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EDITED BY
Taryn Garlock,
Auburn University, United States

REVIEWED BY
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University of Florida, United States
Atle Oglend,
University of Stavanger, Norway

*CORRESPONDENCE
Mohammad Mahfujul Haque
mmhaque.aq@bau.edu.bd

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Forecasting the production and export of shrimp in Bangladesh: a policy focused time series analysis

Mobin Hossain Shohan and Mohammad Mahfujul Haque*

Department of Aquaculture, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh, Bangladesh

Introduction: The study analyses shrimp industry of Bangladesh, highlighting its growth potential amid challenges such as declining export volumes, quality compliance issues, and competition from low-cost producers. Despite expanded farming areas and increased production, exports have fallen due to food safety issues, weak infrastructure, and inadequate regulatory compliance.

Methods: The study employs the Vector Autoregression (VAR) model to forecast shrimp production and exports, analyzing 33 years of data (1991–2023) to identify bottlenecks and policy gaps. Using statistical tests, co-integration analysis, and a literature review, it highlights challenges in legislative policies and quality compliance, offering strategies to enhance standards and global competitiveness.

Results and discussion: The analysis reveals a steady rise in shrimp production, contrasting with a two-fold decline in export quantities from 2011 to 2023, largely due to quality non-compliance and contamination. The VAR(1) model predicts a slight decline in production by 2026–27, with exports potentially decreasing by a factor of 3.2 compared to 2010–11. Key challenges include hazardous residues, poor management practices, and disease outbreaks. Legislative analysis highlights policy gaps, weak enforcement, and insufficient infrastructure as significant barriers to meeting international standards. Addressing these challenges is critical for enhancing the global competitiveness of the industry. Recommendations include incentivizing organic farming under certification, improving post-harvest infrastructure, adopting advanced disease management technologies, and establishing regional testing facilities. A unified shrimp marketing policy is essential to enhance quality, sustainability, and competitiveness in global markets. These strategies aim to align the industry with international standards, boost exports, and ensure long-term sustainability.

KEYWORDS

shrimp production, export, time series analysis, shrimp policy, sustainability, Bangladesh

1 Introduction

Shrimp, among several goods flooding the global export market, has seen governments incentivizing its production through financial support and tax exemptions to boost export earnings and reduce import reliance (Rivera-Ferre, 2009; Bush et al., 2019; Ali et al., 2024). The global surge in shrimp demand is driven by rising incomes and increasing consumer interest in shrimp products (Anderson et al., 2018; de Abreu et al., 2011). Since its origins in Southeast Asia in the 1970s, shrimp farming has expanded significantly worldwide, with the region remaining a major producer (FAO, 2024; Hall, 2004). According to the Observatory of Economic Complexity (The Observatory of Economic Complexity, 2021), India is the largest shrimp exporter, followed by Ecuador and Vietnam. Asia accounts for approximately 55% of global shrimp exports, with Bangladesh, India, Thailand, Indonesia, Vietnam, and China collectively contributing around 92% of shrimp exports of the region (The Observatory of Economic Complexity, 2021).

Shrimp, including both black tiger shrimp (*Penaeus monodon*) and prawn (*Macrobrachium rosenbergii*), plays a crucial role in the economy of Bangladesh as the second most important commodity after readymade garments for earning foreign exchange. The coastal areas of the country, covering 25,000 km^2, have approximately 250,000 ha of tidal plains suitable for shrimp aquaculture (Azad et al., 2009). Due to comparative production advantages and rising global demand, shrimp production and export revenues have expanded dramatically since the 1980s. Between 1980 and 2019–20, the area used for prawn farming increased from 20,000 ha to around 257,888 hectares (DoF, 2021). Despite this massive expansion of shrimp farming areas, shrimp exports have declined in recent years. Between 1991 and 2021, shrimp production by volume increased more than tenfold, whereas shrimp export quantity reduced by 1.8 times between 2011 and 2021 (DoF, 2002, 2022). The earnings from shrimp export decreased from over US$598 million in FY (Fiscal Year) 2011–12 to only US$328 million, a 45% decline (DoF, 2021). The decline in exportable shrimp from Bangladesh is linked to multiple factors, including the lack of practicing certification scheme, centralized quality control, and full traceability system, which are key requirements for meeting international standards (Ferdous and Hossain, 2015; Akter, 2017). These limitations have affected competitiveness of the country in the global shrimp market. In addition to quality-related challenges, other contributing factors such as weak infrastructure, fluctuations in international market prices, processing plant closures, competition from low-cost Vannamei shrimp (*Litopenaeus vannamei*), inadequate training to the farmers, and declining raw material (shrimp) availability have further exacerbated the issue (Akter, 2017; Yunus, 2009; Alam and Ahammad, 2017).

The shrimp industry operates through a complex marketing network, connecting farmers to processing plants via intermediaries such as like local dealers, agents, and depot holders (Bremer et al., 2016). The intensified profit-driven behavior among stakeholders in the shrimp sector has been accompanied by insufficient monitoring of production and weak regulatory compliance. Although Bangladesh holds significant potential to boost production, enhance productivity, modernize processing facilities, and expand shrimp farming, it faces major challenges in meeting export standards. Issues such as chemical, heavy metal, microbial, and antibiotic contamination persist throughout the supply chain, from the farming environment to processing plants. All these factors have collectively contributed to decline in shrimp exports, leading to a steady decline since FY 2010–11, with a reduction of 20,000 MT over the past decade (DoF, 2012, 2021).

To remain competitive in the global shrimp market, Bangladesh needs to adopt new policies and effectively implement existing laws, regulations, and strategies, aligning them with the requirements of buyer countries (Jamal, 2023; Rahman and Hossain, 2009; Cato and Subasinge, 2003). Developing and refining policies requires a solid understanding of future scenarios, which can be achieved through forecasting models. Accurate forecasting of shrimp production and export quantities is vital for maximizing economic benefits, ensuring optimal resource allocation, maintaining stable employment, streamlining supply chains, and enhancing regulatory frameworks to boost industry competitiveness. In this context, this study addresses three key research questions.

- What will be the production and export quantity of shrimp in the future?
- What are the bottlenecks for producing quality shrimp for the export market, according to the published literature in the context of study country?
- What can be the appropriate policy and its implementation measures which will help to comply with the export market requirements and increase the foreign export of shrimp?

Several studies have examined the global competitiveness of agricultural products (Narayan and Bhattacharya, 2019; Leromain and Orefice, 2014; Jha et al., 2007), with specific attention to shrimp exports (Ismail and Abdullah, 2013; Fathima et al., 2006; Umadevi and Eswaraprasad, 2006). Other research has explored the factors influencing shrimp export performance globally (Jatuporn, 2022; Fitriani et al., 2019; Karagöz, 2016), including analyses of shrimp export competitiveness of Bangladesh and its determining factors (Khan et al., 2022). Some recent studies have been conducted on time series modeling and forecasting in fisheries and aquaculture, mostly using ARIMA, SARIMA, and ARIMAX models (Siddique et al., 2025, 2024a, 2024b; Yadav et al., 2020; Raman et al., 2017).

This study is the first to employ multivariate time series modeling to forecast the dynamic relationship and correlations between shrimp production and export volumes in Bangladesh. It also integrates an analysis of production quality bottlenecks and legislative frameworks. Unlike other multivariate models, the Vector Autoregression (VAR) model does not rely on a predefined causal structure, offering a flexible approach to representing interactions among variables. By considering how each variable is influenced by its own past values and those of

other variables in the system, VAR effectively captures the dynamic interdependencies. Its simplicity in managing multiple time series, combined with its capacity to reveal both short- and long-term interactions without imposing strict causal assumptions, makes it particularly advantageous.

2 Materials and methods

2.1 Shrimp production and export trend

The analysis of this study is based on 33 years of data (1990–91 to 2022–23) obtained from the Statistical Yearbook compiled by the Bangladesh Bureau of Statistics and the Fisheries Resources Survey System (FRSS) maintained by the Department of Fisheries (DoF), Bangladesh (DoF, 2022, 2023). Data on hazardous materials in exported shrimp for 2016 were sourced from the Quality Control Laboratory, accredited by the Government of Bangladesh and operated by the DoF.

2.2 Legislation analysis through literature review

To identify key bottlenecks in producing quality shrimp that meets compliance requirements for foreign markets, a comprehensive literature review was conducted. Relevant literature published between 2005 and 2024 was identified using search engines such as Web of Science, Google, Google Scholar, and PubMed. Keywords included "shrimp export," "shrimp production," "drug use in shrimp farming," "quality compliance," and "shrimp contamination." Selected publications focused on shrimp contamination at various stages of the value chain involving substances such as banned antibiotics, heavy metals, aromatic compounds, pathogenic microbes, and microplastics critical to quality compliance, were considered. Data on substances, methods, and key findings were extracted from the reviewed literature. Additionally, the study analyzed legislation related to shrimp production, health and food safety, export marketing, environmental compliance, and social justice through research articles, and gray literature such as gazettes, ministerial orders, policy documents and web documents. The analysis highlighted legal loopholes, implementation challenges, and offered recommendations for improvement.

2.3 Modeling and forecasting with vector autoregression

Several time series models are commonly used for modeling and forecasting, including Autoregressive Conditional Heteroskedasticity (ARCH), Generalized Autoregressive Conditional Heteroskedasticity (GARCH), Seasonal Autoregressive Integrated Moving Average (SARIMA), Autoregressive Integrated Moving Average (ARIMA), and Autoregressive Moving Average (ARMA). However, as this study involves two time series variables, a multivariate approach was employed to analyze them concurrently. Specifically, the study utilized the Vector Autoregressive (VAR) model, which is well-suited for jointly modeling the dynamic relationships between multiple variables.

