**. Integrated fish farming has numerous social, economic, and environmental advantages. These advantages include improved water management, which leads to an increased crop yield per unit of water, improved soil quality, and fish waste recycling. This increases agricultural productivity and minimizes the demand for agricultural inputs, allowing farmers to achieve higher financial profits. Furthermore, this technology allows for climate change adaptation and contributes to food security. Integrated fish farming is considered one of the most sustainability forms of aquaculture, as it resembles natural ecosystems **(Elnwishy *et al.*, 2008; Phong *et al.*, 2010; Ahmed *et al.*, 2014; Chandra *et al.*, 2023; Elewa & Nasr-Allah, 2023)**.

The Nile tilapia is Egypt's principal farmed fish species, accounting for over 60% of production in 2020 **(GAFRD, 2022)**. Water temperatures are too low for tilapia to grow effectively during winter months (from November to March), and accessing the farms becomes challenging. Furthermore, there is an elevated risk of mortality during extremely cold nights **(Eltholth *et al.*, 2015; Abdelghany, 2020; El-Sayed *et al.*, 2022)**. This reality has prompted farmers to experiment by using ponds during winter. According to **El-Sayed (2007)**, some farmers practice integrated farming by growing wheat and fish in ponds throughout winter and flooding them in spring. Crops are not harvested and are instead left to rot in the ponds to supply the necessary nutrients for fish production.

Several Egyptian studies have been conducted in the last decade to analyze the economic returns of wheat production in fish ponds. These studies have shown that these practices are highly profitable and contribute to food security **(Fath El-Bab *et al.*, 2014; Azazi *et al.*, 2016; Gaafar, 2018)**.

However, recent global and local fluctuations in wheat prices may have a substantial impact on the system's economic viability. Therefore, the purpose of this study was to analyze the technical and economic practices of wheat cultivation in fish ponds, as well as identifying major challenges encountered. This knowledge was critical for policymakers in Egypt who aimed to improve food security, water, and land productivity.

MATERIALS AND METHODS

Survey design

Following a review of the literature, the questionnaire was developed that contained participant characteristics, as well as information on the costs, benefits, and obstacles faced by farmers prior to, during, and after wheat harvesting from ponds. Due to the generally low education levels of the farmers in the targeted governorates, these questions were developed in the form of a printed questionnaire **(El-Naggar *et al.*, 2008; Azazi *et al.*, 2016)**.

Data collection

The data were collected from a group of wheat farmers in fish ponds through personal interviews and telephone calls implemented by researchers. The response rate achieved was 80%. Moreover, the questionnaire was distributed after the wheat harvesting season in fish ponds had concluded, and data collection took place in June 2023.

Despite the moderate frequency of small and commercial ponds-based integrated aquaculture-agriculture systems in Egypt, the statistics provided by the General Authority for Fish Resources Development (GAFRD) did not demonstrate the productivity of these systems **(Ibrahim *et al.*, 2023)**. As a result, a convenient sample of 32 wheat farmers cultivating fish ponds in three governorates (Kafr El-Sheikh, Sharkia, and El-Buhaira) was selected. These three governorates account for more than 65% of the total aquaculture production in Egypt **(GAFRD, 2022)**.

Data analysis

The study was based on two main components. First, a cost-benefit analysis was performed to determine the economic viability of cultivating wheat in fish ponds. Second, the study included an analysis that encompassed estimating the Cobb-Douglas production function for wheat production, with the goal of determining the relationships between various factors and wheat yields in fish ponds. Data entry was carried out using Microsoft Excel, and data analysis was done with the statistical software SPSS Version 26.

RESULTS

1. Demographics and characteristics

Table (1) illustrates the sample's demographics and characteristics percent, including gender, marital status, level of education, number of family members, farm size (ha), and aquaculture species. The entire sample consisted of males, with 56% aged 40 or above. Furthermore, 75% of the sample was married, with 62% having 5 or more family members. Regarding farm size, 31% had a farm of 5- 10 hectares, while 69% grew exclusively tilapia in their fish ponds. According to the educational breakdown, 50% had a primary education, while 19% were illiterate.

