Aerator Usage in Typical Nile Tilapia Farms in Northeastern Thailand: A Study in the Context of Climate Change

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ABSTRACT

This study highlights the role of aerator usage in tilapia farming under climate-related challenges, by interviewing the fish farmers about their experience in extreme weather and climate-risk events and examining the factors influencing the adoption of aerators. A survey of 530 tilapia farmers across six provinces in Northeastern Thailand was conducted to assess aerator usage and the impact of climate-related events. About two-thirds of the interviewees were men, over half were aged 50 or more, and the majority, two-thirds, had a primary education level. Cage culture in reservoirs was the most common system, followed by cages in rivers and ponds. Four types of aerators, fountain, diffuser, paddlewheel, and venturi were identified across various aquaculture systems. Regression tree analysis revealed that aerator use was influenced by age and education of the farmers, additional factors included fish release size, aquaculture system, feed conversion rate, and stock density. Logistic regression analysis identified the significance of each factor influencing aerator use. The results showed that older farmers were less likely to adopt aerators, whereas larger fish, reservoir cages, higher farmers' education, and improved FCR increased the likelihood of aerator usage ($p<0.05$). Despite only 20% of farmers using aerators, many acknowledged their potential to reduce fish mortality and improve yields, especially during extreme heat events. The study recommends promoting efficient aerator practices, optimizing their placement, and introducing targeted educational programs to strengthen climate resilience in tilapia farming.

Keywords: Aerator usage, Climate change, Fish mortality, Tilapia farming

INTRODUCTION

Aquaculture plays a crucial role in meeting this demand, especially in Asia, the leading region for production (Joffre *et al*., 2018). In Thailand, Nile tilapia plays a vital role in freshwater aquaculture, accounting for approximately 55% of the country's total freshwater fish production, in which the Northeastern region hosts the highest number of farms nationwide (Fishery Statistics Group, 2023). In 2023, Nile tilapia farming in Thailand achieved significant production levels, reaching 266,480 metric tons, which accounted for 57.95% of the total freshwater fish production. This output was valued at approximately USD 385.17 million (Fisheries Statistics Group, 2023). Despite this success, tilapia farming in Thailand faces several challenges that could hinder future growth, for example inadequate management, disease outbreaks and, environmental pollution (Poulain *et al*., 2018; Ahmed *et al*., 2019).

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Another significant threat to aquaculture is climate change, which impacts fish farming through rising temperatures, more intense rainfall, prolonged droughts, and shifts in water availability and quality (Sriyasak *et al*., 2014, Lebel *et al*., 2015). Rising water temperatures lower dissolved oxygen levels, increasing stress and mortality in fish (Fey *et al*., 2015). Extreme weather events, such as floods and droughts, further disrupt production by damaging infrastructure and introducing pollutants into fishponds (Uppanunchai *et al*., 2015). To address these challenges, many Thai tilapia farmers have adopted strategies such as using aerator devices that increase oxygen content in the water, thereby reducing the risks of diseases, poor water quality, and climate change impacts (Lebel *et al*., 2021a). Aerators are especially beneficial in high-density systems, improving survival rates, growth performance, and water quality (Torrans *et al*., 2015). However, the adoption of aerators in Northeastern Thailand remains inconsistent due to factors such as economic constraints and technical knowledge gaps, despite the lack of scientific information on this issue.

Therefore, this study aimed to: (1) identify the different types of aerators used in Northeastern Thailand, (2) analyze the factors that affect farmers' decisions to adopt or avoid aerators, and (3) provide recommendations for appropriate aerator usage to mitigate the effects of extreme weather on tilapia farming. By addressing these objectives, the research seels to promote sustainable and climate-resilient farming practices that can enhance productivity while reducing the risks posed by environmental challenges.

