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Research Article

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Knowledge and behavior: a study on adoption of best management practices among Sri Lankan shrimp farmers

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Abstract – Shrimp farming in Sri Lanka is economically advantageous but faces challenges like disease outbreaks and environmental issues. The government has introduced Best Management Practices (BMPs) to ensure sustainability. This study aimed to assess BMP knowledge and adoption among Sri Lankan shrimp farmers while identifying socio-demographic and behavioral factors influencing them, which have not been previously assessed. Data were gathered from 131 shrimp farmers in Puttalam district in Sri Lanka through a questionnaire survey and analyzed using descriptive statistics and ordered logistic regressions. The results showed that 26% of farmers had poor BMP knowledge, while 37% each had fair and good knowledge. Regarding adoption, 2% exhibited poor, 89% fair, and 9% good BMP adoption. According to the ordered logistic regression results, BMP training ($p < 0.01$), education ($p < 0.05$), and workforce ($p < 0.05$) significantly affect the knowledge level of BMPs. In contrast, age ($p < 0.05$), experience ($p < 0.05$), income share ($p < 0.1$), and risk preference ($p < 0.1$) significantly affect the adoption of BMPs. It is recommended to provide more BMP training to shrimp farmers, to improve their knowledge. Moreover, considering socioeconomic and behavioral factors is crucial when designing policies and interventions to promote BMP adoption.

Keywords: Disease prevention / antibiotic / socioeconomic / sustainability / training

1 Introduction

Shrimp farming in Sri Lanka is a highly profitable aquaculture venture, with more than 90% of the cultivated shrimp targeted for export markets (FAO, 2024). Shrimp is the second most valuable export of fish and fishery products in the country and contributed to 13% of the fisheries export earnings in 2021(Ministry of Fisheries, 2022). Shrimp farming provides numerous advantages, including enhancing the national economy, providing income and employment for coastal communities, supporting rural development, and contributing to food security.

Shrimp farming began in Sri Lanka in the 1980s and thrived along the coastal border of the Puttalam district in the North Western province due to abundant natural resources favorable for shrimp farming (Munasinghe et al., 2010). In the period 1992–1996, Sri Lanka's shrimp farming experienced a rapid and uncontrolled expansion, but severe White Spot disease (WSD) outbreaks in 1996 led to the closure of many farms (Asbjorn, 2020). Since then, Sri Lankan farmed shrimp production has fluctuated mainly due to multiple disease outbreaks, poor management practices, and environmental degradation (Jayasinghe, 2001). The co-occurrence of Yellow-head Disease (YHD) and WSD has led to an approximate 70% reduction in shrimp export in Sri Lanka (Munasinghe et al., 2010). In 2018, *Litopenaeus vannamei* shrimp was introduced to Sri Lanka in response to requests from various stakeholders (NAQDA, 2018). With its rapid growth rate and adaptability to high-density farming, *L. vannamei* quickly gained popularity in Sri Lanka, replacing the previously dominant commercially cultured shrimp species, *Penaeus monodon.*

In Sri Lanka, shrimp farming is regulated through a collaborative, multi-layered governance system that includes the National Aquaculture Development Authority of Sri Lanka

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(NAQDA), the Sri Lanka Aquaculture Development Alliance (SLADA), and community-based shrimp farmers' associations (Galappaththi and Berkes, 2014; Galappaththi and Berkes, 2015b). NAQDA is a government-sponsored institution under the Ministry of Fisheries, responsible for developing the aquaculture and inland fisheries sector in Sri Lanka. SLADA represents all the stakeholders in the Sri Lankan aquaculture industry, including farmers, hatchery owners, feed suppliers, and shrimp processors. To address shrimp disease management in North Western province, SLADA introduced a zonal system, dividing the shrimp farming area into five main zones and 33 sub-zones based on the connected nature of the natural water system (Puttalam-Mundal-Chilaw lagoon system) and the shrimp disease spreading patterns through the water body (Galappaththi and Berkes, 2015a). Shrimp farmers' associations are organized within these sub-zones, totaling 18 associations as of 2021 (NAQDA, Personal communication, 2021). These organizations collectively regulate shrimp farming, support farmers and address industry challenges.

