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Multivariate analysis of best management practices influencing food safety in *P. vannamei* shrimp culture in Andhra Pradesh, India

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Abstract

Shrimp aquaculture has emerged as a resilient and promising sector in India, contributing significantly to economic growth and food security. The study was conducted among 200 randomly selected shrimp farmers to assess whether adopting Best Management Practices enhances food safety in shrimp farming. Adopting best management practices results in lower disease prevalence, reduced antibiotic dependency, and better compliance with export quality standards. A multiple regression analysis showed that antibiotic & chemical management, water quality management, Pond preparation, and post-harvest hygiene significantly influenced food safety outcomes (p -value < 0.01 , $R^2 = 0.943$). Pearson's correlation analysis indicated a significant positive relationship (p -value < 0.01) between the adoption of best management practices and enhanced food safety. To improve food safety, safer, more sustainable shrimp production can be achieved by strengthening essential BMP practices, such as managing chemicals and antibiotics, maintaining water quality, and properly preparing ponds.

Keywords: Best management practices (BMP's), Adoption, Food safety, shrimp farming, Antibiotic, chemical management, water quality management

Introduction

Shrimp farming is a successful model within India's food production system, which boosts overall economic development (Kumaran *et al.*, 2003; Ahmed, 2013) ^[25, 1] and promotes small-scale entrepreneurs (Belton *et al.*, 2017) ^[5] in the farming sector. The farming sector has been reported to obtain maximum possible output for a given set of inputs (Kumaran *et al.* 2017) ^[24]. For year 2025-26 Shrimp exports recorded growth of 4.6% in quantity and 6.35% in value, highlighting its dominant position in the Indian marine export sector. Shrimp contributed ₹47,973.13 crore (US\$ 5.51 billion), accounting nearly two-thirds of India's total marine product. (MPEDA, 2026). Adoption of Better Management Practices (BMPs) at various levels is essential for effective risk reduction, management, and mitigation to ensure sustainable and successful shrimp farming (Kumaran and Ponniah, 2013; Sivaraman *et al.*, 2019) ^[26, 48]. BMPs such as responsible antibiotic usage, water quality management, biosecurity, hygienic harvesting, and traceability help minimize contamination risks and improve the quality and safety of shrimp intended for human consumption. Food safety defines producing, processing, handling and storing food in way that prevents disease incidence and retains nutrients for healthy diet. The antimicrobial use in aquaculture is increasing greatly, estimated at 63,151 tons in 2010, and projected to rise by 67% in 2030. The countries like Brazil, Russia, India, and South Africa have the highest estimated global antimicrobial

consumption (Van Boeckel TP, Brower C *et al* 2015) ^[50]. Effective BMPs implementation can significantly reduce food safety risks and promote safer and sustainable shrimp production systems. (Sivaraman *et al.*, 2019; Nguyen *et al*) ^[48].

Methodology

A total of 200 shrimp farmers were chosen using a simple random sampling technique from key shrimp-growing areas in the Bapatla district of Andhra Pradesh, India. The study sought to investigate the association between the use of Best Management Practices (BMPs) and food safety in shrimp farming. The null hypothesis (H_0) is adoption of best management practices in shrimp farming have no significant role in food safety outcomes. Primary data were collected using a standardized, pre-tested interview schedule. A list of 32 Best Management Practices related to pond preparation, biosecurity, water quality management, antibiotic and chemical management, biosecurity, feed management, harvest hygiene, and record keeping were identified based on the review of literature and recommended management guidelines to assess the level of BMP adoption by farmers. A binary scoring method was adopted, where "Yes" responses were assigned a score of 1 and "No" responses were assigned a score of 0. The scores obtained for all BMP practices were summed to derive the BMP score for each farmer. Food safety practices at the farm level were evaluated, as a separate set of food safety-related questions

was developed to cover aspects such as hygienic handling, harvesting practices, chemical safety, and traceability. A similar binary scoring system was used for food safety assessment, and the total score was used to calculate the Food Safety Score for each farmer.