METHODOLOGY

Study area and choices of the farmers

This study focused on Nile tilapia farms in five northeastern provinces of Thailand (Figure 1). To ensure representativeness and minimize bias, simple random sampling was used, giving each farm an equal chance of selection. The list of farmers was obtained from the Provincial Fisheries Office of each province. Cohen's method (Cohen, 1977)

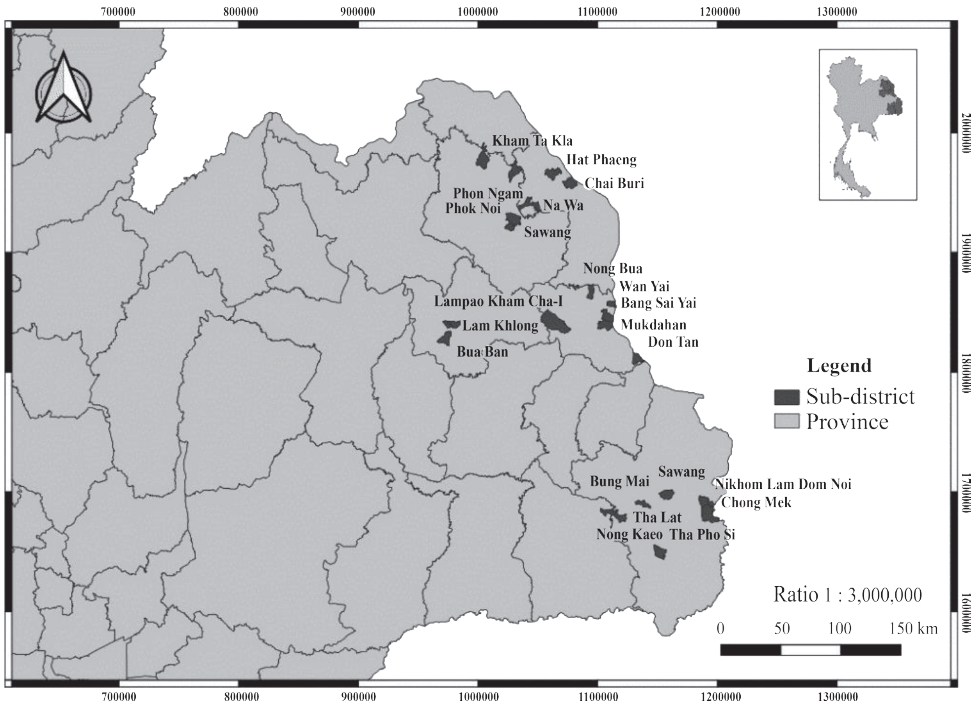


Figure 1. Location map survey for tilapia farmers; the main occupation spread across 5 provinces in Northeastern Thailand from January 2018–May 2018 (Black areas represent sampling location).

was applied to calculate the sample size, using a statistical power of 0.8, an alpha level of 0.05, and an effect size of 0.2. The initial sample size of 450 was increased to 563 to account for 20% potential data loss. After filtering, 530 complete datasets were used for analysis, ensuring data integrity. Data collection took place between January 2018 and May 2018.

A pre-test of the questionnaire, developed under the AQUADAPT-Mekong project (Lebel *et al*., 2020), was conducted to enhance the survey's validity. The questionnaire addressed key areas such as personal information, farm management practices, productivity, tilapia mortality rates, yield losses due to weather variability, and the use of aerators in farming.

Data analyses

The data were processed through several steps, including storage, cleaning, and coding, using Microsoft Excel in Microsoft Office 365 for Education under the RMUTI license. Descriptive statistics were employed to summarize respondents' backgrounds, and the climate-related challenges faced during tilapia farming. A radar chart was employed to display annual mortality rates and examine aerator usage among farmers. To visualize preferences for different aerator types, a balloon plot was created using the 'ggplot2' package (Kassambara, 2023), allowing both distribution and quantity of data to be displayed. Pearson's Chi-squared test was applied to analyze the relationships between aerator types and culture systems, identifying significant deviations from expected distributions. This comparison revealed key variations in aerator preferences and provided valuable insights into the factors influencing farmer decisions.