Table 1. Demographics and characteristics of the sample

Demographic and characteristic		**Frequency (N)**	**Percent (%)**
Gender	Male	32	100.0
	Female	0	00.0
Age (year)	< 20	4	12.5
	21-40	10	31.2
	41-60	12	37.5
	> 60	6	18.8
Marital status	Married	24	75.0
	Single	6	18.8
	Widowed/divorced	2	06.2
Educational	Illiterate	6	18.8
	Primary education	16	50.0
	Secondary/diploma	6	18.8
	University education	4	12.5
Number of family members	1-2	6	18.8
	3-4	6	18.8
	5-6	10	31.2
	≥ 7	10	31.2
Farm Size (ha)	< 5	14	43.8
	5-10	10	31.2
	11-15	6	18.8
	> 15	2	06.2
Aquaculture Species	Tilapia only	22	68.8
	Tilapia, mullet and others	10	31.2

2. Technical practices for wheat cultivation in fish ponds

2.1. Planting season

Wheat planting in fish ponds begins in November, and harvesting occurs in May. During this period, the Nile tilapia growth stops or slows down to avoid the mortality of the Nile tilapia due to its tolerance to low temperatures during winter. It's worth mentioning that some farmers take advantage of this time of the year to plant wheat directly following the fish harvest.

2.2. Fish ponds

The majority of the Nile tilapia farms in Egypt are earthen ponds with clayey soil or a water-retaining qualities. These ponds are typically 0.5 to 2 hectares in size and have low salinity, making them suitable for wheat cultivation. The pond's dual use, for both fish farming and subsequent wheat production, maximizes the utilization of available resources and land, assuring agricultural productivity all year. Fig. (1) displays the stages of wheat cultivation, starting from sowing the seeds after fish harvest and continuing until the wheat spikes are fully developed.

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Fig. 1. The stages of wheat cultivation from the beginning of wheat seed sowing to the completion of the spikes **(Courtesy of Dr. A. Hamza and Dr. A. Khattaby)**

2.3. Seeds

Farmers use 150- 200kg of seeds per hectare. Typically, they use multiple seed varieties, such as Giza-186, Sids-12, Sakha-8, Sakha-93, Misr-1, and Misr-2, known for their tolerance to high salinity levels. These seeds are directly sown after harvesting fish from ponds, maximizing agricultural yield while making optimum use of existing resources.

2.4. Fertilization and pest control

Farmers use inorganic fertilizers at a rate of 240- 475 kilograms per hectare to increase productivity. Farmers do not follow a standardized fertilization program. However, typically the fertilization programme normally contains mostly nitrogen, phosphorus, and potassium fertilizers, with occasional supplementation of minor elements. Additionally, farmers use a variety of pest control products to mitigate the impact of wheat-damaging pests on their crops.

2.5. Irrigation

Irrigation in fishponds for wheat growth is extremely limited. Since the bottom of the fishponds is at a low level, most farmers do not irrigate wheat from planting to harvest. Furthermore, due to its proximity to ponds or water sources, as well as rains during the autumn and winter seasons, the soil maintains moisture. During the wheat planting season, just a few farmers irrigate a few times.

2.6. Labor

During the wheat cultivation period, farmers employ labor for a variety of duties, such as seed sowing (which requires fewer workers than field wheat cultivation), fertilization, and harvesting. Farmers usually recruit local laborers or involve family members in these operations.

2.7. Harvest

At the end of the season, the average wheat harvest reaches approximately 6.6 t/ha, as well as about 19 loads of straw. Due to the low fixed purchase price granted by the government to farmers, most farmers use this crop after grinding it for fish feed.

3. Cost-benefit analysis for integrated wheat-fish farming

The cost-benefit analysis for integrated wheat-fish farming practices in Egypt is shown in Table (2). The results revealed that the overall cost per hectare is estimated to be USD 349. The cost includes seed ($69), fertilizers and pest control ($83), labor ($133), irrigation ($13), and harvesting ($52). Given that the ponds are not used for aquaculture activities during this time of year, there are no fixed expenditures connected with this farming practice. Furthermore, there is no machinery depreciation since irrigation rarely uses machinery. The overall revenue per hectare is USD 1,752, which includes both grain ($1,641) and straw ($111). The net profit per hectare is USD 1,402. The return on investment (ROI) was estimated by 401%.