Given challenges such as disease outbreaks, environmental degradation, and food safety, the adoption of Best Management Practices (BMPs) in shrimp farming has become imperative. BMPs constitute a set of guidelines for shrimp farming, developed based on empirical observations, national and international regulations, and standards (Westers, 2012). BMPs in shrimp farming aim to streamline practices, minimize environmental harm, prevent disease outbreaks, and boost economic and environmental performance (Sivaraman et al., 2019). Previous research findings also confirm implementing BMPs minimizes the risk of disease outbreaks in shrimp farming (Suzuki and Hoang, 2018; Venkateswarlu and Venkatrayulu, 2019).

As part of the rehabilitation efforts for the Sri Lankan shrimp farming industry, NAQDA together with SLADA has prioritized promoting adherence to BMPs among farmers. NAQDA conducts both BMP training and awareness programs for shrimp farmers and oversees the implementation of BMPs at the farm level. In BMP training programs, farmers receive comprehensive guidance and demonstrations on implementing BMPs, including pond preparation, water quality management, organic waste removal, pond fertilization, biosecurity, seed selection, stocking methods, feed management, disease management, and harvesting techniques. In awareness programs, farmers are educated on the principles, importance, and benefits of BMPs, such as reducing environmental impact, enhancing productivity, and minimizing disease risks, to improve their understanding of BMPs. In Puttalam district, 13 NAQDA field officers supervise 33 shrimp farming subzones. These officers conduct BMP awareness programs monthly in the shrimp farm associations within their respective areas. Additionally, NAQDA holds 3-4 BMP training sessions annually at their center for approximately 70 shrimp farmers, with 2–3 representatives from each association attending.

Understanding farmers' adoption behavior is essential in promoting BMPs. Many theories used in empirical studies on farmers' adoption behavior, including the Diffusion of Innovations Theory (Rogers, 1983) and the Behavior Change Wheel (Michie et al., 2011), emphasize the pivotal role of knowledge in adoption decisions. Thus, when evaluating BMP adoption behavior, it is also important to assess the extent of farmers' knowledge of BMPs. According to previous research, farmers' adoption behavior is influenced by multiple factors including psychological (Cafaro and Cavallo, 2019), socio-demographic (Serebrennikov et al., 2020), and contextual factors such as farm size, environmental conditions (water quality, climate, soil type), political and regulatory framework and availability of resources (Piñeiro et al., 2020; Foguesattoet al., 2020).

Shrimp farming in Sri Lanka impacts coastal ecosystems and community livelihoods, with challenges such as environmental degradation and disease outbreaks affecting both, addressing these issues through improved BMP knowledge and adoption is crucial for achieving sustainable practices that benefit both the environment and farmers. So far, no comprehensive study has been conducted to evaluate the knowledge and adoption of BMPs among Sri Lankan shrimp farmers. Therefore, this research aimed to assess the knowledge and adoption level of BMPs among Sri Lankan shrimp farmers and identify the socio-demographic and behavioral factors influencing their knowledge and adoption of BMPs. The findings could contribute to developing more effective policies and interventions to promote BMPs among shrimp farmers and achieve sustainable shrimp farming in Sri Lanka.

2 Materials and methods

2.1 Study area

This study was conducted in the coastal belt of Puttalam district in the North Western Province of Sri Lanka which is the primary hub of shrimp farming in Sri Lanka. Shrimp farming areas in Puttalam district have been administratively divided into 5 zones and 33 subzones by SLADA and NAQDA (Fig. 1).

2.2 Selection of shrimp farms

In 2021, 700 licensed shrimp farms were operated in Puttalam District (NAQDA, Personal communication, 2021). 131 shrimp farms were selected using convenience sampling from the list of registered shrimp farms in 2021 under NAQDA, based on their accessibility and willingness to participate. Due to the survey being conducted during the COVID-19 pandemic, obtaining a representative sample of shrimp farms from each zone was not feasible. The distribution of the selected shrimp farms across the five shrimp farming zones is shown in Table 1.

2.3 Data collection

Data were collected using a pre-tested structured questionnaire developed after consulting with aquaculture specialists. The questionnaire covered information about the characteristics of farmers, farming operations, shrimp production, risk preference, knowledge, and practice questions on BMPs. Risk preference was assessed through a series of hypothetical coin-flip bets, where respondents chose between options with varying levels of risk and reward.