A seven-step methodology (Figure 1) was adopted to achieve this model: initially, a unit root test was conducted to determine the stationarity of the dataset (Dickey and Fuller, 1979). The Augmented Dickey-Fuller (ADF) test was conducted to assess the stationarity of shrimp production and export quantity. The test was performed both with and without a time trend to determine whether the variables were trend-stationary or contained a unit root. If non-stationary at level, first-differencing was applied to achieve stationarity. Since export quantity exhibited a deterministic trend, a time trend was incorporated as an exogenous variable in the Vector Autoregressive (VAR) model to account for structural changes over time. Then the Johansen co-integration test was performed to evaluate the co-integration between shrimp

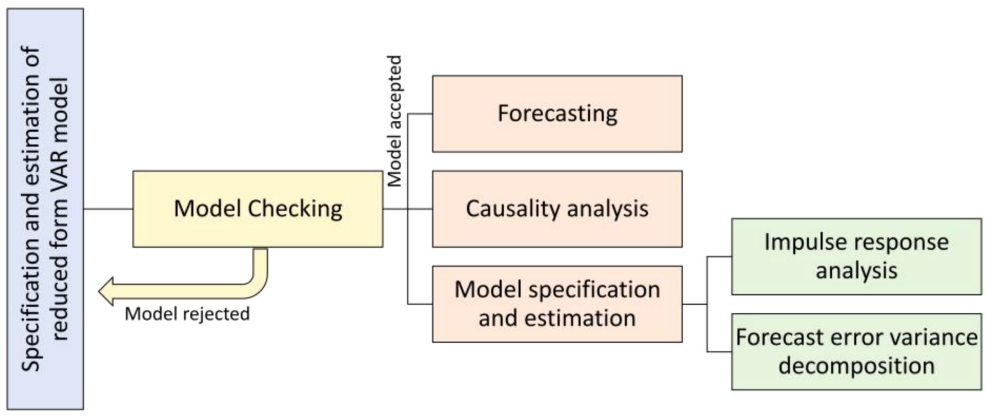

FIGURE 1
Schematic diagram of VAR model. Source: Authors' own, adapted from Lütkepohl, (2006).

production and export quantity (Johansen, 1988). The Granger causality test was conducted to ascertain which variable Granger causes the other (Granger, 1969; Sims, 1972). Identifying the appropriate model and selecting the lag length was a crucial step. Model selection criteria such as Akaike Information Criterion (AIC) (Akaike, 1974), Hannan-Quinn information criteria (HQ) (Hannan and Quinn, 1979), Final Prediction Error (FPE) (Akaike, 1969), and Schwarz Information Criteria (SIC) (Schwarz, 1978) were employed for this purpose. The Impulse Response Function (IRF) was measured to evaluate the impact of shocks on the endogenous variables. The Variance decomposition step analyzed the extent to which the variability in the dependent variable is explained by its own variance versus the variance of the other variable. Finally, the time series model was applied for forecasting. Once the data pattern is identified using this model, it enables accurate forecasting for *h*-steps ahead. The A_p-th order of VAR(p) model, denoted for a set of 'm' time series variables $y_t = (y_{1t}, y_{2t}, \ldots, y_{mt})$, is represented as

$$y_t = c + A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + \gamma t + u_t$$

where the A_i's are m×m coefficient matrices, 'c' is an m×1 vector of constants, *t* is the deterministic trend, γ is the coefficient of the time trend and u_t is an m×1 vector of disturbances where, it assumed to have zero mean and constant variance with no autocorrelation (Supplementary File S1). To validate the VAR model, diagnostic tests were performed. The Portmanteau test was done to detect autocorrelation in residuals, the ARCH test assessed heteroskedasticity, and the stability test verified whether all roots lay within the unit circle. For the analysis, we utilized RStudio (2021.09.2 + 382 version) with the packages 'vars' and 'mFilter'. A detailed method with equation is given in Supplementary File S1.

3 Results

3.1 An overview of the shrimp production and export quantity

Shrimp production in Bangladesh has demonstrated steady growth over the years, rising from 152,520 MT in 2000–01 to 271,302 MT in 2022–23. However, the upward trend in production has not been mirrored by export volumes. Shrimp exports initially increased from 29,713 MT in 2000–01 to 54,891 MT in 2010–11 (Figure 2). After reaching this peak, export quantities sharply declined, dropping to just 25,143 MT by 2022–23. This significant decrease in export volume has severely affected shrimp export revenues, which saw a 45% decline in FY 2020–21 compared to FY 2011–12. Figure 2 underscores the pressing challenge for Bangladesh to sustain and increase its shrimp export, highlighting the need to address the factors behind this decline and implement strategies to improve national shrimp export performance.

3.2 VAR model forecast

3.2.1 Unit root test

In this study, the ADF test was used to assess stationarity. The results revealed that both the production volume and export quantity are non-stationary in their original form (Supplementary Table S1). However, after taking the first difference of shrimp production, the unit root null hypothesis was rejected. Similarly, export quantity was found to be stationary at first difference with a time trend, indicating the presence of a deterministic trend. Therefore, a time trend was incorporated as an exogenous variable to capture this feature. This

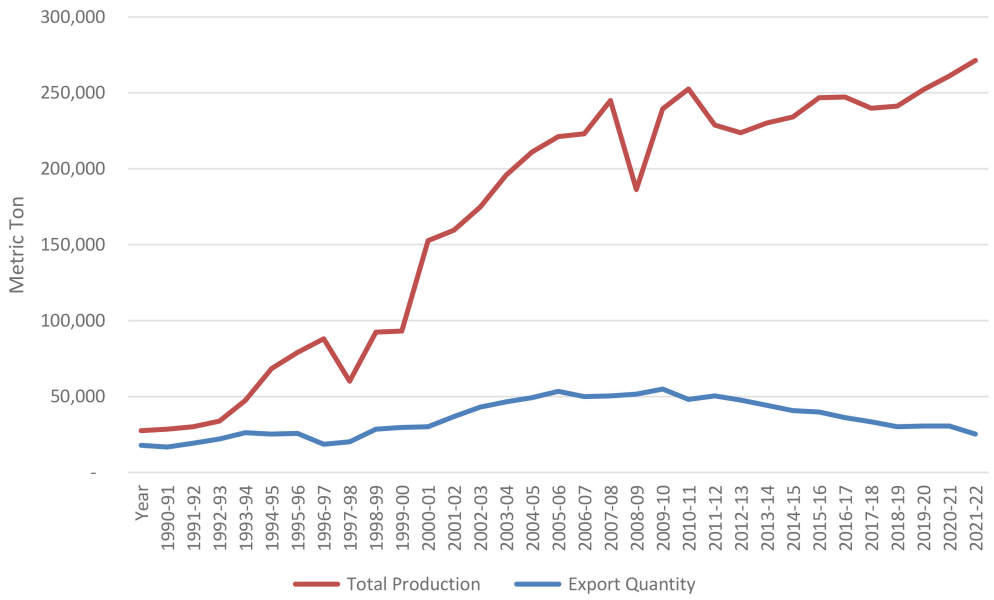

FIGURE 2
The scenario of production and export quantity of shrimp in Bangladesh over the last 33 years (Data source: DoF, 2023).

satisfies the necessary conditions for constructing a VAR model, including the co-integration and Granger causality tests.

3.2.2 Co-integration test

Anecdotal evidence suggests that shrimp production affects export quantities, potentially creating a cointegrated relationship between these variables. The null hypothesis, which posits that there is no cointegration or at most one cointegration between shrimp production and export quantity, is rejected (Supplementary Table S2). Therefore, the model (1) indicating no cointegration between these two variables remains valid. If co-integration were present, this study would have employed the Vector Error Correction Model (VECM). However, the absence of co-integration, along with both variables being stationary at the first difference, justifies the application of the Vector Autoregression (VAR) model. This implies a stable, long-term equilibrium relationship between shrimp production and export quantity. Furthermore, it indicates that historical shrimp production values in Bangladesh can explain the variations in shrimp export quantities.

3.2.3 Granger causality test

The Granger causality test examines whether past changes in one variable (production volume) can predict changes in another variable (export quantity) (Granger, 1969). The test results showed that the null hypothesis, which posits that production does not Granger cause export quantity, is rejected at the 5% significance level. In contrast, the standard causality test fails to reject the null hypothesis, indicating that shrimp production does not Granger-cause export quantity in Bangladesh (Supplementary Table S3). This suggests that changes in export quantity influence shrimp production growth, but changes in production do not drive increases in export quantity. Therefore, a one-way causal relationship exists from export quantity to production in Bangladesh.

The stability of the short-term VAR model's parameters was assessed using the Cumulative Sum (CUSUM) test. The recursive errors consistently remained below the significance threshold ($p \leq 0.05$), as shown by the CUSUM analysis. This indicates that the estimated coefficients remain stable throughout the sample period (Figure 3).

3.2.4 Model selection

The Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQ), Final Prediction Error (FPE), and Schwarz Information Criterion (SC) were used to determine the appropriate lag order for the VAR model. The study selected a lag length of 1 for the VAR model based on the lag selection criteria. Although the Akaike Information Criterion (AIC) and Final Prediction Error (FPE) favored a lag of 2, the Hannan-Quinn (HQ) and Schwarz Criterion (SC) suggested a more parsimonious model with lag 1. Given the trade-off between model complexity and efficiency, and to avoid overfitting with limited observations, the study proceeded with a VAR(1) model (Supplementary Table S4).

3.2.5 Estimation of VAR(1) model

The results of the VAR model highlight how changes in shrimp production impact on the overall export quantity. This analysis is conducted through impulse response analysis and variance decomposition, offering deeper insights beyond simply examining R^2 statistics and VAR model coefficients. Consequently, the percentage influence of each endogenous variable can be calculated using the estimated VAR, aiding in the interpretation of the relationships between the variables (Supplementary Table S5).

3.2.6 Model diagnostic tests

This study performed diagnostic tests for serial correlation, heteroscedasticity, and stability to make sure the VAR model was reliable (Table 1). The appropriate model specification is confirmed by

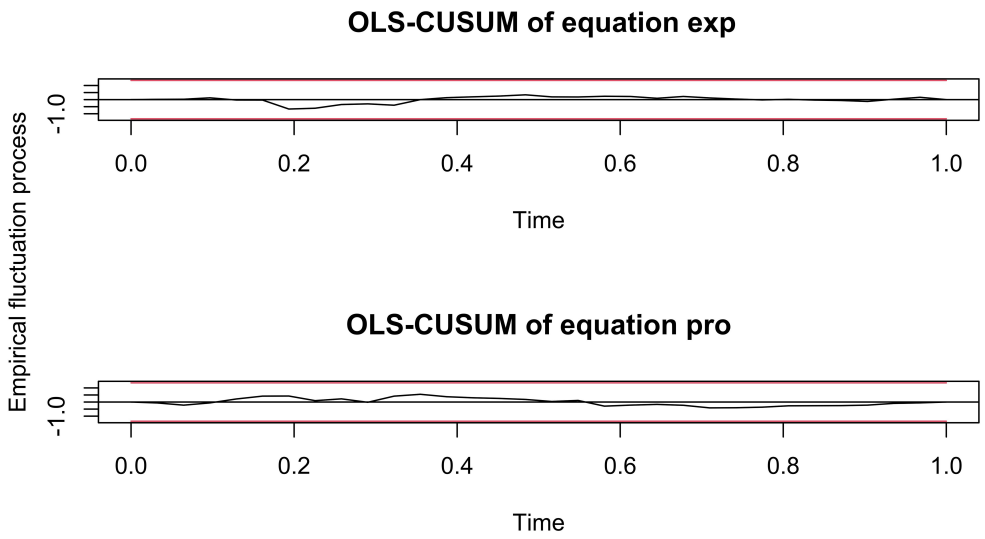

FIGURE 3
The Ordinary Least Square Cumulative Sum (OLS-CUSUM) test; *exp* denotes the total shrimp export quantity, and *pro* denotes the total shrimp production.