When statistically significant differences ($p<0.05$) were identified, Fisher's post-hoc test was used. To further analyze the factors influencing aerator usage, a Classification and Regression Tree (CART) model (Breiman *et al*., 1984) was used. This model evaluated variables such as gender, education, age, cultural experience, farm management (culture system, stocking density, total farm area, and released fish), and productivity metrics (Feed Conversion Ratio FCR and yield). A binary logistic regression was performed to calculate odds ratios, predicting aerator usage based on these variables. The analysis was conducted in program R (R Core Team, 2023) using the 'epitools,' 'stats,' and 'rpart' packages (Aragon *et al*., 2017, Therneau *et al*., 2017), providing valuable insights into the determinants of aerator adoption.

RESULTS AND DISCUSSION

Characteristics of tilapia farmers

A total of 530 tilapia farmers participated in the survey (Table 1), with 62.64% being male. Over half of the respondents (56%) were aged 50 or older, with the largest group between 50–60 years (30.38%). Most farmers (62.08%) had only primary education, and 42.08% had 1–5 years of aquaculture experience. Cage culture in reservoirs was the most common farming system (42.38%), with a stocking density of the range between 1–30 ind·m^{-3} being most prevalent (33.58%). Total farm's area of 200–400 m^3 were common (44.34%), and 45.47% of farmers released fish measuring 5.1–8 cm. Yields of 10–30 kg per cubic meter were reported by 53.39%, with a typical FCR of 1.1–3 (46.13%).

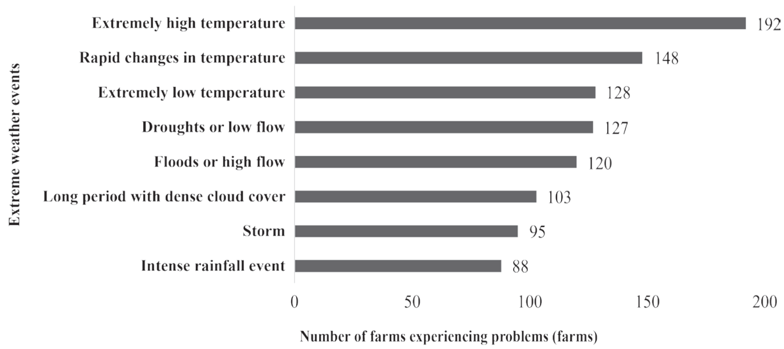
Farmers' experience with climate-related problems and tilapia mortality

More than half of the surveyed tilapia farmers identified extreme weather as a major contributor to significant losses, with 20% directly attributing fish deaths to weather variability. Figure 2a ranks the most common climate events: extreme high temperatures, rapid temperature changes, extreme low temperatures, drought, floods, dense cloud cover, storms, and intense rainfall. Tilapia mortality peaked in October (80%), followed by August (60%), November (50%), and May (30%) (Figure 2b). These findings highlight the severe impact of seasonal climate fluctuations on fish mortality, particularly during periods of extreme temperature and instability.

Table 1. Characteristics of Tilapia farmers across 6 provinces in Northeastern Thailand (January 2018–May 2018, n = 530).

Characteristic	Mode
Demographics profile	
Gender	Male (62.64%)
Age (years)	50–60 (30.38%)
Education	Primary (62.08%)
Farming experience (years)	1–5 (42.08%)
Farm database	
Culture system	Cage in reservoir (42.38%)
Stock density (ind·m^{-3})	1–30 (33.58%)
Total farm's area (m^3)	200–400 (44.34%)
Released fish size (cm)	5.1–8 (45.47%)
Farm production	
Yield (kg·m^{-3})	10–30 (53.39%)
FCR	1.1–3 (46.13%)

(a)



(b)

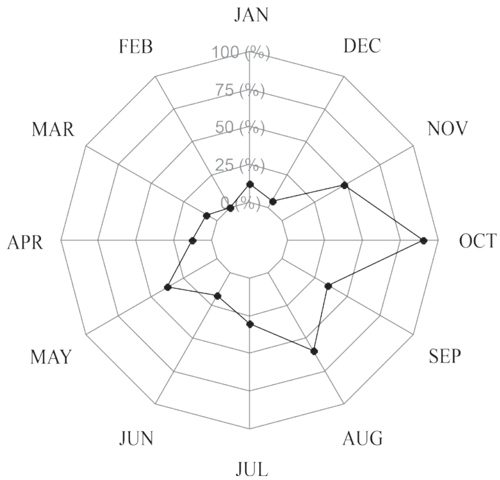


Figure 2. (a) Percentage of tilapia farmers suffering losses due to extreme weather and climate events. (b) Monthly proportion of Nile tilapia mortality in 6 study provinces in Northeastern Thailand. Recall of past 12 months for periods ending from January 2018–May 2018.