The data collected were coded and analysed using the IBM SPSS Statistics software. Descriptive statistics were employed to summarize the information. Multiple regression analysis was used to assess the impact of various BMP components on food safety. This is to find the risk factors in shrimp farming affecting food safety. In the case of the multiple regression model, BMP components were considered as independent variables, while Food Safety Score was handled as the dependent variable. At the 1% and 5% significance levels, the variables' statistical significance was examined. Scatter plots and Histogram of standardised residuals were generated for visual representation of model fit. Additionally, correlation analysis was employed to investigate the connection between food safety and BMP components.

Results and Discussion

The results of the regression analysis (Table 1) revealed that pond preparation, antibiotic and chemical management, soil and water quality management, and harvest and post-harvest management had a significant positive influence on food safety at the 1 per cent level of significance (p -value < 0.01). More over $R^2 = 0.943$ depicts that model explains 94% of variance in Food safety. However, seed selection and feeding management did not show a statistically significant relationship with food safety. Rejected Null hypothesis. The table no 2 shows the descriptive statistics. The fig 1 represents observed versus predicted values scatter plot, revealed a strong positive association between the actual and model-predicted food safety scores. The data points were closely distributed around the regression line, indicating good agreement between observed and predicted values. The coefficient of determination ($R^2 = 0.943$) showed that the regression model explained 94.3% of the variability in food safety, demonstrating good predictive performance and model adequacy.

The dependent variable Food safety was regressed on predictor variable pond preparation. Pond preparation significantly predicted Food safety, $F(6,193) = 531.418$, p value < 0.01 which indicates that pond preparation plays significant role in enhancing food safety ($b = 0.511$, p value < 0.01), in shrimp farming (Table 1). Proper pond preparation such as pond drying, liming (Boyd, C.E., 2008) [6] (Muralidhar, M *et al* 2015) [33] (Hossain, M.M.M.*et al* 2026) [16], (Chattogram 2024) [10] sludge removal (Rahman, M.H *et al* 2022) [42] (Yasin *et al* 2025) [54], (Mandal, A. and Duyari, M., 2024) [29], (Reddy, A.K., 2025) [43] (Hossain, M.M.M.*et al* 2026) and disinfection may help reduce pathogen load (Iber, B.T. and Kasan, N.A., 2021) [17] (Pillai SM 2012) and improve pond hygiene, thereby lowering contamination risks and disease occurrence. (Sai Susmitha Bhargavi K., *et al* 2024) [47] (Suzuki, A. and Hoang Nam, V., 2018) [49] (Venkateswarlu, V. and Venkatrayulu, C., 2019) [51].

The intensification of aquaculture has contributed to the emergence of several bacterial diseases, resulting in increased use of antimicrobials. (Defoirdt T, *et al* 2007) [13]

(Defoirdt T., 2011) [14]. Antibiotic and chemical management significantly predicted food safety outcomes $F(6,193) = 531.418$, p value < 0.01) which indicates antibiotic and chemical management has significant role in food safety ($b = 0.862$, p value < 0.01) in shrimp farming (Table 1). This indicates that responsible use of chemicals, avoidance of banned antibiotics (Paul, R., 2024) [38], maintenance of treatment records (D'Abramo, L.R., 2009) [12] and adherence to recommended dosages (Ali, H *et al*, 2016) and withdrawal periods (Okocha, R.C *et al* 2018) [37] (Quyen, N.T.K *et al* 2020) [40] significantly improve food safety conditions in shrimp farms (Kunda, S.K., 2005) [28] (Carlino-Costa, C. and Belo, M.A.D.A., 2025) [9]. The indiscriminate use of antimicrobials in aquaculture, resulting in the presence of residues in aquaculture products and producing adverse health consequences in people, needs the deployment of appropriate control mechanisms to protect consumers. (Okocha, 2018) [37]. The results support earlier findings that improper chemical usage (Gautier, D., 2000) [15] (Noriega-Orozco, L. 2010) and antibiotic misuse (Islam, M.S. and Bjarnason, P., 2008) [18] are major contributors to residue-related food safety concerns (Rigos, G. and Kogiannou, D., 2023) [45] (Nazmul Alam, S.M., 2025) [35] in aquaculture production systems. Hazard Analysis Critical Control Points system identifies specific hazards from primary production to final consumption to ensure food safety (Broughton, E.I. and Walker, D.G., 2010). [7] HACCP systems support regulatory control measures and facilitate international trade by enhancing confidence in the safety of traded food products. (CAC. 1997), (Mohanty *et al* 2016) [31], (Awuchi, C.G., 2023) [4].

