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The Effectiveness of Biosecurity Implementation in Vannamei Shrimp (*Litopenaeus vannamei*) Hatcheries on Post-Larvae Survival Rate in Situbondo Regency, East Java, Indonesia

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A R T I C L E I N F O

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A B S T R A C T

This study examined the effects of biosecurity on larval survival and productivity in Pacific white shrimp hatcheries in Situbondo, East Java. Tested variables included water quality, vector control, sanitation and disinfection, shrimp health monitoring, larval survival, and hatchery productivity. A quantitative, cross-sectional approach involved 104 hatchery operators, managers, and technical supervisors. Questionnaire, observation, and interview data were analyzed using SEM-PLS. Water quality significantly affected survival and productivity, while vector control affected survival only. Sanitation, disinfection, and health monitoring affected productivity but not survival. Survival significantly affected productivity and mediated the effects of water quality and vector control only. These findings support integrated biosecurity, emphasizing water quality and vector control for survival, alongside sanitation and health monitoring for improved overall hatchery productivity

INTRODUCTION

Pacific white shrimp (*Litopenaeus vannamei*) is an important aquaculture commodity in Indonesia, and improving its productivity remains a priority for national aquaculture development (Kementrian Kelautan dan Perikanan, 2024). Hatcheries play a fundamental role in this production system by supplying postlarvae for grow-out operations. In Situbondo Regency, East Java, the connection between hatcheries and grow-out ponds makes the quality and availability of postlarvae particularly important. However, intensive production can increase exposure to pathogens and compromise production outcomes. Viral diseases represent a major challenge to shrimp aquaculture because they can cause substantial mortality and economic losses (Lightner, 2011). These challenges highlight the need to examine hatchery management practices that support larval survival and productivity.

Biosecurity provides a preventive approach to managing disease risks through practices designed to limit pathogen introduction and spread within aquaculture facilities (Subasinghe et al., 2023). In shrimp hatcheries, these practices include water quality management, vector control, sanitation and disinfection, and shrimp health monitoring. Water quality management supports suitable rearing conditions, while vector control reduces potential pathways of pathogen transmission. Sanitation and disinfection address contamination of facilities and equipment, whereas health monitoring supports the early identification of health problems. Together, these practices provide a basis for maintaining a controlled production environment and reducing disease risks (WOAH, 2021).

The effectiveness of biosecurity depends on its consistent implementation throughout the production process. Differences in staff competency, facility availability, and management practices may influence how preventive measures are applied. Research on disease prevention in Pacific white shrimp farming and biosecurity implementation in shrimp hatcheries demonstrates the practical relevance of these measures to aquaculture management (Harijono & Nazran, 2025; Usman et al., 2022). Nevertheless, evaluating biosecurity as a general management practice may provide insufficient information about which components are most closely associated with hatchery outcomes. Distinguishing the effects of individual components is therefore necessary to identify management priorities, particularly when hatcheries face limitations in infrastructure, personnel, or operational resources.

A central issue addressed by this study is whether different biosecurity components influence hatchery productivity directly or indirectly through larval survival. Water quality is relevant to both the condition of the rearing environment and shrimp production performance (Anjaini et al., 2024; Boyd, 2020). However, water quality, vector control, sanitation and disinfection, and health monitoring may have different relationships with survival and productivity. Examining these relationships within a single model can clarify whether practices associated with improved larval survival also contribute to productivity through that pathway. This distinction is important because measures that support survival may require different management priorities from measures that influence overall production outcomes.

This study contributes to knowledge by integrating four biosecurity components, larval survival, and hatchery productivity within a structural model focused on Pacific white shrimp hatcheries in Situbondo. Its contribution lies in distinguishing direct relationships with productivity from indirect relationships through larval survival, supported by information from hatchery operators, managers, and technical supervisors. This context-specific approach provides evidence relevant to hatchery management and offers a more differentiated understanding of biosecurity implementation. Accordingly, this study aims to examine the effects of water quality, vector control, sanitation and disinfection, and shrimp health monitoring on larval survival and hatchery productivity, assess the relationship between larval survival and hatchery productivity, and determine whether larval survival mediates the relationships between these biosecurity components and hatchery productivity.