TABLE 1 Model diagnostic test results.

Test	Statistic	p-value	Interpretation
Portmanteau Test (Serial Correlation)	Chi-squared=36.39	0.79	No significant serial correlation in residuals (model is well-specified).
Multivariate ARCH Test (Heteroscedasticity)	Chi-squared=57	1.00	No significant heteroscedasticity (residual variance is stable).
Roots (Stability Test)	0.36, 0.36	–	All roots < 1, confirming model stability.

the Portmanteau test, which shows no serial correlation (Chi-squared = 36.39, p = 0.79). Stable variance is ensured by the ARCH (Multivariate) test, which indicates no heteroscedasticity (Chi-squared = 57, p = 1.00). The stability of the model is confirmed by the stability test, which reveals that all roots (0.3505) fall inside the unit circle. These findings support the robustness of VAR model for future studies.

3.2.7 Impulse response function

Evidence suggests a negative relationship between the quantity of shrimp exported and total production, as illustrated in (Figure 4a). As production increased, export quantities declined. Negative effects on total shrimp production were observed, reducing export quantities for up to three periods (Figures 4a, b). After the third period, the lag dependency intensified significantly and remained elevated for several periods. By the sixth period, the impact of the shock generally became positive. (Figure 4b) shows that the influence of export quantity on total shrimp production fluctuates until the fifth period, at which point the response turns positive, leading to long-term growth. Overall, the data suggest that

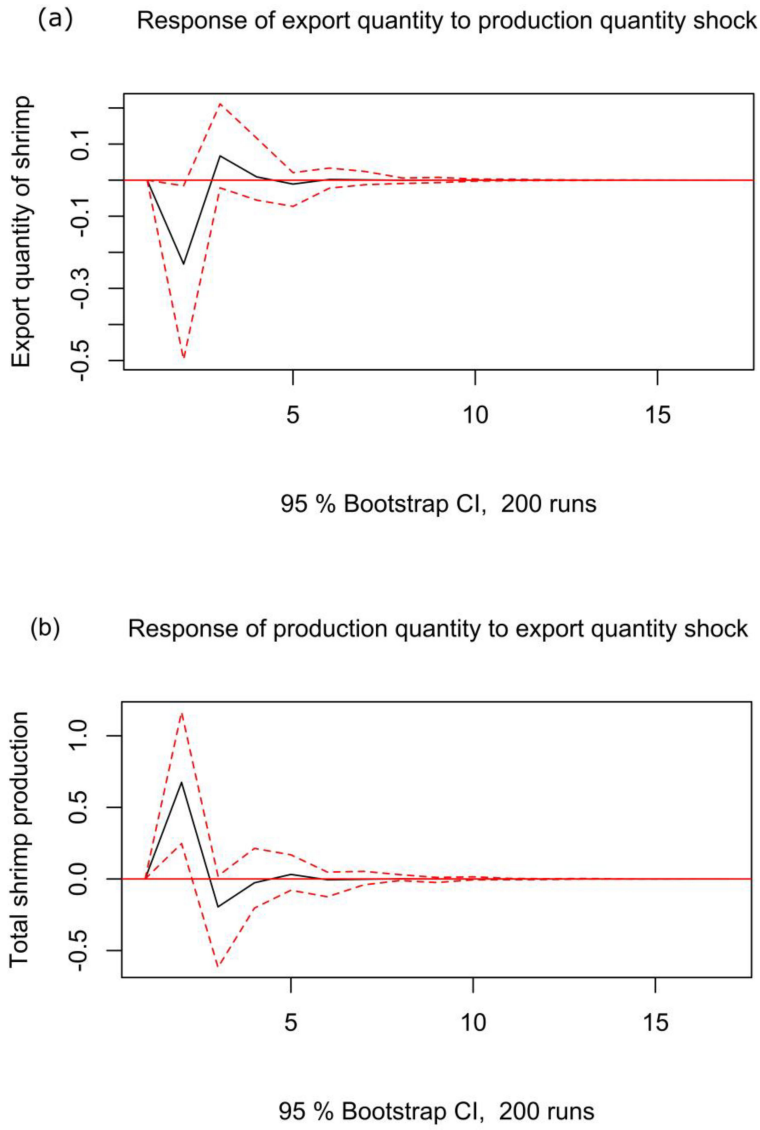

FIGURE 4
Impulse response function for two variables: **(a)** export quantity of shrimp response to total shrimp production shock; **(b)** total shrimp production response to export quantity of shrimp shock.

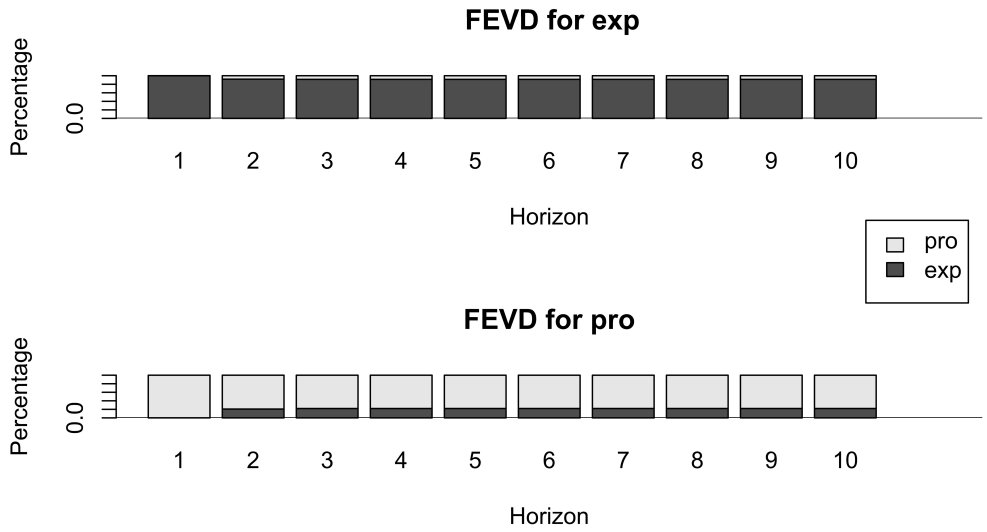

FIGURE 5
Forecast error variance decomposition of production and export quantity of shrimp in Bangladesh; *exp* denotes the total shrimp export quantity, and *pro* denotes the total shrimp production.

total shrimp production in Bangladesh tends to decrease export quantities over the long term.

3.2.8 Variance decomposition analysis

The variance decomposition highlights the extent to which each variable explains the dynamics of others within the autoregressive framework. Analyzing the influence of shrimp production on shrimp export quantity (Figure 5) reveals that at t=1 in the variance decomposition, shrimp export quantity predominantly influenced itself. However, by t=2, the contribution of total shrimp production to variations in shrimp export quantity became notable, accounting for approximately 20% of the observed changes. This influence gradually increased, with minor fluctuations, and peaked at around 40% between t=4 to t=10. Concurrently, the contribution of shrimp export quantity itself rose steadily, reaching a maximum of about 30% at t=10. These findings underscore the significant role of total shrimp production in driving changes in shrimp export quantity, highlighting its stronger influence over time.

3.2.9 Forecasting

The VAR(1) model forecast indicates that total shrimp production in Bangladesh is projected to fall from 234,344 MT in 2023–24 to 201,530 MT by 2026–27 (Figure 6; Supplementary Table S6). While the forecast for total shrimp production shows a consistent downward trend, the export quantity of shrimp follows a similar pattern. Over the four-year forecast period, the export quantity declines and the lowest projected export quantity, 16,618 MT, is expected in 2026–27, one-third the volume exported during the 2010–11 Fiscal Year (FY) (Supplementary Table S6). These results suggest that both shrimp production and export quantity are anticipated to decline. This indicates that production cannot increase in a linear manner without the support of export earnings, which are crucial for sustaining and expanding the industry. Therefore, adopting good aquaculture practices, ensuring traceability, obtaining eco-labels and organic certifications, and meeting buyer-country requirements are critical for boosting shrimp exports from Bangladesh.

3.3 Bottlenecks in producing quality shrimp to meet export compliance

The detection of antimicrobials and other hazardous residues in exported shrimp from Bangladesh led the EU to impose a trade ban. In response, the Fish Inspection and Quality Control Laboratory under the DoF began testing shrimp samples for antimicrobial agents to prevent the export of non-compliant products. For instance, tests on shrimp samples revealed residues from 15 banned antibiotics, including Nitrofuran and Chloramphenicol in exportable shrimp (Table 2). The VAR(1) model showed a decline in shrimp export quantities despite increased production, consistent with current trends (Section 3.2). The results from antimicrobial residue tests further supported the findings of the model, explaining why over 80% of the country's shrimp production remains unexportable. Further investigation is needed to determine how contamination occurs at various stages of the supply chain, including shrimp ponds, processing facilities, and deposits found in shrimp samples.