Similarly, soil and water quality management had significantly predicted food safety ($b = 0.720$, p value < 0.01) (Table 1). Regular monitoring and appropriate maintenance of water quality indicators, including dissolved oxygen, pH, ammonia levels, and pond hygiene, play an important role in improving food safety, controlling disease outbreaks, and decreasing microbial contamination in aquaculture. (Reilly, A. and Käferstein, F.J.A.R., 1997) [44] (Kanduri, L. and Eckhardt, R.A., 2008) [20] (Carlino-Costa, C. and Belo, M.A.D.A., 2025) [9]. Khatun, M.S *et al.* (2020) [21] stated that farmers followed at least 50% of the GAP criteria then the foods (shrimp/prawn) were safe for human consumption. Good water quality management reduces stress in shrimp, lowering reliance on antibiotics and pesticides, promoting food safety. (Quyen, N.T.K 2020) [40] (Natrah, I., *et al*, 2025) [34].

The table 1 shows harvest and post-harvest management practices also significantly predicted food safety ($b = 0.928$, p value < 0.01). Hygienic harvesting practices, the use of clean containers, timely chilling, and proper handling during transit all play an important role in reducing microbe contamination and maintaining shrimp quality (Maw, W.W., 2025), (Alam, S.N., 2016) [2]. Harvest bins should be cleaned and sanitised before and after harvesting to avoid microbial contamination (Ryan, J.M., 2017) [46].

Seed selection ($b = 0.625$, p value > 0.01) and feeding management ($b = 0.570$, p value > 0.01) were statistically non-significant. Overall, the regression results indicate that food safety in shrimp aquaculture is substantially influenced by management practices such as pond hygiene, responsible chemical use, water quality control, and sanitary harvesting

practices. The results emphasized that it is crucial to encourage shrimp farmers to implement scientifically advised BMPs to raise food safety standards, lower the risk of contamination, and boost the shrimp aquaculture industry's export competitiveness. Vietnam, shrimp farmers improved food safety by culturing shrimp according to the Good Aquaculture Practices (GAP) in Vietnam (VietGAP), while other farmers still practice intensive farming without any certification. Farmers with weak practices in quality control and high use of antibiotics reported disease incidence (Quyen, N.T.K *et al*, 2019) ^[41], like EHP, and lower productivity (Sai Susmitha Bhargavi K., *et al* 2024) ^[47]. It is essential to strengthen farmer association and social capital at the cluster level. Ensure adoption of farm-level biosecurity measures and collective compliance with improved management practices through a cluster-based strategy. (Kumaran, 2012; World Bank Report, 2014; Joffre *et al*. 2022) ^[27].

The histogram of standardized residuals (Fig 2) exhibited an approximately normal distribution with residuals centered around zero. The mean standardized residual was nearly zero (Mean = 1.12E-15) and the standard deviation was

close to one (SD = 0.985), indicating appropriate standardization of errors. The distribution closely followed the normal curve, suggesting that the normality assumption underlying the multiple linear regression model was adequately met. Minor deviations at the tails were observed but were not substantial enough to affect model validity.

The Pearson correlation analysis presented in table 3 showed the relationship between adoption of best management practices and food safety in shrimp farming. The table 4 shows descriptive statistics. The Pearson correlation of best management practices and food safety was found highly positive and statistically significant ($r = 0.967$, $p\text{-value} < 0.01$) This shows increase in adoption of best management practices ensures an increase in food safety for consumption (Walker and Mohan 2009) ^[52] (Corsin, F *et al*. 2008; Kono, H *et al* 2024) ^[11, 22]. Best Management Practices are intended to develop a sustainable shrimp aquaculture industry, to improve food safety of the final product and for social benefits derived from shrimp farming (Kumara, K.R.P.S. and Hettiarachchi, M., 2018) ^[23] (Quyen, N.T.K *et al* 2020) ^[40].

Table 1: The table showing the results of multiple regression analysis between BMP components and Food safety

Regression weights	Coefficient (B)	P value	St. Error	t- value
PP →FS	0.511	0.001*	0.111	4.610
SS→ FS	0.625	0.228	0.128	4.872
FD →FS	0.570	1.001	0.166	3.437
ACM→FS	0.862	0.000*	0.117	7.377
SWQ→FS	0.720	0.002*	0.118	6.109
HPH→FS	0.928	0.000*	0.286	3.249
R² = 0.943		Adjusted R² = 0.941		

Significant at 1% level, Dependent variable - Food safety, 95% confidence interval.