LITERATURE REVIEW

Biosecurity and Disease Prevention Perspective

Biosecurity encompasses preventive management practices intended to limit the introduction and spread of pathogens within aquaculture production systems (FAO, 2020; WOAH, 2021). Its implementation involves coordinated environmental management, contamination prevention, and health assessment to protect cultured organisms from disease risks (Subasinghe et al., 2023). This perspective provides a conceptual basis for examining water quality, vector control, sanitation and disinfectants, and shrimp health examination in relation to larval survival and hatchery productivity (FAO, 2020; WOAH, 2021). Previous research provides supporting evidence from different production settings, although its applicability depends on the species, production stage, and outcomes examined (Akmal et al., 2020; Samanta et al., 2015; Zhou et al., 2018). Research on shrimp grow-out systems offers relevant management insights, while studies of poultry provide broader evidence concerning disease prevention and production outcomes rather than direct evidence of shrimp larval survival (Akmal et al., 2020; Samanta et al., 2015). These findings support the development of context-specific hypotheses for shrimp hatcheries rather than assuming that relationships established in other sectors necessarily apply to larval production (Subasinghe et al., 2023).

Water Quality, Larval Survival and Hatchery Productivity

Water quality represents the physical, chemical, and biological characteristics of the rearing environment, including temperature, dissolved oxygen, salinity, pH, and nitrogen compounds (Boyd, 2020). Maintaining suitable water conditions is important because environmental instability can disturb larval physiology and reduce the success of rearing (Nkuba et al., 2021). Water quality management therefore provides a biological basis for predicting differences in larval survival and production performance (Boyd, 2020; Nkuba et al., 2021). (Akmal et al., 2020) discuss the implementation of closed-system technology in shrimp grow-out operations, providing relevant evidence concerning water management and the application of preventive production

practices. (Ratnawati et al., 2022) report significant differences in Pacific white shrimp larval survival under different phytoplankton treatments, demonstrating the responsiveness of survival to rearing-management conditions. However, these studies provide related support rather than an isolated test of water quality effects on both larval survival and hatchery productivity (Akmal et al., 2020; Ratnawati et al., 2022). Taken together, these sources support the prediction that suitable water conditions contribute to larval survival and help maintain favorable production conditions (Boyd, 2020; Nkuba et al., 2021).

H1: Water Quality has a Positive Effect on Larval Survival

H2: Water Quality has a Positive Effect on Hatchery Productivity

Vector Control, Larval Survival and Hatchery Productivity

Vector control concerns preventive measures intended to restrict potential biological carriers of pathogens and reduce opportunities for infectious exposure within production facilities (WOAH, 2021). Within the biosecurity perspective, controlling potential transmission pathways complements environmental management and other disease-prevention practices (Subasinghe et al., 2023). (Zhou et al., 2018) demonstrate that several exposure-control practices, including species separation and restrictions on poultry sourcing and storage, are associated with reduced avian influenza contamination or infection in live bird markets. These findings support the general principle of managing transmission pathways, although they do not directly establish the effects of vector control in shrimp hatcheries (Zhou et al., 2018). Research concerning disease prevention in Pacific white shrimp farming further provides a relevant operational context for evaluating preventive practices in shrimp production (Harijono & Nazran, 2025). Based on this preventive reasoning, vector control is expected to support larval survival and production continuity by limiting opportunities for pathogen introduction (Subasinghe et al., 2023; WOAH, 2021).

H3: Vector Control has a Positive Effect on Larval Survival

H4: Vector Control has a Positive Effect on Hatchery Productivity

Sanitation and Disinfactants, Larval Survival and Hatchery Productivity

Sanitation and disinfectants refer to cleaning practices and the appropriate application of disinfecting agents to control potential contamination within production facilities (FAO, 2020; WOAH, 2021). These practices form part of a preventive approach intended to reduce opportunities for pathogen transmission through the production environment (Subasinghe et al., 2023). (Zhou et al., 2018) report that cleaning and disinfection are associated with reduced avian influenza infection risk in live bird markets. (Samanta et al., 2015) also report significantly increased egg production following the adoption of a biosecurity strategy, supporting a broader relationship between preventive management and production outcomes. However, the latter study evaluates a package of biosecurity practices, so the production improvement cannot be attributed exclusively to sanitation or disinfectants (Samanta et al., 2015). In shrimp production, research on disease prevention provides a practical basis for considering sanitation within an integrated management approach (Harijono &

Nazran, 2025). Consequently, cleaner production conditions are expected to support larval survival and contribute to hatchery productivity, although these specific relationships remain hypotheses requiring empirical evaluation (FAO, 2020; Subasinghe et al., 2023).