Shrimp farming in Bangladesh faces multifaceted challenges, including contamination, disease, and poor management practices. Antibiotic residues such as chloramphenicol, nitrofurans, and tetracyclines were detected in shrimp feed, water, and muscle, largely due to indiscriminate and unregulated use for disease prevention without proper diagnostics. Heavy metals like mercury, cadmium, and lead were found in shrimp samples, often

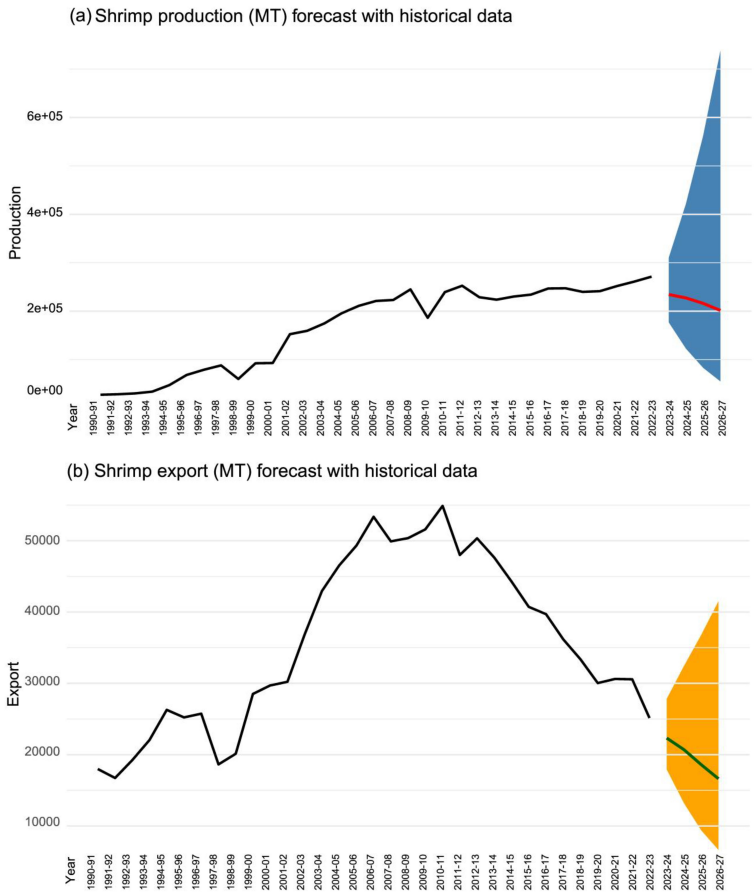

FIGURE 6
The forecasting of **(a)** production and **(b)** export quantity of shrimp in Bangladesh.

exceeding international safety limits, while polycyclic aromatic hydrocarbons and microplastics were also identified, raising significant food safety concerns. Pathogenic microbial contamination, including drug-resistant *Vibrio* spp., *E. coli*, and *Salmonella* spp., was prevalent in shrimp and export-quality samples, attributed to poor processing and transport conditions (Supplementary Table S7). Diseases such as white spot syndrome and red body disease severely impacted shrimp yields and farm profitability, compounded by inadequate hatchery compliance and quality control practices. Additionally, a 454% increase in chemical treatments was observed, highlighting mismanagement and the need for sustainable farming practices (Supplementary Table S7). These issues underscore the urgent need for better regulatory oversight, farmer education and training, and compliance with international quality standards to ensure the sustainability and safety of the shrimp industry.

TABLE 2 Number of shrimp samples testing positive for antimicrobial contamination by the DoF, Bangladesh, in 2016 (Adapted from Heal et al., 2021).

Substance	Number of positive shrimp samples
Antimicrobials	**26**
Antibiotics	**15**
Nitrofurans	13
Chloramphenicol	2
Nitroimidazoles	0
Antimicrobial dyes	**11**
Crystal violet derivatives	6
Malachite green derivatives	5

Bold values indicate the sum of the values in the subcategories beneath them.

3.4 Legislation related to quality shrimp production and export compliance

3.4.1 Evolution of policies governing shrimp production and export compliance

The Bangladesh shrimp industry has undergone several policy phases, beginning from colonial rule, followed by post-partition regulations, and later through various reforms after independence. The Private Fisheries Protection Act 1899, enacted during British rule, empowered landowners to refuse shrimp farming, a provision that later conflicted with Bangladesh's shrimp zone policies (Quassem et al., 2003). After partition British India in 1947, and

independence of Bangladesh in 1971, shrimp emerged as a key economic sector, promoting the Shrimp Mohal Management Policy 1992, which designated shrimp estates but also created land tenure uncertainties that discouraged investment.

Subsequent measures, including the Shrimp Cultivation Taxation Act 1992, and National Fisheries Policy 1998, introduced tax incentives to stimulate production. However, these policies led to overcapacity, with processing plants operating at only 20% of their capacity, with limited support for small-scale shrimp farmers (Quassem et al., 2003). Attempts to improve shrimp quality resulted in the Fish Hatchery Act 2010, and Fish Quarantine Act 2018, yet weak enforcement led to disease outbreaks and export rejections. Further reforms, such as National Shrimp Policy 2014, and Industrial Policy 2022, aimed to ensure compliance with Hazard Analysis and Critical Control Point (HACCP) and WTO standards but lacked robust enforcement mechanisms. Additionally, the existing framework the Fish and Fish Products (Inspection and Quality Control) Ordinance 1983, and BSTI Act 2003, set quality standards but had inadequate sampling criteria, weak traceability, and poor alignment with the Pure Food Rules 1967. The Export Promotion Bureau Ordinance of 1977 does not provide accreditation for private testing laboratories, and the Export Policy (2018–21) lacks strategies for branding indigenous shrimp.

Despite a shift toward modern trade and sustainability-focused policies, persistent gaps in coordination, enforcement, and alignment with global standards undermine shrimp export competitiveness of Bangladesh. These challenges are rooted in policy failures that prioritize financial incentives over sustainable development. While hatcheries and processors receive substantial subsidies, critical areas like farm production, post-harvest care, and marketing remain underfunded. Overcapacity in processing plants has saturated the market, disadvantaging early investors. Generous tax incentives, including holidays (5–7 years), reduced income tax (0.25%), duty exemptions, and subsidized land leases, have fostered inefficiencies rather than resilience. Furthermore, high-interest loans (9–11%) support businesses but do little to improve traceability or value addition. Going forward, policy reforms must focus on enhancing post-harvest infrastructure, ensuring better resource allocation, and promoting long-term sustainability and competitiveness (DoF, 2006).

3.4.2 Regulatory gaps and implementation challenges in shrimp farming policies

The regulatory framework for shrimp farming in Bangladesh encompasses various policies addressing production, financial incentives, food safety, export, environmental compliance, and social justice. Policies such as the Shrimp Mohal Management Policy 1992, National Fisheries Policy 1998, and National Land Use Policy 2001 aim to promote shrimp production and land zoning for aquaculture. However, conflicting provisions, such as those between the Shrimp Mohal Policy and the Private Fisheries Protection Act 1899, highlight the need for amendments to ensure compliance with international standards like the FAO Code of Conduct for Responsible Fisheries. Similarly, the Fish Hatchery Act, 2010 mandates disease-free broodstock production but faces challenges due to insufficient quarantine infrastructure, enabling the entry of untested broodstock into the market. Gaps in enforcement and operational inefficiencies, such as the inactive *Central Shrimp Cell*, further hinder the effective implementation of these policies (Supplementary Table S8).

In terms of fiscal measures and food safety, policies like the Shrimp Cultivation Taxation Act, 1992, Pure Food Ordinance 1959, and Fish and Fish Products Inspection Ordinance 1983 provide guidelines for taxation, quality control, and export incentives. However, these policies lack alignment with global standards like HACCP and Codex, and their implementation is hampered by weak coordination among regulatory bodies. The National Shrimp Policy 2014, while promoting sustainable shrimp farming, offers vague strategies for financial incentives and climate resilience measures. In the export and environmental sectors, initiatives such as the Export Policy (2018–21) and National Environmental Policy 1992 have struggled with poor operationalization, including a non-functional *Fish Bank* and irregular monitoring of environmental compliance (Supplementary Table S8). Social justice issues, including inadequate workplace hygiene for women in processing plants and limited enforcement of child labor policies, further underscore the gaps in implementation and inter-agency coordination across the shrimp value chain.

3.4.3 Policy lessons from Vietnam and India

For actionable policy recommendations and strategic development, this study examines the policies and initiatives of Vietnam and India, two leading shrimp exporters and developing nations. Vietnam has successfully developed a structured aquaculture governance framework that has strengthened its shrimp export industry. Key initiatives include the addition of the German-based Naturland organic shrimp certification (Jonell and Henriksson, 2015), the Vietnamese Cooperative Law and farmer cluster management (Ha and Bush, 2010), and National Program for Aquaculture Development (1999–2010), which set an ambitious compliance target of 100% by processing companies, and 50% by the farmers with FAO Code of Conduct standards. The country has also introduced Codes of Practice (COP), Good Aquaculture Practices (GAP), and Best Management Practices (BMP) to improve food safety, disease control, and traceability (Tran et al., 2013; Anh et al., 2011). Additionally, species diversification, particularly the introduction of Vannamei shrimp alongside black tiger shrimp, has further strengthened its global competitiveness (Lebel et al., 2010). Vietnam has also invested in human resource development, increasing the number of aquaculture training institutes from three in 1975 to nineteen in 2018, mainly in the Mekong River Delta, with diversified programs to meet industry demands (Tu et al., 2019).

India, meanwhile, has emerged as the largest shrimp exporter among developing nations by leveraging competitive pricing policies (Singh et al., 2022) and benefiting from lower anti-dumping duties in the US market (Krishnan and Babu, 2022). The country has significantly improved traceability and biosecurity, ensuring compliance with international trade standards. A key factor in success of India has been the establishment of domestic

SPF shrimp broodstock production, which is now managed by the *Rajiv Gandhi Centre for Aquaculture*, with further expansion planned to enhance broodstock availability (Rubel et al., 2021).

In contrast, Bangladesh faces challenges due to the absence of a centralized quality control system, weak enforcement mechanisms, limited farmer training, and poor value chain coordination. To enhance its export competitiveness, Bangladesh can adopt lessons from Vietnam and India by implementing a centralized quality control policy, promoting species diversification, strengthening cooperatives, expanding farmer training programs, and improving biosecurity and traceability measures. These strategic improvements would facilitate greater compliance with international standards and boost the position of Bangladesh in the global shrimp market.