Knowledge questions were aimed to assess farmers' fundamental understanding of BMPs, including antibiotic use.

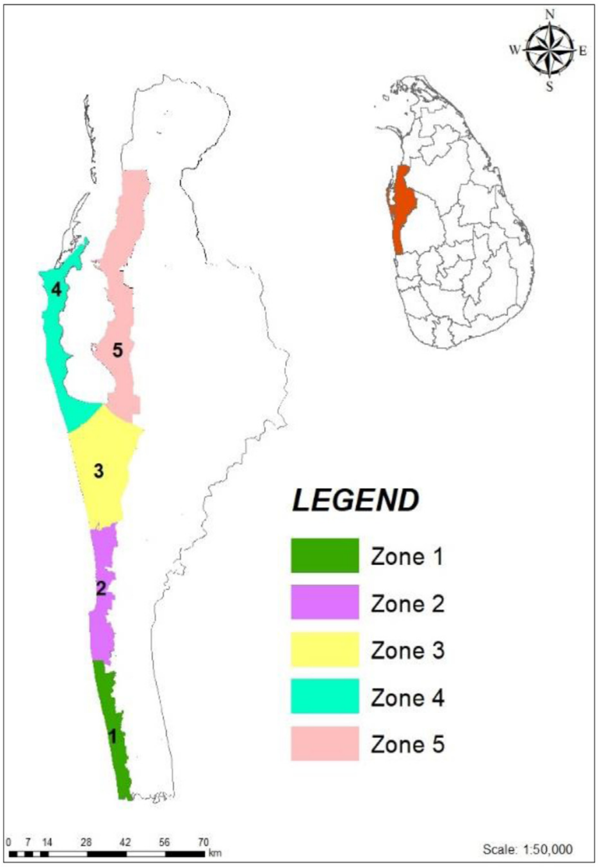

Fig. 1. Five shrimp farming zones in Puttalam District – North-Western province in Sri Lanka.

Table 1. Distribution of the selected farms by shrimp farming zone.

Zone	Total number of farms	Number of farms surveyed
1	109	54
2	417	37
3	186	29
4	28	7
5	110	4
Total	**850**	**131**

Source: NAQDA, personal communication, 2021.
Note: The total number of farms in each zone included both operating farms, which were active with stocked shrimp, and non-operating farms, which had no shrimp stock and were inactive.

Respondents were asked to rate their knowledge of BMPs using a 3-point scale comprising poor, fair, and good options, as guided by the literature (Kambey et al., 2021). Additionally, true and false questions were included regarding antibiotic use. There were 6 basic practiced questions, formulated based on the BMP guidelines provided by NAQDA. These questions determined whether farmers' behaviors complied with BMPs, and were assessed on a scale that varies depending on the specific practice.

Data collection was carried out by six trained data collectors who visited each selected farm and conducted interviews with the farm owner or manager. The structured questionnaire was administered during these visits, and interviews typically lasted around 30 min. To comply with COVID-19 health protocols, measures such as social distancing and personal protective equipment were strictly followed. The survey was conducted in Sinhalese, the local language and all participating farmers were fluent in Sinhalese. The data collection took place in October 2021.

2.4 Fundamental aspects of BMPs and study-specific focus

NAQDA classifies shrimp farms into three categories: Grade A, B, and C, based on the level of infrastructure and available facilities. Grade A farms have the highest level of facilities, followed by Grade B, and Grade C. Grade A and B farms must allocate 30% of their total farming volume for water storage tanks and 20% for sedimentation tanks. For grade C farms the storage tank and the sediment tank should be 20% and 10% of the total extent of the culture ponds respectively. All the grow-out ponds in Grade A farms must be lined with DHEP liners.

NAQDA has developed a set of BMP guidelines specific to each farm grade covering 13 key aspects; (1) basic requirements, (2) pond water preparation, (3) post-larvae selection, (4) post-larvae transport, (5) stocking, (6) feeding, (7) water quality, (8) shrimp health, (9) wastewater management, (10) disease reporting, (11) harvesting, (12) recordkeeping, and (13) changing the culture species. This study focuses on Grade C farms, as they constitute the majority of shrimp farms. Six fundamental BMPs were selected for the analysis; pond preparation, water quality management, shrimp stocking density, feeding management, shrimp health management, and wastewater management because they are critical for minimizing disease risks and improving farm sustainability.