Farmers' direct experiences with climate change, such as temperature fluctuations and extreme weather events, influence their decision to adopt aerators. However, financial limitations and knowledge gaps can hinder this adoption, even when the benefits are clear.

Types, aerator usage practices, and decision-making process

Among all surveyed farms, 20% of respondents used aerators, with four types identified: fountain (44%), diffuser (47%), paddlewheel (7%), and venturi (2%). Pearson's chi-squared test showed that aerator usage differed significantly across farming systems ($p<0.05$). Figure 3 illustrates that diffuser aerators were primarily used in cages in reservoirs, while fountain aerators were most common in cages in rivers and earthen ponds. Paddlewheel aerators were mainly employed in earthen ponds, and venturi aerators were exclusively found in cages within reservoirs.

Figure 4 shows two aerator usage patterns among farmers: routine operation combined with emergencies, accounting for 69%, and emergency-only use, which made up 31%. Farmers typically activated aerators in response to signs like fish surfacing, dead fish on the water, and rising temperatures during hot weather.

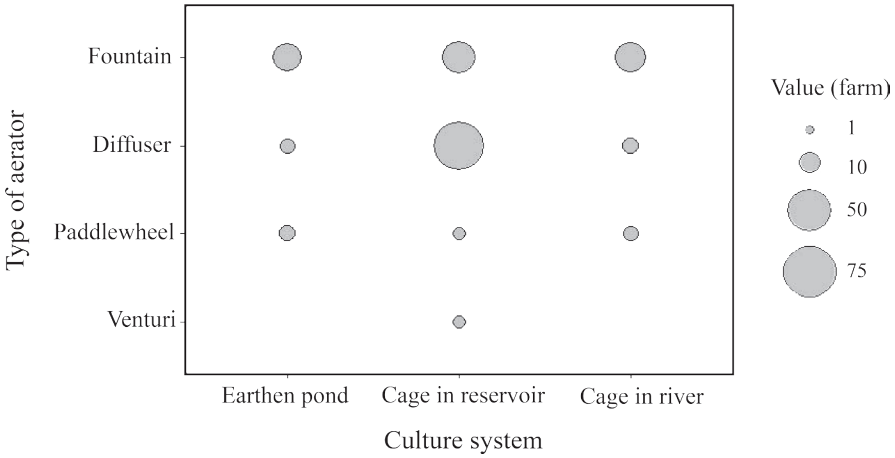


Figure 3. The distribution of each type of aerator in different culture systems, with the size of the gray dot indicating the number of farms where aerators were found across 6 provinces in Northeastern Thailand from March 2018–December 2018.

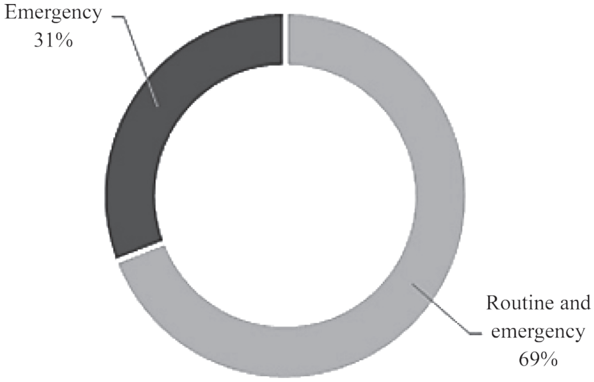


Figure 4. Aerator usage pattern in tilapia aquaculture system in 6 provinces in Northeastern Thailand from March 2018–December 2018.