4 Discussion

This study developed a VAR (1) model to forecast shrimp production and export quantities in Bangladesh, revealing an upward trend in production over the next five years, contrasted with a decline in export volumes. This contrasting scenario arises from several factors influencing domestic production and international market dynamics. The favorable ecological conditions of Bangladesh, including an extensive coastal line in the southeast and southwest, a suitable climate, and ample freshwater resources, have been instrumental in boosting shrimp production (Alam and Ahammad, 2017). Additionally, the government recognizes the sector's potential and has implemented various supportive measures to drive its growth (Spreij, 2023). These measures include investments in infrastructure, initiatives for research and development, and financial assistance and incentives to empower shrimp farmers.

Over the years, shrimp farming in Bangladesh has advanced significantly with the adoption of improved farming practices, enhanced pond management techniques, and the integration of modern technologies (Islam, 2012; Islam and Wahab, 2005). These innovations have boosted productivity and operational efficiency in the sector. Simultaneously, the economic growth of Bangladesh has contributed to the emergence of a growing middle class with greater purchasing power (Hashim, 2015). This economic shift has driven substantial domestic demand for shrimp, particularly in urban areas. Consequently, local shrimp markets have expanded at the district and divisional levels, with consumers increasingly incorporating prawn and shrimp into their diet (Hossain et al., 2024). This rising demand offers profitable opportunities for local shrimp farmers, further strengthening the domestic shrimp industry.

Shrimp exports have gradually declined in recent years. According to the VAR (1) model used in this study, shrimp exports are projected to decrease to 16,618 MT in the FY 2026–27, which is less than one-third of the 54,891 MT exported in FY 2010–11 (DoF, 2012). Similarly, the export earnings from frozen food products, primarily shrimp and prawn, have also dropped significantly. While these exports generated over US$598 million in FY 2011–12, the value fell to US$328 million in FY 2020–21, marking a 45% decline over the decade (DoF, 2021; BFFEA, 2021). Besides, the failure to maintain consistent quality control led to periodic export bans from the EU and USA, resulting in an estimated US$35 million in lost revenue between 2008 and 2012. Additionally, compliance with GAPs and HACCP increased production costs by 15–20%, reducing profitability for small-scale farmers. By 1997, the shrimp industry had invested US$17.6 million in upgradation, while the government allocated US$382,000 for labs and personnel development, and partners contributed US$72,000 for training. However, these efforts were insufficient to prevent the EU ban, which led to a US$15 million loss over five months. Maintaining HACCP compliance further imposes an annual cost of US$2.2million on the industry and US$225,000 on the government (Cato and Subasinge, 2003).

To address these challenges and enhance export competitiveness, strategic interventions are needed. Enhancing farmer training, implementing certified farming practices, adopting advanced technology, strengthening the supply chain, and ensuring compliance with international standards could drive substantial growth in Bangladesh's shrimp industry. By integrating intensive shrimp cultivation with strict adherence to quality and safety regulations, the industry can enhance its market acceptance and revenue potential. If production reaches 8,000–10,000 Kg/ha, similar to India, while meeting global compliance requirements, exports could exceed US$1 billion annually, up from the current US$330 million, contributing significantly to Bangladesh's GDP. This expansion would help reclaim lost market shares in the EU and US, potentially boosting GDP by 0.5%–1%. Furthermore, developing shrimp-based economic zones and improving infrastructure would generate thousands of jobs, reinforcing the agriculture and aquaculture sectors and fostering long-term sustainability.

Several factors have contributed to the decline in shrimp exports from Bangladesh. One major challenge is the vulnerability of Bangladesh's shrimp farming to disease outbreaks, such as Early Mortality Syndrome and White Spot Syndrome Virus (Hasan et al., 2020; Heal et al., 2021). Despite efforts to manage these outbreaks and sustain production levels, maintaining the quality of shrimp production remains a significant issue. As a result, despite increasing production volumes, export quantities declined. Historically, Bangladesh experienced consistent growth in shrimp exports, with some notable exceptions, such as a decline in 1998–99 due to a European Union (EU) embargo for non-compliance with HACCP regulations (Rahman, 2001; Yunus, 2009). Between 2005 and 2009, approximately 100 shipments of frozen prawn products were rejected by the EU, leading to a loss of over US$500 million in foreign currency earnings (Sarkar et al., 2018). This crisis was triggered by the detection of 'Nitrofuran' in exported shrimp products, causing significant financial setbacks for Bangladesh (Barua, 2010).

Buyer countries require that shrimp products meet three essential criteria: they must be safe and healthy for consumers, produced in an environmentally sustainable manner, and adhere to social equity standards throughout production and processing. These criteria are grounded in international laws and regulations, which must be satisfied before export. For the European Union (EU) market, shrimp exports must comply with several regulations,

including the General Food Law (EC 178/2002), Procedures for Official Control (EC 882/2004), General Hygiene Rules for all Food Products (EC 852/2004), Specific Hygiene Rules for Food Products of Animal Origin (EC 853/2004), and Controls of Products of Animal Origin (EC 854/2004) (CBI, 2007).

Additionally, food safety regulations under HACCP are detailed in Articles 5 and 6 of Regulation (EC) No 852/2004. In the United States, shrimp import requirements are governed by the Code of Federal Regulations, specifically Fish and Fishery Products (21 CFR Part 123) and Current Good Manufacturing Practices (21 CFR Part 110). Compliance requires maintaining stringent quality standards, mitigating contamination risks (Section 3.3), and ensuring proper infrastructure and operational practices through effective policy implementation (Section 3.4). The decline in shrimp exports since 2012 is primarily driven by export-related safety and quality concerns rather than rising domestic demand (DoF, 2022). Of the 129 processing plants operating in Bangladesh, only 53 are approved for export to the EU, reflecting the challenges in meeting international food safety and quality standards (United Nations Conference on Trade and Development, 2017). While domestic demand has been growing, driven by an expanding urban middle class and the rise of restaurants in major cities, this increase has not significantly impacted export trends. Instead, the primary reasons for declining exports are low-quality shrimp production in ponds and processing plants, along with the inability to meet international safety standards at competitive prices.

International markets impose stringent quality and safety standards on seafood products, requiring exporting countries to comply with phytosanitary and sanitary measures to ensure food safety and prevent the spread of diseases (Dhar et al., 2021). Non-compliance with these standards has led to restrictions or bans on shrimp exports (Yunus, 2009). Bangladesh has faced ongoing challenges in consistently meeting these requirements, leading to a decline in export demand (Rahman, 2001; Sarkar et al., 2018). In recent years, the seafood industry has witnessed significant investment and development in alternative seafood products (GFI, 2021). The global seafood market is increasingly shifting toward plant-based and lab-grown seafood, driven by concerns of overfishing, environmental sustainability, and ethical sourcing (Marwaha et al., 2022). Major markets, including the US, EU, and Japan, now prioritize sustainable and certified seafood, such as Aquaculture Stewardship Council (ASC), Marine Stewardship Council (MSC), and organic-labeled shrimp. This trend has further impacted Bangladesh's shrimp exports, as competing nations like India and Vietnam have rapidly adopted eco-certifications and digital traceability systems, making their products more attractive to international buyers. Moreover, sustainability and environmental impact have become critical concerns for international markets (Afroz and Alam, 2013). Compliance with sustainable practices, such as responsible aquaculture, certification schemes, and traceability, is increasingly essential for securing access to global markets (Anh et al., 2011; Tran et al., 2013; Haque et al., 2021). To enhance its position, Bangladesh must focus on innovations in production and processing to add value to its exports and capture a larger market share (Ferdous and Hossain, 2015). Investments in improving the safety and quality of shrimp exports are also necessary to avoid detention and rejection at foreign markets due to stringent import requirements (Akter, 2017). Ensuring high-quality exports is pivotal for Bangladesh to strengthen its standing in the global shrimp market. Bangladesh faces stiff competition from shrimp-producing nations like Vietnam, Thailand, and India, which have established strong global market presences with competitive pricing and superior quality control (Akter, 2017; Boyd et al., 2021; Karim, 2003). The Vannamei shrimp has become increasingly popular in the global market due to its rapid growth rate, high productivity, lower cost, and strong demand (Jamal, 2023). The rise of Vannamei shrimp poses a challenge to the demand for Bangladeshi black tiger shrimp, potentially impacting export competitiveness (Rahman and Hossain, 2009). The shrimp industry in Bangladesh is further complicated by environmental degradation, pollution, the irresponsible use of antibiotics, overextraction of groundwater resources (Paul and Vogl, 2011), a shortage of skilled labor, inadequate export policies, limited access to affordable high-quality seed, domestic instability, and fierce global competition (Rahman and Hossain, 2009). Addressing these multifaceted challenges is crucial for the sustainable growth of Bangladesh's shrimp industry.

The export policies of the Bangladesh government (e.g., 2003–06 and 2007–11) were designed to strengthen institutional capacity, harness information technology, promote value addition, diversify products, develop a skilled workforce, support new exporters, and increase awareness of international trade systems among stakeholders. These policies introduced various incentives to support the exporters (Akter, 2017) and attempt to align with evolving global trade trends. However, to effectively expand shrimp exports, these policies must prioritize the identification and operationalization of new buyer countries. Developed nations, while offering lucrative markets, often impose stringent food safety and quality regulations that make market entry challenging for Bangladeshi exporters.

In contrast, China, despite being a developing nation, offers a more accessible market with relatively less rigid import regulations. This makes it a strategic destination for Bangladesh to diversify its shrimp exports. In 2022, China granted 99% duty-free access to Bangladeshi products. However, rather than increasing, exports to China declined from US$715 million in FY21 to US$677 million in FY23 (EPB, 2024). This indicates that market access alone is insufficient without parallel improvements in infrastructure, production and compliance.

From December 2024, Bangladesh has started to receive 100% duty-free access to the Chinese market, a development expected to significantly boost shrimp exports, especially for high-value black tiger shrimp. This opportunity was further strengthened by Bangladesh receiving heritage certification in 2022 (Seafood Network, 2024). China's shrimp imports surged by 51.6% to 661,822 MT in 2022, making it the second-largest importer globally from 2019 to 2022, behind only the US markets. The import value surged from $1.81 billion in 2018 to US$6.29 billion in

2022, underscoring China's strong growing demand (N'Souvi et al., 2024). Bangladesh has potential to capitalize on this demand by aligning production with Chinese market requirements, following Vietnam's successful model.