2.5 Data analysis

Descriptive statistics were used to describe shrimp farmers' and farming characteristics, correct knowledge answers, and various practices regarding the BMPs. Farmers' knowledge of BMPs was assessed based on their responses to the knowledge question rated as poor, fair, and good. In evaluating BMP adoption, scores were assigned to responses for each practice question (e.g., 1 for adherence, 0 for non-adherence). The practice questions are shown in Table 6. Subsequently, the overall practice level of each farmer was categorized as poor, fair, or good based on the total score: below 50% for poor, 50–75% for fair, and above 75% for good.

Socio-demographic and behavioral factors influencing BMP knowledge and adoption were individually analyzed through ordered logistic regressions. This method is preferred when the dependent variable is discrete and classified into more than two categories according to its order of magnitude (Nwakuya and Mmaduka, 2019). In this study, the dependent variable (knowledge/adoption level) was categorized into three

Table 2. Socio-demographic profile of shrimp farmers and farming characteristics ($n = 131$).

	Mean	SD	% farmers
Shrimp farming experience (years)	14	± 8.08	
Ave. share of income from shrimp farming from total income (%)	94.5	± 12.76	
Ave. labor per farm	3	±1.76	
Ave. stocking density/m2 per year (number of shrimps)			
P. monodon	56.41	± 15.96	
L. vannamei	96.33	± 43.21	
Age			
Younger (<30 years)	7		5%
Middle age (30–50 years)	99		76%
Older (>50 years)	25		19%
Education level			
Up to Middle school (O/L) or below	93		71%
High school (A/L) or above	38		29%
Ethnicity			
Sinhala	100		76%
Tamil	20		15%
Muslim	11		9%
Cultivated shrimp variety			
P. monodon	101		77%
L. vannamei	30		23%
BMPs training			
Yes	45		34%
No	86		66%
Disease occurrence			
Yes	46		35%
No	85		65%
Risk preference			
Risk averse/neutral	90		69%
Risk taker	41		31%

***Note*:** Education levels were categorized based on the education system in Sri Lanka, where the Ordinary Level examination (O/L) aligns with middle school and the Advanced Level (A/L) aligns with high school.

ordinal levels: poor, fair, and good. Odds Ratios (OR) were employed to interpret coefficients, indicating the change in odds for a higher category of the dependent variable with a one-unit increase in the predictor variable, while other variables remained constant. Data were analyzed using STATA 15 software.

Econometric model used in Ordered Logistic Regressions

$$log\left(\frac{p(y \le j)}{1 - p(y \le j)}\right) = \alpha_j + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k$$

where y = Dependent variable (Knowledge or Adoption); j = levels of knowledge/adoption (1= poor, 2=fair, 3= good); $p(y \le j)$ Cumulative probability of y being less than or equal to level j; α_j = Intercept (thresholds) for each level of j; β_{1-k} = Coefficients; x_{1-k} = Independent variables.

3 Results

3.1 Socio-demographic profiles of shrimp farmers and farming characteristics

The surveyed shrimp farmers had an average farming experience of 14 years. Additionally, their shrimp farming income accounted for an average of 94.5% of their total household income, indicating that shrimp farming serves as their primary source of income. Most of the farmers (76%) were in the middle-aged category. Similarly, the education level of the majority of the farmers (71%) was up to middle school (O/L) or lower. Seventy-six percent (76%) of the farmers were Sinhalese followed by 15% Tamils and 9% Muslims. Seventy-seven percent (77%) of shrimp farms had *P. monodon* shrimp whereas 23% of farms had *L. vannamei,* as farmers had not yet fully transitioned to *L. vannamei*, which was newly introduced. Only 33% of farmers had undergone BMP training. Thirty-five percent (35%) of farms had experienced disease-related issues in the preceding year. The majority of farmers (69%) exhibited risk-averse or risk-neutral behavior, while 41% were identified as risk-takers. The socio-demographic profile of shrimp farmers and farming characteristics are summarized in Table 2.