FS- Food safety, PP- Pond Preparation, SS-Seed selection, FD- Feeding management,

ACM- Antibiotic and chemical management, SWQ-Soil and water quality management HPH- Harvest and post-harvest

Table 2: Descriptive statistics (N= 200)

	Mean scores of variables
Food safety	11.29 ± 2.567
Pond preparation	5.56 ± .761
Seed selection	4.28 ± .448
Feeding	2.89 ± .320
Antibiotic and chemical management	4.65 ± 1.164
Soil and water quality	4.72 ± 1.029
Harvest and postharvest	4.23 ± .565

Table 3: The table showing the results of Pearson correlation analysis relationship between BMP components and Food safety.

Variables	Food safety	Pond preparation	Seed selection	Feeding	Antibiotic & chemical	Soil & water quality	Harvest & postharvest
Food safety	1.000						
Pond preparation	0.773	1.000					
Seed selection	0.061	0.022	1.000				
Feeding	0.347	0.263	0.222	1.000			
Antibiotic & chemical	0.926	0.818	-0.053	0.200	1.000		
Soil & water quality	0.878	0.530	0.018	0.358	0.775	1.000	
Harvest & postharvest	0.876	0.625	-0.252	0.147	0.874	0.875	1.000

** Correlation is significant at the 0.01 level (2-tailed).

Table 4: Descriptive statistics (N= 200)

Variables	Mean scores
Food safety	11.29 ± 2.567
BMP score	26.19 ± 3.334

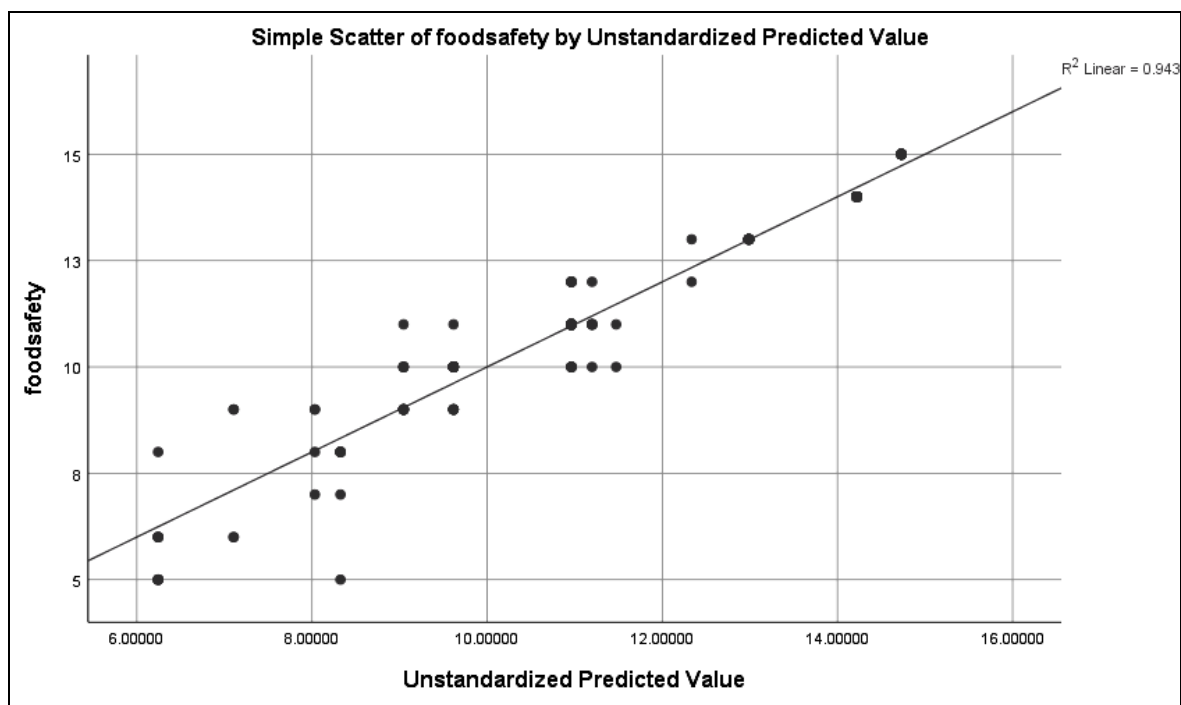


Fig 1: Scatter plot showing the relationship between observed food safety scores and model-predicted values