To enhance its export capacity, Bangladesh can leverage Chinese-funded modernization projects, including Special Economic Zones (SEZs) in Chattogram and infrastructure support from China Eximbank's for processing plants (TBS Report, 2025). These developments, combined with full duty-free access, position Bangladesh to significantly expand shrimp exports and strengthen bilateral trade ties with China. To fully utilize these opportunities, Bangladesh must also comply with China's import regulations, such as those from the General Administration of Customs of China (GACC) and the Certification and Accreditation Administration of China (CNCA) standards (N'Souvi et al., 2024). Moreover, adopting standardized grading systems and targeted certification schemes can enhance product quality and market competitiveness. Consistent quality grading can foster buyer confidence and facilitates access to both stringent markets like the EU and US, and more accessible markets like China. Certifications aligned with global import market standards, such as HACCP, GMP, BRCGS, ASC Farm, and Chain of Custody strengthen compliance with food safety, traceability, and sustainability norms, as demonstrated by ACI Agrolink Limited in Bangladesh (Amian Shrimp, 2025). However, successful implementation of such standards requires coordinated efforts among producers, processors, regulatory bodies, and certifiers. Notably, a FAO-led initiative that clustered small-scale shrimp farmers to promote Good Aquaculture Practices (GAPs) and traceability improved both yields and income (van der Pijl, 2014). Establishing standardized systems not only improves product quality but also helps mitigate trade barriers, such as those posed by EU-imposed sanitary and phytosanitary measures thus enhancing global competitiveness of Bangladesh.

Shrimp farming was expected to expand in coastal regions through improved technology under the National Fisheries Policy 1998. This policy emphasized zoning coastal areas for shrimp cultivation, enhancing extensive farming methods, advancing appropriate technologies, integrating shrimp and rice cultivation, ensuring the quality of feed production, and improving post-harvest shrimp handling practices. Additionally, it prioritized establishing commercial shrimp hatcheries through private initiatives and expanding Quality Control Laboratories (Sections 8.2, 8.4–8.8, 8.10–8.13, 8.17–8.23). The policy also recommended a moratorium period to conserve brood shrimp and enhance production. Further measures included technological improvements, strengthened quality control methods, advancements in post-harvest technologies, and maintaining hygienic standards, particularly for the export market (Sections 8.3, 8.9, and 8.14–8.16). Over the years, the Bangladesh government has introduced various acts, laws, rules, policies, and regulations to manage and conserve fisheries resources. However, only a limited number of them have been partially implemented, making it challenging to regulate the utilization of aquatic resources effectively and protect diversity of fish species (Rahman et al., 2018). One notable example is the National Shrimp Policy 2014, which primarily aimed to promote aquaculture expansion but did not place sufficient emphasis on environmental sustainability. While significant research has been conducted on finfish and shellfish aquaculture, focusing on production techniques, species combination, and technological advancements (Haque, 2007; Little et al., 2007; Haque et al., 2014; Bremer et al., 2016; Alam et al., 2019; Haque et al., 2021; Hoque et al., 2021; Shohan et al., 2024), there remains a noticeable gap in policy-related studies. In particular, research on policy implementation, effectiveness, and overall impact on the aquaculture sector is limited. This gap hinders the development of evidence-based policies that could enhance sustainability, improve regulatory frameworks, and address industry challenges. To address these issues, relevant institutions should prioritize and allocate funding for policy research, enabling a deeper understanding of the aquaculture sector's needs and facilitating the formulation of well-informed strategies for long-term growth and sustainability.

5 Conclusion

The shrimp industry in Bangladesh has experienced significant growth in production over the years, but export quantities have declined due to issues related to quality compliance, environmental sustainability, and policy implementation. Despite several laws, policies, and regulations introduced by the government, effective enforcement remains limited, which has hindered the sector's growth. The findings from the VAR(1) model and the analysis of shrimp farming practices and legislation highlight the need for a more balanced approach to policy, with greater attention to quality control, sustainable farming practices, and enhanced support for smallholder farmers. The study emphasizes that improving production quality and ensuring compliance with international standards are key factors for enhancing competitiveness of Bangladesh in the global shrimp market. Based on the findings of the VAR(1) model, responsible shrimp farming analysis (Table 2; Supplementary Table S7), and legislation review (Supplementary Table S8), this study presents the following recommendations.

- The Government of Bangladesh's fiscal and financial support programs currently prioritize hatcheries and processors, leading to an imbalance. To address this, registered shrimp farmers should be incentivized to adopt organic semi-intensive farming practices, aiming to produce high-quality shrimp and achieve eco-labeling and certification.
- Over the years, processors have expanded their capacity due to volume-based incentives. This study recommends revising these incentives and reallocating subsidies to support the development of domestic specific pathogen-free (SPF) black tiger shrimp and other potential shrimp species. This will ensure a greater supply of SPF post-larvae (PL) for the farmers to intensify their farming practices.
- Licensing for ghers (local Bengali terms meaning shrimp farms) should be systematically implemented for smallholders, who dominate the sector. Although gher

licensing was initiated in 1998, it has not been effectively extended to all farmers.

- Since most shrimp farms are small-scale, export-oriented shrimp products undergo aggregation at various stages before reaching processing plants, increasing the risk of microbial contamination and post-harvest spoilage. The DoF should establish a 'One-Stop Post-Harvest Logistics Service, with a certified agency responsible for harvesting, post-harvest handling, sufficient icing, and transportation using refrigerated vehicles.
- A comprehensive database and interactive map-based information system should be developed to include data on land utilization, zoning, drainage systems, disease viability, antibiotic use, treatment dosages, mortality rates, and access to SPF fry.
- Advanced technologies such as GIS, remote sensing (Bayot et al., 2008; Rajitha et al., 2007), machine learning algorithms (Saleetid and Green, 2019), and the Internet of Things (Blancaflor and Baccay, 2022) should be employed for sustainable management and early disease surveillance of the shrimp farms, following best practices from India, Thailand, and Ecuador.
- The GoB should incentivize the establishment of accredited private laboratories at regional levels for PCR and residue testing to ensure quality compliance. Although a private laboratory was set up in Khulna, its services have not been expanded (Alam et al., 2021).
- A National Shrimp Marketing Policy should be implemented to standardize quality production and food safety, with clear limits for compliance. Moreover, a targeted marketing strategy for black tiger shrimp should focus on price, production costs, and global competitiveness.
- Policymakers can draw lessons from Vietnam and India by adopting actionable strategies such as implementing a centralized quality control system, promoting species diversification, strengthening cooperatives, expanding farmer training programs, and enhancing biosecurity and traceability measures. These strategic improvements would help ensure greater compliance with international standards and strengthen the position of Bangladesh in the global shrimp market.

The limitations of this study include the lack of focus on the global shrimp export landscape and the omission of variables like GDP, trade prices, and processing costs, which could have enhanced the analysis. Furthermore, existing literature lacks projections for shrimp production and exports using multivariate time series modeling. The study finds that while shrimp production has increased, export quantities have declined, challenging the assumption that higher production leads to higher exports. Export quantities are influenced by factors such as quality, policy implementation, and law enforcement.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: The data will be made available upon request. Requests to access these datasets should be directed to Mobin Hossain Shohan, Department of Aquaculture, Bangladesh Agricultural University, Mymensingh, Email: shohan.1706097@bau.edu.bd.

Author contributions

MMH: Resources, Supervision, Validation, Writing – review & editing. MHS: Conceptualization, Formal analysis, Investigation, Methodology, Software, Writing – original draft.

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References

Afroz, T., and Alam, S. (2013). Sustainable shrimp farming in Bangladesh: A quest for an Integrated Coastal Zone Management. *Ocean Coastal Manage.* 71, 275–283. doi: 10.1016/j.ocecoaman.2012.10.006

Akaike, H. (1969). Fitting autoregressive models for prediction. *Ann. institute Stat. Mathematics* 21, 243–247. doi: 10.1007/BF02532251

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Trans. Automatic Control* 19, 716–723. doi: 10.1109/TAC.1974.1100705

Akter, F. (2017). The export trend of shrimp industries in Bangladesh: an analysis. *Sci. Res. J.* 5, 80–95.

Alam, S., and Ahammad, S. U. (2017). Shrimp aquaculture in Bangladesh: Domestic regulatory responses and compliance with MEAs. *Marine Policy* 82, 122–133. doi: 10.1016/j.marpol.2017.04.018

Alam, M. M., Haque, M. M., Aziz, S. B., and Mondol, M. M. R. (2019). Development of pangasius–carp polyculture in Bangladesh: Understanding farm characteristics by, and association between, socio-economic and biological variables. *Aquaculture* 505, 431–440. doi: 10.1016/j.aquaculture.2019.02.076

Alam, M., Islam, M., and Bhuiyan, M. K. (2021). *Project completion report on 'Establish Aquatic Animal Disease Diagnostic Laboratory Project'* Project Completion Report, WorldFish, Penang, Malaysia. pp 53. Available at: https://hdl.handle.net/20.500.12348/5626.

Ali, E. M., Elahi, E., Shahriar, S., and Rana, M. S. (2024). Does government intervention promote export competitiveness? An empirical case study of Bangladesh seafood exports. *Aquaculture Economics Manage.*, 1–21. doi: 10.1080/13657305.2024.2387705

Amian Shrimp (2025). *Certifications & Membership*. Available online at: https://www.amianshrimp.com/certifications-membership/ (Accessed 05 April 2025).

Anderson, J. L., Asche, F., and Garlock, T. (2018). Globalization and commoditization: The transformation of the seafood market. *J. Commodity Markets* 12, 2–8. doi: 10.1016/j.jcomm.2017.12.004

Anh, P. T., Bush, S. R., Mol, A. P., and Kroeze, C. (2011). The multi-level environmental governance of Vietnamese aquaculture: global certification, national standards, local cooperatives. *J. Environ. Policy Plann.* 13, 373–397. doi: 10.1080/1523908X.2011.633701

Azad, A. K., Jensen, K. R., and Lin, C. K. (2009). Coastal aquaculture development in Bangladesh: Unsustainable and Sustainable Experiences. *Environ. Manage.* 44, 800–809. doi: 10.1007/s00267-009-9356-y

Barua, P. (2010). Nitrofuran: Pull the trigger to safeguard the national interest. *Aquanet* 1, 35-37.

Bayot, B., Sonnenholzner, S., Ochoa, X., Guerrerro, J., Vera, T., Calderón, J., et al. (2008). An online operational alert system for the early detection of shrimp epidemics at the regional level based on real-time production. *Aquaculture* 277, 164–173. doi: 10.1016/j.aquaculture.2008.02.035

BFFEA (2021). *Annual report 2020* (Dhaka, Bangladesh: Bangladesh Frozen Foods Exporters Association). Available at: https://www.bffea.net/export.php.