3.2 Knowledge of BMPs and the factors influencing knowledge

3.2.1 Knowledge of BMPs

Poor knowledge of BMPs was reported by 26% of farmers, while fair and good knowledge levels were reported by 37%

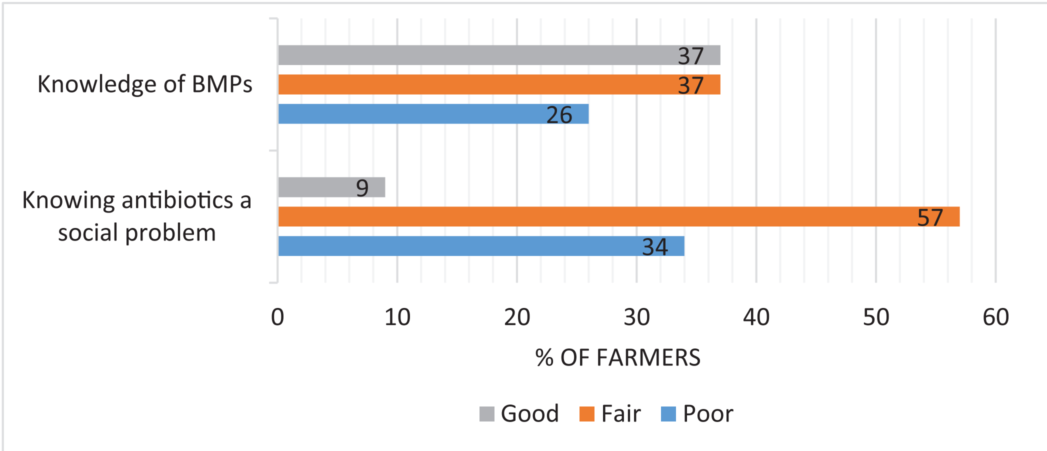

Fig. 2. Shrimp farmers' knowledge of BMPs and antibiotic use.

Table 3. Shrimp farmers' knowledge regarding the antibiotic use.

	Correct answer	Proportion correct (%)
Antibiotics are effective against viral diseases	FALSE	77
Antibiotics may harm human health in the long term	TRUE	74
Antibiotics can be used as disinfectants in aquaculture ponds	FALSE	82
Antibiotics increase the clearness of aquaculture pond water	FALSE	89

each. Further, the majority of farmers (57%) reported having fair knowledge about antibiotics being a social problem. Conversely, 34% of farmers reported having poor knowledge while only 9% of them claimed to have good knowledge about the matter (Fig. 2).

The majority of farmers provided correct answers to questions concerning their knowledge about the use of antibiotics (Tab. 3).

3.2.2 Factors influencing knowledge

Ordered logistic regression was performed to identify the factors related to farmers' knowledge regarding BMPs. Table 4 provides detailed information on the variables utilized in the ordered logistic regression analysis. Results revealed that among the variables examined BMPs training ($p < 0.01$), education ($p < 0.05$), and workforce ($p < 0.05$) are statistically significant and contribute to improving the knowledge level of BMPs (Tab. 5). The farmers who attended BMP training were 8.8 times more likely to possess higher knowledge compared to those who didn't attend. Further, the farmers with a high school education or above were 4.2 times more likely to have a higher knowledge of BMPs compared to farmers with a middle school education or below. The likelihood of belonging to a higher knowledge level rises 1.32 times with each additional worker in the workforce.

3.3 Adoption of BMPs and the factors influencing adoption

3.3.1 Adoption of BMPs

Shrimp farmers' responses to practice-related questions varied depending on the specific practice (Tab. 6). All farmers practiced pond cleaning before the start of shrimp farming. Ninety-eight percent (98%) of shrimp farmers test water quality weekly. Only 7% of farmers stocked shrimp at the appropriate stocking density, and 15% practiced proper feeding. The majority of farmers had never administered medicines (antimicrobials) to treat diseased shrimp (72%). Most of the farmers (64%) did not disinfect pond wastewater with disinfectants in case of shrimp disease outbreaks.

3.3.2 Factors influencing adoption

Based on the computed adoption level scores, 2%, 89%, and 9% of farmers had poor, fair, and good adoption of BMPs, respectively. Ordered logistic regression was performed to identify the factors (Tab. 4) associated with the adoption level of BMPs. The results indicated that age ($p < 0.05$), experience ($p < 0.05$), income share ($p < 0.1$), and risk preference ($p < 0.1$) significantly affect the adoption of BMPs. Older farmers were found to be less likely (OR = 0.02) to adopt BMPs compared to younger farmers. For each additional year of experience, the adoption of BMPs slightly improved by 1.14 times. Adoption of BMPs minimally improved by 1.04 times for every percent increment in income share from shrimp farming. Risk-averse or neutral farmers were 5.1 times more likely to adopt BMPs compared to risk-taking farmers. The results of ordered logistic regression analysis are summarized in Table 7.