The CART analysis, with a complexity parameter (CP) of 0.193, identified seven key factors influencing farmers' decisions regarding aerator use: age, released fish size, aquaculture system, education, FCR, stocking density, and total farm area (Figure 5). Factors such as gender, experience, and productivity had minimal influence. Farmers under 60.5 years old were less likely to use aerators for fish smaller than 7.8 cm, while older farmers considered more variables, particularly in reservoir cages, where aerator use was more common. Education also played a significant role; farmers with higher education levels were more likely to use aerators, whereas those with lower education prioritized FCR when making decisions.

Further logistic regression analysis identified five significant factors influencing aerator use ($p<0.05$, 95% CI), as outlined in Table 2. Older farmers were 0.68 times less likely to adopt aerators compared to younger farmers. Farmers who stocked larger fish were 10.87 times more likely to use aerators than those who stocked smaller fish. Farmers operating reservoir cages were 2.42 to 3.01 times more likely to implement aerators than those utilizing river or earthen pond cages. Higher education levels were positively associated with aerator adoption, and farmers with better FCR were also more likely to use aerators. Conversely, stocking density and total farm area did not significantly affect the decision to use aerators ($p>0.05$).

DISCUSSION

This study reveals that aerator adoption among typical tilapia farms in Northeastern Thailand is relatively low, a trend also observed in other Mekong River basin countries, including Laos, Cambodia, Myanmar, and Vietnam (Lebel *et al*., 2021b). In these regions, farmers' routine operations combined with emergencies use aerators sporadically, typically in response to extreme weather events or

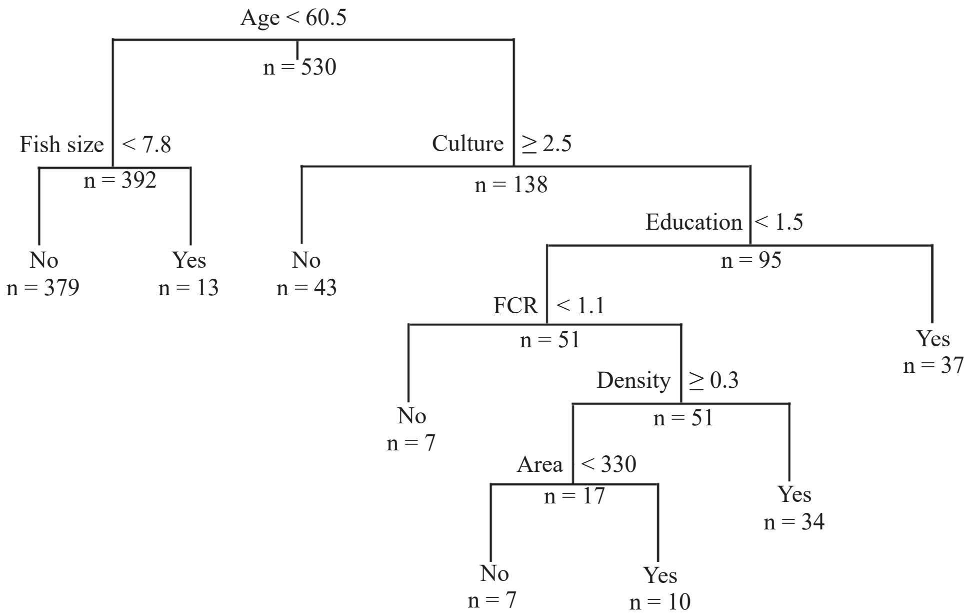


Figure 5. CART analysis showing predictors of tilapia farmers' decision to use or not use aerators across 6 provinces in Northeastern Thailand from January 2018–May 2018.

Note: Age = Farmer's age (years); Fish size = Size of fish released (cm); Culture = Culture systems; cage in reservoir = 1, cage in river = 2 and earthen pond = 3; Education = The highest education achieved by farmers; No formal = 0, Primary = 1 , Secondary = 2, University = 3 and Upper University = 4); FCR = feed conversion ratio; Density = Stock density (ind·m^{-3}); Area = total area used for farming (m^{3})

Table 2. Logistic regression model for ever having used aeration in aquaculture for Tilapia culture in Northeastern Thailand.