Blancaflor, E. B., and Baccay, M. (2022). Assessment of an automated IoT-biofloc water quality management system in the *Litopenaeus vannamei*'s mortality and growth rate. *Automatika: J. Control Measurement Electronics Computing Commun.* 63, 259–274. doi: 10.1080/00051144.2022.2031540

Boyd, C. E., Davis, R. P., and McNevin, A. A. (2021). Comparison of resource use for farmed shrimp in Ecuador, India, Indonesia, Thailand, and Vietnam. *Aquaculture Fish Fisheries* 1, 3–15. doi: 10.1002/aff2.23

Bremer, S., Haque, M. M., Haugen, A. S., and Kaiser, M. (2016). Inclusive governance of aquaculture value-chains: Co-producing sustainability standards for Bangladeshi shrimp and prawns. *Ocean Coastal Manage.* 131, 13–24. doi: 10.1016/j.ocecoaman.2016.07.009

Bush, S. R., Belton, B., Little, D. C., and Islam, M. S. (2019). Emerging trends in aquaculture value chain research. *Aquaculture* 498, 428–434. doi: 10.1016/j.aquaculture.2018.08.077

Cato, J. C., and Subasinge, S. (2003). Case study – the shrimp export industry in Bangladesh: food safety in food security and food trade. 2020 Vision Focus Brief. Available online at: https://hdl.handle.net/10568/157332.

CBI (2007). *Centre for the promotion of imports from developing countries* (EU Legislation- Fish and Aquaculture Product). Available at: http://www.cbi.eu/?pag=84&doc=4351 (Accessed June 12, 2024).

de Abreu, M. C. S., de Mattos, P., Lima, P. E. S., and Padula, A. D. (2011). Shrimp farming in coastal Brazil: Reasons for market failure and sustainability challenges. *Ocean Coastal Manage.* 54, 658–667. doi: 10.1016/j.ocecoaman.2011

Dhar, A. R., Uddin, M. T., and Nielsen, M. (2021). Enhancing export potential of Pangasius and Tilapia through quality assurance and safety compliances: Case study of processing plants and exporters in Bangladesh. *Aquaculture* 531, 735921. doi: 10.1016/j.aquaculture.2020.735921

Dickey, D. A., and Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *J. Am. Stat. Assoc.* 74, 427–431. doi: 10.1080/01621459.1979.10482531

DoF (2002). *Yearbook of fisheries statistics of Bangladesh 2001-02* Vol. 19 (Dhaka, Bangladesh: Fisheries Resources Survey System (FRSS), Department of Fisheries; Ministry of Fisheries and Livestock), 41p.

DoF (2006). *Shrimp Sub-Strategy*. Department of Fisheries, Matshya Bhaban, Ramna, Dhaka, Bangladesh. pp 52.

DoF (2012). *Yearbook of fisheries statistics of Bangladesh 2011-12* Vol. 29 (Dhaka, Bangladesh: Fisheries Resources Survey System (FRSS), Department of Fisheries; Ministry of Fisheries and Livestock), 44p.

DoF (2021). *Yearbook of fisheries statistics of Bangladesh 2020-21* Vol. 38 (Dhaka, Bangladesh: Fisheries Resources Survey System (FRSS), Department of Fisheries; Ministry of Fisheries and Livestock), 138p.

DoF (2022). *Yearbook of fisheries statistics of Bangladesh 2021-22* Vol. 39 (Dhaka, Bangladesh: Fisheries Resources Survey System (FRSS), Department of Fisheries; Ministry of Fisheries and Livestock), 139p.

DoF (2023). *Yearbook of fisheries statistics of Bangladesh 2022-23* Vol. 40 (Dhaka, Bangladesh: Fisheries Resources Survey System (FRSS), Department of Fisheries; Ministry of Fisheries and Livestock), 124p.

EPB (2024). *Annual report 2023-24, Export Promotion Bureau of Bangladesh* (Ministry of Commerce, Government of the People's Republic of Bangladesh), 65p. Available at: https://epb.gov.bd/site/view/annual_reports/Annual-Report.

FAO (2024). *FAO fisheries and aquaculture - fishStatJ - software for fishery and aquaculture statistical time series* (Rome, Italy: FAO). Available at: https://www.fao.org/fishery/en/topic/166235?lang=en (Accessed January 07, 2025).

Fathima, K. B., Biradar, R. S., and Shyam, S. S. (2006). Growth pattern and competitiveness of Indian shrimp export trade. *Fishery Technol.* 43 (1), 99–106. https://core.ac.uk/download/pdf/33019733.pdf.

Ferdous, S. R., and Hossain, S. D. (2015). Prospect and challenge of Bangladesh frozen food : A way to overcome. *Online Int. Interdiscip. Res. J.* 5, 7–23.

Fitriani,, Santosa, D. B., and Saputra, P. M. A. (2019). Analysis of determinants exports and spatial linkages: A case study of Indonesian Frozen and fresh shrimp. *Adv. Economics Business Manage. Res.* 98, 173–179. doi: 10.2991/icot-19.2019.37

GFI (2021). *Record $3.1 billion invested in alt proteins in 2020 signals growing market momentum* (Good Food Institute). Available at: https://gfi.org/blog/2020-state-of-the-industry-highlights/ (Accessed November 19, 2024).

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* 7, 424–438. doi: 10.2307/1912791

Ha, T. T. T., and Bush, S. R. (2010). Transformations of Vietnamese shrimp aquaculture policy: empirical evidence from the Mekong Delta. *Environ. Plann. C: Government Policy* 28, 1101–1119.

Hall, D. (2004). Explaining the diversity of Southeast Asian shrimp aquaculture. *J. Agrarian Change* 4, 315–335. doi: 10.1111/j.1471-0366.2004.00081.x

Hannan, E. J., and Quinn, B. G. (1979). The determination of the order of an autoregression. *J. R. Stat. Society: Ser. B (Methodological)* 41, 190–195.

Haque, M. M. (2007). *Decentralized fish seed networks in northwest Bangladesh: Impacts on rural livelihoods* (United Kingdom: Institute of Aquaculture, University of Stirling), 491.

Haque, M. M., Alam, M. M., Hoque, M. S., Hasan, N. A., Nielsen, M., Hossain, M. I., et al. (2021). Can Bangladeshi pangasius farmers comply with the requirements of aquaculture certification? *Aquaculture Rep.* 21, 100811. doi: 10.1016/j.aqrep.2021.100811

Haque, M. M., Little, D. C., Barman, B. K., Wahab, M. A., and Telfer, T. C. (2014). Impacts of decentralized fish fingerling production in irrigated rice fields in Northwest Bangladesh. *Aquaculture Res.* 45, 655–674. doi: 10.1111/are.12000

Hasan, N. A., Haque, M. M., Hinchliffe, S. J., and Guilder, J. (2020). A sequential assessment of WSD risk factors of shrimp farming in Bangladesh: Looking for a sustainable farming system. *Aquaculture* 526, 735348. doi: 10.1016/j.aquaculture.2020.735348

Hashim, S. M. (2015). *Bangladesh's growing middle class* (Dhaka, Bangladesh: The Daily Star). Available at: https://www.thedailystar.net/op-ed/politics/Bangladeshs-growing-middle-class-162670 (Accessed October 20, 2024).

Heal, R. D., Hasan, N. A., and Haque, M. M. (2021). Increasing disease burden and use of drugs and chemicals in Bangladesh shrimp aquaculture: A potential menace to human health. *Marine Pollution Bull.* 172, 112796. doi: 10.1016/j.marpolbul.2021.112796

Hossain, A., Nielsen, M., and Nielsen, R. (2024). The choice of prawn or shrimp? Lesson from consumer preferences and price acceptance in the Bangladesh wet fish market. *Aquaculture* 583, 740580. doi: 10.1016/j.aquaculture.2024.740580

Hoque, M. S., Haque, M. M., Nielsen, M., Badiuzzaman,, Rahman, M. T., Hossain, M. I., et al. (2021). Prospects and challenges of yellow flesh pangasius in international markets: secondary and primary evidence from Bangladesh. *Heliyon* 7, e08060. doi: 10.1016/j.heliyon.2021.e08060

Islam, M. S. (2012). *Evolution of shrimp farming in Bangladesh* (Global Seafood Alliance). Available at: https://www.globalseafood.org/advocate/evolution-of-shrimp-farming-in-bangladesh/ (Accessed December 20, 2025).

Islam, M. S., and Wahab, M. A. (2005). A review on the present status and management of mangrove wetland habitat resources in Bangladesh with emphasis on mangrove fisheries and aquaculture. *Hydrobiologia* 542, 165–190. doi: 10.1007/s10750-004-0756-y

Ismail, M. M., and Abdullah, A. M. (2013). Shrimp trade competitiveness of Malaysia and selected ASEAN countries. *J. Int. Food Agribusiness Marketing* 25, 98–115. doi: 10.1080/08974438.2013.800009

Jamal, M. R. (2023). Can Vannamei shrimp (*Litopenaeus vannamei*) revitalise Bangladesh's dying shrimp industry? *Aquaculture Int.* 31, 1637–1641. doi: 10.1007/s10499-022-01045-9

Jatuporn, C. (2022). Impact assessment of the COVID-19 pandemic on shrimp exports in Thailand: an empirical study using time series analysis. *Sustainability* 14, 16518. doi: 10.3390/su142416518

Jha, S., Srinivasan, P. V., and Landes, M. R. (2007). *Indian wheat and rice sector policies and the implications of reform (USDA-ERS Economic Research Report, 41)* (Washington DC, USA: U.S. Department of Agriculture, Economic Research Service), pp. 45.

Johansen, S. (1988). Statistical analysis of co-integration vectors. *J. Economic Dynamics Control* 12, 231–254. doi: 10.1016/0165-1889(88)90041-3

Jonell, M., and Henriksson, P. J. G. (2015). Mangrove–shrimp farms in Vietnam—Comparing organic and conventional systems using life cycle assessment. *Aquaculture* 447, 66–75. doi: 10.1016/j.aquaculture.2014.11.001

Karagöz, K. (2016). Determining factors of Turkey's export performance: An empirical analysis. *Proc. Economics Finance* 38, 446–457. doi: 10.1016/S2212-5671(16)30216-7

Karim, M. (2003). *A gross oversimplification: Stop blaming shrimp* (Dhaka, Bangladesh: Shrimp Seal of Quality Organization Official Paper), 1.