4 Discussion

The results of this study provide insight into Sri Lankan shrimp farmers' knowledge and adoption behavior related to

Table 4. Variables used in ordered logistic regression analysis.

Variables	Description
Dependent Variables	
Knowledge or adoption level	1 = Poor, 2 = Fair, 3 = Good
Independent Variables	
Age	Younger (<30 years) = 0 (Reference) Middle age (30–50 years) = 1, otherwise = 0 Older (>50 years) = 1, otherwise = 0
Education	Up to Middle school (O/L) or below = 0 High school (A/L) or above = 1
Experience	Shrimp farming experience in the years
Ethnicity	Sinhalese = 1 Other = 0
Shrimp Variety	*L. vannamei* =1 *P. monodon* = 0
Income share	% of shrimp farming income from the total household income
Workforce	Number of workers (family and hired)
Stocking density	Number of post-larvae/m^2 per annum
Risk preference	Risk averse/neutral =1 Risk taker = 0
BMPs training	Yes = 1 No = 0
Disease occurrence	Whether the farm experienced a disease outbreak last year, Yes = 1 No = 0

Table 5. Ordered logistic regression analysis of factors associated with shrimp farmers' knowledge of BMPs ($n = 131$).

Variables	OR	95% CI	*P* Value
Dependent variable			
Knowledge level (poor, fair, good)			
Independent variables			
Age			
Middle age	0.91	0.18–4.63	0.91
Old	0.90	0.13–6.45	0.92
Education	4.23	1.41–12.69	0.01*
Experience	1.02	0.97–1.08	0.35
Ethnicity	1.70	0.47–6.16	0.42
Shrimp Variety	1.88	0.60–5.93	0.28
Income share	1.01	0.98–1.03	0.67
Workforce	1.32	1.00–1.73	0.04*
Risk preference	0.86	0.37–2.01	0.72
BMPs training	8.84	3.77–20.69	0.00**
Disease occurrence	0.58	0.26–1.32	0.20
Thresholds			
Cut1	1.64	–1.66–4.95	
Cut2	3.95	0.56–7.34	
Log pseudolikelihood	–111.568		
Pseudo R squared	0.217		

Note 1: * and ** represent statistical significance at 5% and 1% respectively.
Note 2: OR = Odds Ratio; CI = Confidence Interval.

Table 6. Shrimp farmers' responses to practices related questions.

Practice-related questions	Responses	% of farmers
1. Cleaning of shrimp ponds before the start of shrimp farming (sludge removal, drying, liming, chlorination, sun drying, etc.)	1). I don't do it	0
	2). Occasionally do	3
	3). I do it	97
2. Observation frequency of water quality and bottom sediment per pond during shrimp farming	1). Monthly	2
	2). Weekly	98
	3). Daily	0
3. Shrimp stocking density is appropriate	1). Under crowded	93
	2). Appropriate	7
	3). Overcrowded	0
4. The amount of feed fed to the shrimp is adequate	1). Low	84
	2). Proper quantity	15
	3). High	1
5. Administering medicines (antimicrobials) to treat diseased shrimp	1). Never	72
	2). Occasionally	10
	3). Administered	18
6. Disinfecting pond wastewater with disinfectants in case of shrimp disease outbreaks	1). Not disinfect	64
	2). Occasionally	24
	3). Disinfect	12

Table 7. Ordered logistic regression analysis of factors associated with shrimp farmers' adoption of BMPs ($n = 131$).