Table 2. Cost-benefit analysis for integrated wheat-fish farming practices in Egypt (USD/ ha/ production cycle) in 2023

Item	Mean	SD	Percent (%)
Variable costs			
Seed	68.83	6.85	19.70
Fertilizers and pest control	82.95	20.45	23.74
Labor	132.73	12.99	37.98
Irrigation	12.90	4.55	3.69
Harvesting	52.02	3.54	14.89
Total costs	349.43	33.15	100.00
Grain	1,640.63	175.20	93.65
Straw	111.23	18.63	6.35
Total benefits	1,751.85	190.95	100.00
Net Profit**	1,402.43	170.83	
Return on investment (ROI)***	401.35%		

*1 USD = approximately 50 Egyptian pounds (EGP), while the official announced rate is 30.96.
**Net Profit = Total benefits - Total costs.
***Return on Investment (ROI) = (Net Profit/Total Costs) × 100%.

4. Statistical estimation of wheat production in fish ponds

Table (3) presents the results of a multiple linear regression analysis for wheat production in fishponds. The regression model revealed a high relationship between wheat production and the predictors (constant, area, seed, labor, fertilizers, and pest control). The coefficient of determination (R Square) value of 0.869 implies that the predictors can explain approximately 87% of the variance in production, demonstrating a high level of predictive power. Furthermore, the adjusted R Square value of 0.855 confirms that the model fits the data well. The standard error of the estimate, which is 0.842, represents the average difference between the actual production values and the regression model's predicted values. The data showed that the regression model is statistically significant (F = 62.152, $P < 0.001$), suggesting that the predictors had a substantial effect on production.

The coefficients represent the relationships between the predictors and the dependent variable. The constant term had a coefficient of 1.257 (T= 0.376, P= 0.709), indicating that when all predictors are zero, the estimated production is 0.057. Fertilizers and pest control exhibited the highest standardized coefficient (Beta= 0.638, T= 5.688, P= 0.000) among the predictors, indicating a strong positive relationship with production. Seed demonstrated a moderately positive relationship (Beta= 0.319, T= 2.810, P= 0.009). Labor and area had weaker correlations with production (Beta= 0.045, T= 0.578, *P*= 0.568; Beta= 0.154, T= 0.659, *P*= 0.524, respectively).

The variance inflation factor (VIF) was calculated to assess multicollinearity among the predictor variables. The VIF values for all predictors were below 2.7, indicating no significant multicollinearity issues.

Table 3. Multiple linear regression results for wheat production in fish ponds in Egypt during the 2023 season

Summary				Coefficients				
R Square	**Adj. R Square**	**F**	***P- value***		**Beta**	**T**	***P- value***	**VIF**
0.869	0.855	62.152	0.000**	(Constant)		0.376	0.709	
				Fertilizer	0.638	5.688	0.000**	2.696
				Seed	0.319	2.81	0.009**	2.772
				Labor	0.045	0.578	0.568	1.277
				Area	0.154	0.659	0.524	2.531

** $P< 0.001$

Based on these results, it is possible to conclude that fertilizers and pest control have the strongest influence on wheat yield, followed by seed. However, the correlations between labor and area with production, on the other hand, were not statistically significant. Regarding the results presented in Table (3), the Cobb-Douglas production function for wheat production can be represented as:

$$Q = 0.376 * F^{0.638} * S^{0.319} * L^{0.045} * A^{0.154}$$

$$(5.688)^{**}\ (2.810)^{**}\qquad (0.578)^{n.s}\ (0.659)^{n.s}$$

$$R^2 = 0.869 \qquad F = 62.152$$

In accordance with this equation, the amount of seed, fertilizers, pest control, labor, and the area of cultivation all have an impact on wheat yield. The constant term represents the estimated production when all predictors are zero. The coefficients indicate the strength and direction of the correlations between the predictors and production. Specifically, the coefficient for fertilizers (0.638) indicates that for each unit increase in fertilizers, the production is projected to increase by 0.638 units, when all other predictors remain constant.

5. Challenges

Wheat farmers in fishponds face several challenges, including:

1. Lack of standardized fertilization and pest control programs

   The absence of standardized programs for fertilization and pest control is a significant hurdle. Many farmers lack access to key information, making the optimization of these critical components of wheat cultivation in aquaculture environments challenging.

2. Lack of farming guidance

   Inadequate agricultural guidance is a common issue. Farmers often lack knowledge about different wheat seed varieties and their suitability for specific aquaculture pond conditions. This knowledge gap can negatively impact crop productivity.