Predictor variable	Ever used aeration. ** Odds Ratio (95% CI)	p-value
Aging farmers (vs. less aged farmers)	**0.68** (0.50–0.92)	0.014
Large fish (vs. smaller fish)	**10.87** (3.39–50.15)	<0.001
Culture (different farming method)		
Earthen pond	1	
Cage in river	2.42 (1.53–3.89)	<0.001
Cage in reservoir	3.01 (1.86–4.97)	<0.001
Education (highest level achieved)		
Primary or less	1	
High school	1.62 (1.41–1.94)	0.023
Tertiary	1.45 (1.22–1.97)	0.031
FCR (high vs. low)	1.86 (1.09–3.32)	0.024
Model summary	**r^2 = 0.167**	

Note: If the 95% confidence interval (CI) for the odds ratio of a predictor includes '1' then that predictor is not significant (at $p<0.05$) ** The data are categorized by the results of the CART analysis in Figure 5.

contractual obligations. One of the primary barriers to wider adoption is the high installation cost, frequently raised by the farmers interviewed. This finding is consistent with Xu *et al*. (2021), who noted that, despite financial constraints, diffuser aerators are commonly used in reservoir cages due to their efficiency in transferring oxygen throughout the water column. Farmers often limit aerator usage to cut operational costs, even though daily aerator use is common. The study also identifies October as the period with the highest fish mortality, coinciding with the transition from the rainy season to winter. During this period, unstable water temperatures and reduced circulation lead to oxygen depletion, which increases mortality rates (Nounmusig, 2018; Liu *et al*., 2019). This raises questions about whether similar mortality peaks occur during the transition from summer to the rainy season. Given the effect of temperature fluctuations on oxygen levels and fish health, seasonal shifts likely present similar risks. Further research is needed to explore mortality patterns during these transitions (Boyd *et al*., 2017).

Farmers often activate aerators when observing fish surfacing for air, the appearance of dead fish, or rising water temperatures. These practices highlight strategies to manage water quality and oxygen levels. Some farmers utilize a combination of routine and emergency aeration, which helps to stabilize water quality and optimize fish health. Conversely, others limit aeration to emergency situations, thus missing the continuous benefits of regular aeration, such as enhanced feed conversion and reduced fish stress during temperature fluctuations (Is-haak *et al*., 2020).

However, continuous aeration poses its challenges, including the need to balance aerator usage to provide adequate oxygenation while avoiding negative effects like foam formation. Overuse of aerators can result in foam accumulation, caused primarily by fish waste and uneaten feed. This foam deteriorates water quality by fostering microbial activity, which consumes dissolved oxygen and may lead to hypoxia in deeper water layers (Zhang *et al*., 2022). Additionally, excessive foam increases the risk of pathogen and parasite proliferation, raising the likelihood of disease outbreaks (Ding *et al*., 2023). As a result, farmers must carefully regulate aeration intensity and feed inputs to control foam while maintaining sufficient oxygen levels.

The study further highlights key differences in aerator usage between typical tilapia farms and more intensive aquaculture systems. In tilapia farms, aerators are often used intermittently, either during emergencies or for routine aeration in smaller ponds, where the focus tends to be on minimizing costs. In contrast, intensive systems, such as those employed in shrimp farming, rely on continuous aeration. Paddlewheel aerators, commonly mounted on rafts or pond dikes, are frequently used to maintain oxygen levels and water circulation in larger ponds (Boyd *et al*., 2017; Is-haak *et al.*, 2019). Intensive systems typically require more advanced aeration to meet the higher oxygen demands associated with greater stocking densities and feed inputs, supporting higher productivity while reducing stress on the cultured species.

Temperature fluctuations, particularly those exceeding 30 °C, pose significant challenges for tilapia. These temperatures induce stress, elevate glucose and lactate levels, and hinder growth (Paredes-Trujillo and Mendoza, 2022). High temperatures also degrade water quality and complicates farm management (Yang *et al*., 2021; Crentsil *et al*., 2020). Effective aeration strategies, along with improved farm practices, are essential to managing these challenges (Kumar *et al*., 2013). Diffuser aerators and solar-powered aerators, which reduce operational costs while maintaining necessary oxygen levels, are gaining attention in aquaculture. Diffuser aerators are suitable for environments with low water flow and high stocking densities, offering a cost-effective alternative to paddlewheel aerators (Li *et al*., 2019; Betanzo-Torres *et al*., 2021). Solar-powered aerators present a sustainable, energy-efficient solution that aligns with climate-smart practices, particularly in areas with high solar exposure, further reducing aquaculture's carbon footprint (de Oca Munguia and Llewellyn, 2020).