Variables	OR	95% CI	*P* value
Dependent variable			
Adoption level (poor, fair, good)			
Independent variables			
Age			
Middle age	0.86	0.13–5.70	0.88
Old	0.02	0.01–0.69	0.03**
Education	1.52	0.37–6.31	0.56
Experience	1.14	1.04–1.25	0.01**
Ethnicity	0.38	0.06–2.36	0.30
Shrimp Variety	0.83	0.16–4.35	0.82
Income share	1.04	1.00–1.09	0.07*
Workforce	0.77	0.54–1.08	0.13
Risk preference	5.16	0.76–35.14	0.09*
BMPs training	0.68	0.21–2.18	0.51
Disease occurrence	0.96	0.22–4.19	0.96
Thresholds			
Cut1	–1.24	–5.47–2.98	
Cut2	7.43	1.63–13.24	
Log pseudolikelihood	–38.356		
Pseudo R squared	0.237		

Note 1: * and ** represent statistical significance at 10% and 5% respectively.
Note 2: OR=odds ratio; CI=confidence interval.

BMPs, which will be useful in developing more effective policies and interventions to promote BMPs. This, in turn, will help minimize environmental degradation while ensuring sustainable shrimp farming in Sri Lanka. Given that shrimp farming is the primary income source for the majority of farmers, the effective implementation of BMPs is essential not only for their economic stability but also for environmental conservation.

The findings indicated varying levels of BMP awareness among shrimp farmers in Puttalam district, suggesting an opportunity for enhancing knowledge from poor and fair levels to good levels. Similar findings were reported by Patil et al., (2021) and Maiti et al., (2016). Literature confirms that farmers are more likely to adopt BMPs when exposed to knowledge about BMPs (Baumgart-Getz et al., 2012; Boyer et al., 2018). Several studies have also reported that insufficient information or limited access to high-quality information on BMPs is a significant barrier to adoption (Liu et al., 2018; Mishraet al., 2018).

Regarding the factors influencing BMP knowledge, a positive association between BMP training and knowledge indicate the importance of providing more training/awareness programs to improve BMP knowledge among farmers. This finding aligns with Hörner et al.,'s (2019) discovery of a positive impact of training on farmers' knowledge about integrated soil fertility management in Ethiopia. Similarly, many studies have emphasized the importance of training farmers in technology adoption to disseminate knowledge about agricultural innovations and improve their comprehension of new practices (Challa and Tilahun, 2014; Kinyangi, 2014).

Moreover, the farmers with a high school education or above were more likely to have a higher knowledge of BMPs compared to farmers with a middle school education or below, which may be attributed to their increased access to information and greater ability to understand BMPs. Many studies have reported that farmers with higher education levels possess greater knowledge, comprehension skills, and access to information, enabling them to understand better and respond to various situations (Ofuoku et al., 2008; Alam et al., 2017). The observation of an increase in the knowledge level of BMPs with a larger workforce could be associated with the idea that having more workers facilitates the sharing of knowledge and encourages social learning.

The study findings highlighted significant disparities in the adoption of BMPs among Sri Lankan shrimp farmers. While practices like pond cleaning and water quality testing are widely adopted, others such as proper feeding, maintaining appropriate stocking density, and disinfecting pond wastewater during disease outbreaks need improvement. Potential reasons for the low adaptability of some practices may include unfamiliarity, high costs, high labor requirements, and a reluctance to adopt these practices (Swinton et al., 2015; Gillespie et al., 2007).

Mahagamage and Jayakodi (2020) also revealed that certain BMP practices adopted by the majority of farmers were inconsistent with the recommendations of BMPs, including high stocking density, stocking of post-larvae smaller than the recommended age, less or no chlorination, release of diseased shrimps into the main water source. Therefore, addressing these disparities is crucial for enhancing shrimp farming sustainability and productivity. Further, the study uncovered that some shrimp farmers are using antibiotics in violation of BMP regulations, highlighting the need for stricter enforcement to mitigate the risks associated with antibiotic misuse in shrimp farming (Kono et al., 2024).

When evaluating the adoption levels of BMPs, it was found that the majority of farmers (82%) exhibited a fair adoption of BMPs, aligning with the findings of Sahu et al., (2014) regarding shrimp farmers in Odisha state, India. Regarding the factors influencing BMP adoption, the lower likelihood of older farmers adopting BMPs compared to younger farmers can be attributed to their familiarity with traditional farming methods, leading to reluctance to adopt new practices. Many studies have reported that older livestock farmers are significantly less likely to adopt BMPs (Yang and Sharp, 2017; Glenk et al., 2014). The increase in the adoption of BMPs with an increase in farming experience can be due to the development of skills and understanding of BMPs as farmers gain more experience. Studies by Savage and Ribaudo in 2013 and Glenk et al., in 2014 also indicated that livestock farmers with greater years of farming experience are significantly more inclined to adopt BMPs.