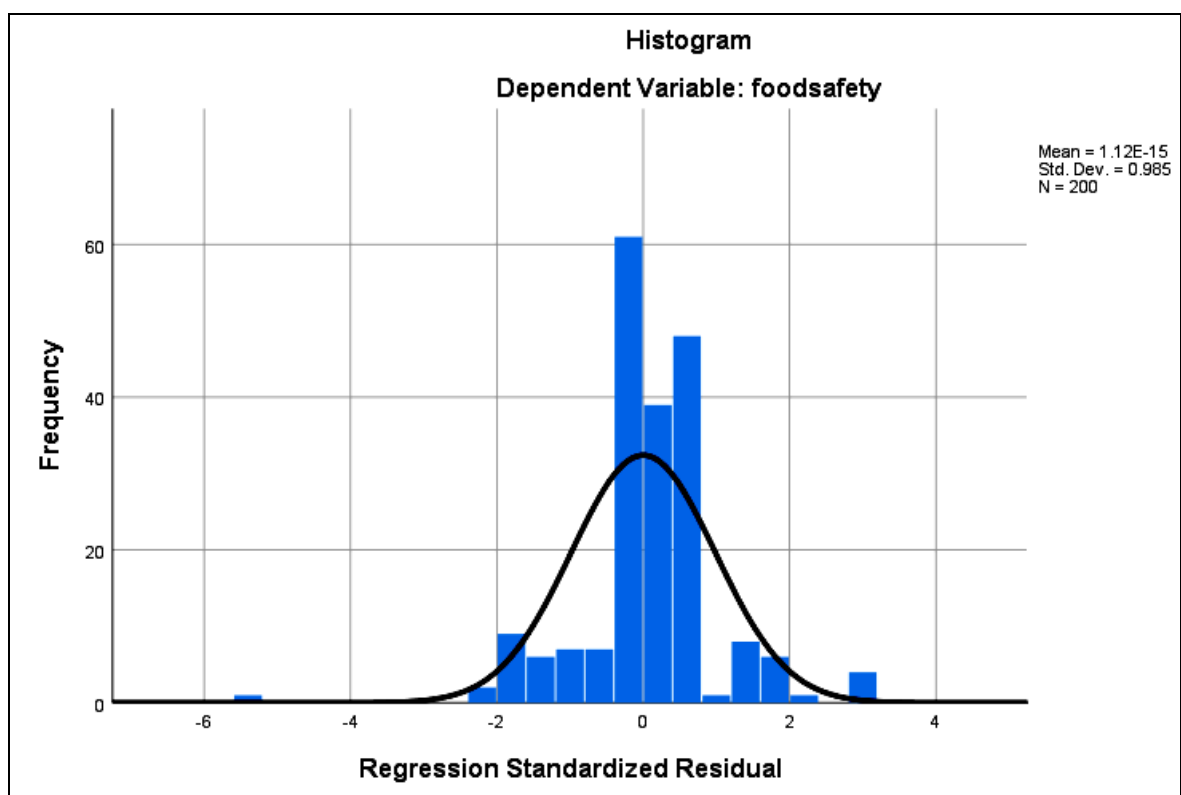


Fig 2: Distribution of Standardized Residuals for the Food safety Multiple Linear Regression Model

Conclusion

The study's findings indicate that adopting Best Management Practices (BMPs) has a significant positive influence on food safety in shrimp aquaculture systems. BMP components related to pond preparation, antibiotic and chemical management, water quality management, and harvest hygiene were identified as major determinants of food safety outcomes. Strengthening BMP adoption and implementation at the farm or cluster level may therefore

help reduce contamination risks, improve product safety, and support sustainable shrimp production

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Author contribution

P. Mukkanti - Data Collection Analysis & Preparation of Manuscript,
Sumanth Kumar Kunda- Research methodology sampling plan discussion of result manuscript revision.

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