3. Government-mandated wheat pricing

   Governments may enforce fixed prices for the purchase of wheat, often set lower than the cost of imported wheat. Moreover, wheat prices may be less competitive when compared to alternative feed ingredients. Hence, farmers might choose to utilize their wheat crops as feed for fish.

4. Challenges in managing integrated wheat-fish farming

   The integration of fish farming and wheat cultivation is difficult since fish are typically harvested before November, leaving farmers vulnerable to unexpected problems, including disease outbreaks, feed shortages, or market price fluctuations. These factors may force farmers to postpone fish harvesting, resulting in missed opportunities to plant wheat.

5. Rising groundwater levels in fish ponds

   The proximity of multiple fish farms creates a significant obstacle to wheat cultivation. In some cases, it becomes difficult to cultivate specific wheat areas due to this proximity. At the same time, neighboring ponds are often used to store fish produce, resulting in higher water levels at pond bottoms. This increase in water levels poses obstacles for various wheat farming processes, including harvesting and plowing.

6. Land-use regulations

Some farmers are concerned that cultivating wheat in aquaculture ponds may result in their land being classified as suitable for agriculture. This situation could potentially violate laws that prohibit the use of land suitable for agriculture in aquaculture.

These challenges collectively pose complex hurdles for wheat farmers in aquaculture ponds, affecting their productivity and decision-making processes.

DISCUSSION

Integrated wheat-fish in ponds has demonstrated promising economic benefits, aligning with prior studies **(Fath El-Bab *et al.*, 2014; Azazi *et al.*, 2016; Gaafar, 2018)**. The significant increase in total revenue in this study is attributed to the increase in wheat prices per ton, which has risen from USD 67.5- 70 **(Azazi *et al.*, 2016; Gaafar, 2018)** to USD 250 per ton in 2023. This strategy, in addition to its economic advantages, contributes to sustainable farming practices and resource optimization, offering several additional benefits:

- Nutrient recycling promotes the discharge of organic nutrient residues, mainly nitrogen and phosphorus, into the lower part of the ponds. This practice directly enhances water quality, reduces parasite infestation, improves nutrient availability, promotes fish growth, and boosts overall production **(Saraswathy *et al.*, 2019; Hasibuan *et al.*, 2023).**
- Water conservation: integrated wheat cultivation in fish ponds eliminates the need for significant irrigation water usage **(Gaafar, 2018)**.
- Fish food source: the remaining wheat crop residues at the pond bottom become a valuable source of fish feeding **(Azazi *et al*., 2016; Gaafar, 2018)**.
- Increasing productivity: the integrated system contributes to increasing plant productivity and enhancing fish production compared to the traditional system **(Fath El-Bab *et al*., 2014; Mulokozi, 2021)**.

- Reduced fertilizer usage: compared to conventional field-based wheat farming, wheat production in fish ponds requires substantially less fertilizer input. Fish waste enriches soil fertility by serving as a source of organic fertilizers, renewing nitrogen, and phosphorus elements. This valuable fertilizer is extracted from the pond bottom **(Ahmed *et al*., 2014; Azazi *et al.*, 2016; Gaafar, 2018)**.

Previous studies have attempted to estimate the expected production quantities resulting from the implementation of integrated wheat cultivation in fish ponds at the national level. **Gaafar (2018)** estimated the quantity to be approximately 1.5 million tons, based on the assumption that the fish farm area is 155,000ha in addition to another 63,000ha surrounding the northern lakes that can be reclaimed for wheat cultivation and irrigated with farm drainage water. Additionally, **Azazi *et al.* (2016)** proposed several scenarios based on assuming a fish farm area of 126,000 hectares. Three scenarios were applied, utilizing 25, 50, and 75% of the fish farm area for integrated cultivation of wheat and fish. Production from this activity would amount to 181,000, 362,000, and 875,000 tons, respectively. It is worth noting that the variation in the estimated areas in these studies is due to differences in data sources (Central Information Center at the Ministry of Irrigation in collaboration with the National Authority for Remote Sensing, GAFRD). Both estimates did not consider the fact that some farms have a high salinity percentage. These farms account for 20% of the total area of fish farms in Egypt, and they are used for marine aquaculture. Furthermore, harvesting 25- 50% of the production in one month, for example, would result in a drop in tilapia prices and an increase in prices in the other months of the year. To address this issue, a set of strategies should be suggested to reduce the impact of this problem and avoid overestimating the wheat production that can be achieved from fish ponds.