Khan, M. A., Hossain, M. E., Islam, M. S., Rahman, M. T., and Dey, M. M. (2022). Shrimp export competitiveness and its determinants: a novel dynamic ARDL simulations approach. *Aquaculture Economics Manage.* 27, 221–248. doi: 10.1080/13657305.2022.2089772

Krishnan, M., and Babu, S. C. (2022). Covid-19 Opens up domestic market for Indian shrimp. *Aquaculture* 550, 737818. doi: 10.1016/j.aquaculture.2021.737818

Lebel, L., Mungkung, R., Gheewala, S. H., and Lebel, P. (2010). Innovation cycles, niches and sustainability in the shrimp aquaculture industry in Thailand. *Environ. Sci. Policy* 13, 291–302. doi: 10.1016/j.envsci.2010.03.005

Leromain, E., and Orefice, G. (2014). New revealed comparative advantage index: Dataset and empirical distribution. *Int. Economics* 139, 48–70. doi: 10.1016/j.inteco.2014.03.003

Little, D. C., Karim, M., Turongruang, D., Morales, E. J., Murray, F. J., Barman, B. K., et al. (2007). "Livelihood impacts of ponds in Asia-opportunities and constraints," in *Fishponds in farming systems*. Eds. A. J. van der Zijpp, J. A. J. Verreth, L. Q. Tri, M. E. F. van Mensvoort, R. H. Bosma and M. C. M. Beveridge (Wageningen Academic Publishers, The Netherlands), 177–202.

Lütkepohl, H. (2006). "Vector autoregressive models," in *Palgrave handbook of econometrics, volume 1, econometric theory*. Eds. T. C. Mills and K. Patterson (Palgrave Macmillan, Houndmills, Basingstoke), 477–510.

Marwaha, N., Beveridge, M. C. M., and Phillips, M. J. (2022). Fad, food, or feed: alternative seafood and its contribution to food systems. *Front. Sustain. Food Syst.* 6. doi: 10.3389/fsufs.2022.750253

N'Souvi, K., Sun, C., Che, B., and Vodounon, A. (2024). Shrimp industry in China: Overview of the trends in the production, imports and exports during the last two decades, challenges, and outlook. *Front. Sustain. Food Syst.* 7. doi: 10.3389/fsufs.2023.1287034

Narayan, S., and Bhattacharya, P. (2019). Relative export competitiveness of agricultural commodities and its determinants: Some evidence from India. *World Dev.* 117, 29–47. doi: 10.1016/j.worlddev.2018.12.013

Paul, B. G., and Vogl, C. R. (2011). Impacts of shrimp farming in Bangladesh: challenges and alternatives. *Ocean Coastal Manage.* 54, 201–211. doi: 10.1016/j.ocecoaman.2010.12.001

Quassem, M. A., Khan, B. U., Uddin, A. M. K., Ahmad, M., and Koudstaal, R. (2003). *A systems analysis of shrimp production. Working paper WP 014, program development office for integrated coastal zone management plan (PDO-ICZMP)* (Gulshan, Dhaka, Bangladesh: Saimon Centre), 87.

Rahman, M. (2001). *EU ban on shrimp imports from Bangladesh: A case study on market access problems faced by the LDCs* (Bangladesh: Center for Policy Dialog). Available at: http://cuts-international.org/mustafizur-paper.doc.

Rahman, M. M., and Hossain, M. M. (2009). Production and export of shrimp of Bangladesh : problems and prospects. *Progesstive Agric.* 20, 163–171. doi: 10.3329/pa.v20i1-2.16868

Rahman, M. A., Lee, S. G., Molla, M. H. R., Asare, O. E., Megwalu, F. O., Jahan, B., et al. (2018). Fisheries management and governance in Bangladesh. *MOJ Ecol. Environ. Sci.* 3, 381–385. doi: 10.15406/mojes.2018.03.00117

Rajitha, K., Mukherjee, C. K., and Chandran, R. V. (2007). Applications of remote sensing and GIS for sustainable management of shrimp culture in India. *Aquacultural Eng.* 36, 1–17. doi: 10.1016/j.aquaeng.2006.05.003

Raman, R. K., Sathianandan, T. V., Sharma, A. P., and Mohanty, B. P. (2017). Modelling and forecasting marine fish production in Odisha using seasonal ARIMA model. *Natl. Acad. Sci. Lett.* 40, 393–397. doi: 10.1007/s40009-017-0581-2

Rivera-Ferre, M. G. (2009). Can export-oriented aquaculture in developing countries be sustainable and promote sustainable development? The shrimp case. *J. Agric. Environ. Ethics* 22, 301–321. doi: 10.1007/s10806-009-9148-7

Rubel, H., Woods, W., Pérez, D., Unnikrishnan, S., Felde, A. M. J., Zielcke, S., et al. (2021). *A strategic approach to sustainable shrimp production in India: The case for improved economics and sustainability* (Boston, USA: Boston Consulting Group (BCG), 51.

Saleetid, N., and Green, D. M. (2019). Network structure and risk-based surveillance algorithms for live shrimp movements in Thailand. *Transboundary Emerging Dis.* 66, 2450–2461. doi: 10.1111/tbed.13303

Sarkar, M. S. I., Bhuyan, M. S., Hasan, M., and Uddin, M. R. (2018). A critial evaluation of regulatory regime in the shrimp hatchery of Bangladesh in light of the EU requirements. *J. Aquat. Sci. Marine Biol.* 1, 14–19. doi: 10.22259/2638-5481.0101003

Schwarz, G. (1978). Estimating the dimension of a model. *Ann. Stat* 6 (2), 461–464. doi: 10.1214/aos/1176344136

Seafood Network (2024). *China's duty-free access for Bangladeshi Black Tiger Shrimp promises major boost for the sector*. Available online at: https://seafoodnetworkbd.com/chinas-duty-free-access-for-bangladeshi-black-tiger-shrimp-promises-major-boost-for-the-sector (Accessed December 21, 2024).

Shohan, M. H., Siddique, M. A. B., Mahalder, B., Haque, M. M., Goswami, C., Ahmed, M. B. U., et al. (2024). Multifaceted linkages among eco-climatic factors, plankton abundance, and gonadal maturation of hilsa shad, *tenualosa ilisha*, populations in Bangladesh. *Climate* 12, 40. doi: 10.3390/cli12030040

Siddique, M. A. B., Mahalder, B., Haque, M. M., and Ahammad, A. S. (2024a). Impact of climatic factors on water quality parameters in tilapia broodfish ponds and predictive modeling of pond water temperature with ARIMAX. *Heliyon* 10, e37717. doi: 10.1016/j.heliyon.2024.e37717

Siddique, M. A. B., Mahalder, B., Haque, M. M., and Ahammad, A. S. (2025). Impact of climatic and water quality parameters on Tilapia (Oreochromis niloticus) broodfish growth: Integrating ARIMA and ARIMAX for precise modeling and forecasting. *PloS One* 20, e0313846. doi: 10.1371/journal.pone.0313846

Siddique, M. A. B., Mahalder, B., Haque, M. M., Shohan, M. H., Biswas, J. C., Akhtar, S., et al. (2024b). Forecasting of tilapia (Oreochromis niloticus) production in Bangladesh using ARIMA model. *Heliyon* 10. doi: 10.1016/j.heliyon.2024.e27111

Sims, C. A. (1972). Money, income, and causality. *Am. Economic Rev.* 62, 540–552.

Singh, N. D., Krishnan, M., Sivaramane, N., Ramasubramanian, V., and Kiresur, V. R. (2022). Market integration and price transmission in Indian shrimp exports. *Aquaculture* 561, 738687. doi: 10.1016/j.aquaculture.2022.738687

Spreij, M. (2023). *National aquaculture legislation overview Bangladesh. Fisheries and Aquaculture Division* (Rome: Food and Agriculture Organization of the United Nations). Available at: http://www.fao.org/fishery/legalframework/nalo_bangladesh/en (Accessed June 9, 2024).

TBS Report (2025). *China pledges duty-free access till 2028, help relocate manufacturing to Bangladesh* (The Business Standard). Available at: https://www.tbsnews.net/foreign-policy/what-ca-yunus-chinese-vice-premier-xuexiang-discussed-1103261 (Accessed November 25, 2024).

The Observatory of Economic Complexity (2021). *Frozen shrimps and prawns*. Available online at: https://oec.world/en/profile/hs/frozen-shrimps-prawns (Accessed July 2, 2023).

Tran, N., Bailey, C., Wilson, N., and Phillips, M. (2013). Governance of global value chains in response to food safety and certification standards: the case of shrimp from Vietnam. *World Development* 45, 325–336. doi: 10.1016/j.worlddev.2013.01.025

Tu, N. V., Tu, N. P. C., and Kha, N. H. N. (2019). "Roles of research and education in freshwater aquaculture development: A case of striped catfish farming in Vietnam," in *Bologna process and fisheries education for sustainable development*. Eds. A. Figus and T. Potempa (Germany: Eurolink University Press), 143–162.

Umadevi, K., and Eswaraprasad, Y. (2006). Export competitiveness of Indian shrimp in the world market. *Indian J. Agric. Marketing* 20, 90.

United Nations Conference on Trade and Development (2017). *Fishery exports and the economic development of least developed countries* (Bangladesh, Cambodia: the Comoros, Mozambique, Myanmar and Uganda). Available at: https://unctad.org/system/files/official-document/aldc2017d2_en.pdf (Accessed February 22, 2023).

van der Pijl, W. (2014). *An update of shrimp and prawn supply chain initiatives in Bangladesh: Recommendations for inclusive shrimp supply chain development for the STDF project (LEI Report 14-028)* (Wageningen UR: University & Research Centre).

Yadav, A. K., Das, K. K., Das, P., Raman, R. K., Kumar, J., and Das, B. K. (2020). Growth trends and forecasting of fish production in assam, India using ARIMA model. *J. Appl. Nat. Sci.* 12, 415–421. doi: 10.31018/jans.v12i3.2353

Yunus, M. (2009). EU ban, HACCP compliance and shrimp exports from Bangladesh. *Bangladesh Development Studies* 32 (3), 41–57.