H5: Sanitation and Disinfectants have a Positive Effect on Larval Survival

H6: Sanitation and Disinfectants have a Positive Effect on Hatchery Productivity

Shrimp Health Examination, Larval Survival and Hatchery Productivity

Shrimp health examination concerns the assessment of shrimp condition to identify potential health problems and inform disease-management decisions (FAO, 2020; WOAH, 2021). Diagnostics and disease surveillance are important components of aquatic biosecurity because they provide information for preventive and corrective responses (Subasinghe et al., 2023). (Usman et al., 2022) examine biosecurity implementation and virus detection in a tiger shrimp hatchery, providing a relevant hatchery context for integrating health assessment with preventive management. However, their study concerns tiger shrimp rather than Pacific white shrimp and should therefore be treated as related evidence rather than direct confirmation of the present hypotheses (Usman et al., 2022). Health examination is expected to support survival when the information obtained leads to timely and appropriate management responses (FAO, 2020; Subasinghe et al., 2023). It may also contribute to productivity by supporting informed decisions concerning shrimp health and production management (Subasinghe et al., 2023).

H7: Shrimp Health Examination has a Positive Effect on Larval Survival

H8: Shrimp Health Examination has a Positive Effect on Hatchery Productivity

Larval Survival and Hatchery Productivity

Larval survival describes the proportion of individuals remaining alive from the beginning to the end of a specified rearing period and provides an indicator of rearing success (Haspiani et al., 2024; Noor & Aziz, 2023). Survival reflects the combined influence of environmental conditions, feeding, stocking density, and preventive management during larval production (Izwar et al., 2025; Suryadi & Merdekawati, 2021). Larval survival also provides information for evaluating production performance and identifying management conditions that require improvement (Scabra et al., 2021). Lower mortality is associated conceptually with reduced biological losses and a greater opportunity to obtain productive output from the rearing cycle (Sarmin et al., 2025). Accordingly, larval survival is expected to contribute positively to hatchery productivity while remaining distinct from broader operational performance (Sarmin et al., 2025; Scabra et al., 2021).

H9: Larval Survival has a Positive Effect on Hatchery Productivity

The Mediating Role of Larval Survival

The proposed mediation mechanism combines the biosecurity perspective with the role of survival as an indicator of successful larval production (Scabra et al., 2021; Subasinghe et al., 2023). Under this reasoning, preventive practices may contribute to productivity partly by preserving larvae throughout the rearing period (FAO, 2020; Sarmin et al., 2025). Water quality is expected to support survival through favorable environmental conditions, while survival may subsequently contribute to production outcomes (Nkuba et al., 2021; Scabra et al., 2021). Vector control is expected to reduce opportunities for infectious exposure, providing a preventive pathway through which survival may contribute to productivity (Subasinghe et al., 2023; WOAH, 2021). Sanitation and disinfectants are expected to support this pathway through contamination control, whereas shrimp health examination may support it through health assessment followed by appropriate management responses (FAO, 2020; Usman et al., 2022). These mediation hypotheses are developed by combining the conceptual relationships described in the literature rather than treating the cited studies as direct tests of the proposed indirect effects (Scabra et al., 2021; Subasinghe et al., 2023).

H10: Larval Survival mediates the Positive Effect of Water Quality on Hatchery Productivity

H11: Larval Survival mediates the Positive Effect of Vector Control on Hatchery Productivity

H12: Larval Survival mediates the Positive Effect of Sanitation and Disinfectants on Hatchery Productivity

H13: Larval Survival mediates the Positive Effect of Shrimp Health Examination on Hatchery Productivity