Further, a minimal increase in BMP adoption with the increase in income share from shrimp farming can be explained by the fact that with higher income farmers can afford to invest in BMPs and benefit from them. Previous research has similarly found that livestock producers with higher incomes are more likely to adopt BMPs (Yang and Sharp, 2017; Holley et al., 2020). Moreover, the higher likelihood of risk-averse/neutral farmers adopting BMPs compared to risk-taking farmers can be attributed to the convergence of risk-averse/neutral behavior with a cautious and preventive approach. Hence, adopting BMPs can be a practical and strategic way to effectively manage risks and uncertainties in shrimp farming for such farmers. This finding complies with the research conducted by Rahelizatovo and Gillespie (2004) and Savage and Ribaudo (2013) indicating that risk-averse livestock farmers are more likely to adopt BMPs.

This study contributes to the existing literature by identifying socio-demographic and behavioral factors influencing BMP knowledge and adoption among Sri Lankan shrimp farmers that have not been previously examined. The findings emphasize the importance of BMP training and education as key drivers of knowledge acquisition, while also highlighting the impact of age, experience, income share, and risk preference on BMP adoption. In addition, the findings highlighted a distinction between the factors affecting knowledge and those affecting adoption. While BMP training enhances farmers' knowledge, it didn't significantly impact BMP adoption, suggesting there may be some barriers to the adoption such as psychological, and financial constraints.

It can be suggested that introducing financial incentives and subsidies could significantly boost BMP adoption by reducing implementation costs, thereby encouraging farmers to adopt these practices. Rules and regulations against BMP violations and antibiotic use need to be strictly enforced by the government. NAQDA and shrimp farmers' associations can play a vital role in monitoring these rules at the field level. It is recommended to provide more BMP training to shrimp farmers, focusing on practices with low adoption rates, such as proper feeding, maintaining appropriate stocking density, and disinfecting pond wastewater during disease outbreaks. Other informational interventions, such as distributing brochures and manuals on BMPs, establishing demonstration farms, and promoting peer-to-peer learning, can also be effective. NAQDA, SLADA, and shrimp farmers' associations can collaboratively provide financial incentives, organize training programs, and implement various other interventions to promote Best Management Practices (BMPs) among farmers. Moreover, considering socioeconomic and behavioral factors is crucial when designing policies and interventions to promote BMP adoption. Further research is needed to identify the barriers to BMP adoption and develop strategies to overcome them. This study has several limitations. First, it focused exclusively on small-scale shrimp farmers, which may not represent the entire shrimp farming community in Sri Lanka. Additionally, convenience sampling was employed to select farmers due to the COVID-19 situation, which may have introduced bias in the results.

5 Conclusions

Despite providing numerous socio-economic benefits, shrimp farming in Sri Lanka faces challenges such as disease outbreaks, environmental degradation, and food safety concerns. Adopting BMPs is essential to overcome these challenges and ensure sustainable shrimp farming. The findings of this study suggest that the majority of shrimp farmers in the Puttalam district possess sufficient knowledge and adoption of BMPs, but there is still room for improvement. Similarly, the results indicate that their knowledge regarding the use of antibiotics needs to be improved. Within BMPs, pond cleaning and water quality testing are extensively adopted. However, challenges persist in certain BMP practices, particularly related to stocking density, feeding, and wastewater management. The study also exposed hidden behaviors regarding antibiotic use among Sri Lankan shrimp farmers, potentially violating BMP regulations. Thus, the rules and regulations against BMP violations and antibiotic use must be strictly enforced by the government and closely monitored by NAQDA and shrimp farmers' associations.

Knowledge and behavior of Sri Lankan shrimp farmers regarding BMPs are influenced by many factors including their socioeconomic aspects, farming characteristics, and behavioral factors. Knowledge level is influenced by BMP training, education, and workforce whereas adoption level is influenced by age, experience, income share, and risk preference. It is recommended to provide more BMP training to shrimp farmers to enhance their knowledge of BMPs. In formulating policies and intervention programs to enhance BMP adoption among shrimp farmers, it is important to consider their socioeconomic and behavioral factors which are currently overlooked, and tailor strategies accordingly for effective implementation.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author, [HK].

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