Farmer demographics, particularly age, also influence aerator adoption. Farmers over the age of 60.5 are significantly less likely to use aerators than younger farmers. This trend aligns with Barnes *et al*. (2019), who found that older farmers tend to be more conservative when adopting new technologies, possibly due to their awareness of financial risks. Younger farmers, on the other hand, are more open to technological innovations and more willing to invest in aerators when recognizing the benefits of reducing fish stress and mortality. Fish size plays a significant role in aerator usage; larger fish, typically exceeding 7.8 cm in length, have higher oxygen demands due to their body mass and gill surface area. As a result, farmers managing larger fish, especially in high-density systems like reservoir cages, are more likely to use aerators regularly (Blasco *et al*., 2022).

The adoption of climate-smart technologies like aerators is largely influenced by economic challenges and climate variability, rather than factors such as gender, experience, or productivity. This research found no notable effect of gender or farming experience on aerator use. Both male and female farmers faced similar obstacles regarding climate effects and financial limitations (Hebsale Mallappa and Pathak, 2023; Sisay *et al*., 2023). Likewise, experienced and inexperienced farmers both struggled with the costs of purchasing and operating aerators. Climate factors, particularly extreme weather, and seasonal shifts were the primary drivers of farmers' decisions to adopt strategies for preserving fish health and productivity (Sisay *et al*., 2023). Additionally, access to information and financial assistance were critical in encouraging aerator adoption. Extension services that offer training and highlight the long-term benefits of aerators can guide farmers in making better-informed choices (Gemtou *et al*., 2024; Rodríguez-Barillas and Poortvliet, 2024). Combining financial incentives with educational programs is vital to fostering climate-smart practices and enhancing resilience to climate fluctuations (de Oca Munguia and Llewellyn, 2020).

The r^2 value of 0.167 from the logistic regression model (Table 2) indicates that while 16.7% of the variation in aerator use is explained, the model offers valuable insights into aquaculture management. The significant odds ratio for fish size (10.87) highlights that larger farms are more inclined to adopt aerators, which is essential for optimizing production (Obiero *et al*., 2019). Moreover, the odds ratio of 3.01 for cage culture in rivers emphasizes the need for management strategies tailored to specific farming systems. In agricultural and social science research, decision-making is often complex and multifactorial, contributing to lower r^2 values. R^2 values between 0.1 and 0.2 are typical in these disciplines, reflecting the complexity of human behavior (Fischer, 1972; Hair *et al*., 2019).

Adoption of aquaculture technologies like aerators is influenced by financial constraints, environmental conditions, and farm management practices. Financial limitations and risk aversion, particularly in developing countries, pose significant barriers to technology adoption (Crentsil *et al*., 2020). Socioeconomic factors, including education and access to extension services, play a crucial role in shaping farmers' perceptions of new practices (Diedrich *et al*., 2019; Obiero *et al*., 2019). Climate change adds complexity, as fluctuating conditions increase perceived risks in adopting new technologies (Betanzo-Torres *et al*., 2021; Parappurathu *et al*., 2023). Addressing these barriers is vital for promoting sustainable aquaculture and increasing productivity.

CONCLUSIONS

There are 4 common aerator types used by tilapia c in northeast of Thailand, which the diffuser type was the most popular, followed by fountain type. Various factors influenced the aerator used by farmers such as farm type, stocking size, and experience on climate-related risks, in which the young and higher education farmers were more likely to adopt using aerator in their farms. Promoting aerator usage among tilapia farmers in Northeastern Thailand, therefore, will require an extension program, which should address on how aerator usage can help mitigate climate-related risks, enhance farm productivity, and support the sustainable development.

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