Furthermore, this study found that the productivity per hectare is higher than that indicated by previously studies **by Azazi *et al.* (2016)** and **Gaafar (2018)**. This indicates that maximizing wheat productivity per unit area can be achieved by implementing some strategies. Therefore, if we assume the possibility of using 25% of the farms area (assuming the farm's area is 140,000ha), this will mean that the estimated production will reach 230,000 tons and will furtherly increase to 276,000 tons with an improvement in current hectare productivity by about 20%. Consequently, addressing this activity, along with other solutions to bridge the gap between wheat consumption and productivity in Egypt, is essential. Additionally, measures such as reducing losses in the storage and trading stage, replacing in-kind bread subsidies with cash support, pricing wheat supply at international prices, setting policies that incentivize farmers, improvement of the current agricultural productivity and working to change consumption patterns for the Egyptians and increasing their income can all be considered a solution to address the disparity between wheat consumption and production in Egypt.

To address the aforementioned challenges, it is possible to adopt the following set of strategies:

1. Best management practices (BMPs) training

   Implementing BMPs involves training farmers in standardized fertilization and pest control programs. This training not only provides important instruction, but it also has a significant impact on increasing production and profitability of wheat farming in fish ponds. Farmers may optimize crop yields and limit the negative effects of pests by providing them with the knowledge and skills required to adhere to these practices, ultimately leading to improved profits and sustainable farming practices.

2. Introducing fast-growing Nile tilapia strains

   This technique will help to shorten the length of tilapia production, providing farmers with more time to market their fish before the wheat planting season begins in addition to offering financial incentives for investment in fish processing

3. Encouraging investment in the field of fish processing

   Especially tilapia, through providing facilities for investors, financial and tax incentives is essential. These incentives may include tax reductions for companies specialized in fish processing and offering low-interest loans for new factories. This will boost the fish processing sector's expansion and add value to the products, assisting in accommodating large fish production during the months of September, October, and November and marketing it during the period of reduced production.

4. Utilization of temporary farms in integrated farming

   Stopping the execution of authorities' orders to remove temporary farms and converting them into integrated farms, which can be used to cultivate wheat in fish ponds while preserving fish production and accumulating farmers' extensive experience. This approach maximizes land and water productivity by producing an additional crop, wheat.

5. Developing new wheat varieties suitable for fish farming environments in ponds

   Due to varying salinity levels in fish farming ponds, the focus should be on developing wheat strains adapted to this environment.

6. Price policy revision

   Consider revising government-mandated wheat prices to ensure competitiveness with imported wheat, encouraging farmers to prioritize wheat for food production for human consumption rather than for fish feed.

7. Organizational strategies

   Create techniques to encourage all farmers in specific areas to cultivate wheat in fish ponds. This balancing is necessary to minimize problems related to water level fluctuations or seepage that could harm wheat crops due to the presence of water-filled fish ponds adjacent to the targeted wheat cultivation ponds. These areas can be considered as a starting point for future expansion into other regions.

8. Legislative framework

   Establish clear and legally recognized criteria for the practice of cultivating wheat in aquaculture ponds. This is essential to provide legal recognition for this activity and alleviate farmers' concerns about potential violations of land use regulations.

   These strategies are designed to tackle challenges & improve the sustainability and productivity of Egypt's integrated wheat-fish farming. They represent a comprehensive set of solutions aimed at preventing fish production shortages, all while promoting the cultivation of wheat in fish ponds to foster the development of integrated wheat-fish systems.

CONCLUSION

This study provides valuable insights into the benefits of wheat cultivation in integrated pond-based aquaculture-agriculture systems, which extend beyond the exceptionally high return on investment of up to 401%. It contributes to maximizing the returns from natural resources utilization, particularly water and land, and helps in solving the problem of food security. Additionally, there are other benefits such as increasing the productivity of fish ponds due to the presence of crop wheat residues, as well as wheat cultivation's contribution to the decomposition of a significant amount of organic matter in pond bottoms. These practices also help avoid problems related to the Nile tilapia's tolerance to cold, which can result in significant losses.

However, there are several challenges that hinder the growth of these practices. To address these challenges, we have developed a set of strategies for their control. These strategies will greatly contribute to improving productivity, increasing profitability, and encouraging farmers to expand in this sustainable system. This system can be implemented in countries that rely on pond-based aquaculture systems and face problems related to the low tolerance of cultivated species.

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