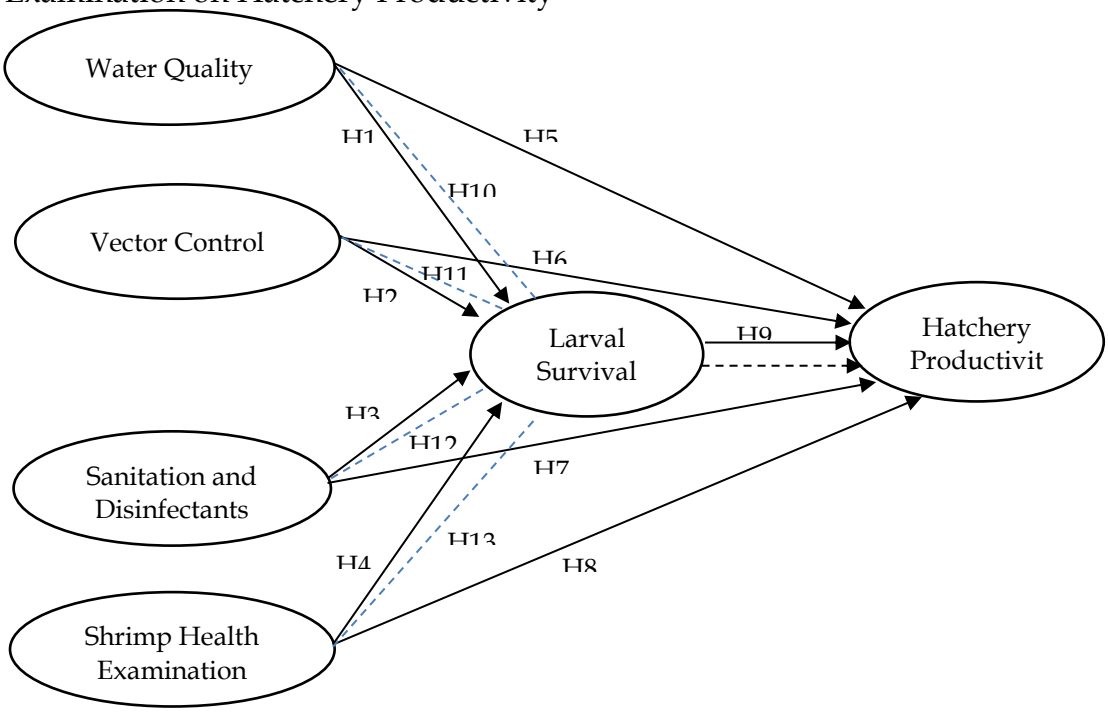


Figure 1. Conceptual Framework

METHODOLOGY

Research Design and Procedures

This study employed a quantitative approach with a cross-sectional design to examine the relationships between biosecurity practices, larval survival, and hatchery productivity in Pacific white shrimp (*Litopenaeus vannamei*) hatcheries in Situbondo Regency, East Java, Indonesia. Data collection took place from November 2025 to February 2026 through structured questionnaires, field observations, and interviews. The research model included four independent variables: water quality, vector control, sanitation and disinfectants, and shrimp health examination. Larval survival served as the mediating variable, while hatchery productivity was the dependent variable. Questionnaire indicators were measured using a five-point Likert scale ranging from strongly inappropriate (1) to strongly appropriate (5). The indicators were developed with reference to aquaculture biosecurity principles concerning environmental management, pathogen prevention, sanitation, and health assessment (FAO, 2020; WOAH, 2021).

Population and Sample

The population comprised hatchery operators, managers, technical supervisors, and personnel responsible for shrimp larval production and biosecurity management in Situbondo Regency. Purposive sampling was employed to select respondents based on their knowledge of and direct involvement in hatchery operations and biosecurity implementation. A total of 104 respondents participated in the study.

Data Analysis Tools and Techniques

Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to examine direct relationships and the mediating role of larval survival (Hair et al., 2022). The analysis consisted of measurement-model and structural-model assessments. The measurement model was evaluated using indicator loadings, average variance extracted (AVE), Cronbach's alpha, composite reliability, and rho_A to assess construct validity and reliability (Hair et al., 2022). The structural model was assessed using path coefficients, the coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2). Bootstrapping was applied to test the significance of direct and indirect relationships, using a two-tailed t-statistic greater than 1.96 or a p-value below .05 at the 5% significance level. Mediation was assessed through the significance of the specific indirect effects of each biosecurity variable on hatchery productivity through larval survival (Hair et al., 2022).

RESEARCH RESULT

Respondent Characteristics

In this study, respondent characteristics were identified based on gender, age, educational background, and working experience. Data regarding respondent characteristics were obtained through questionnaires collected from 104 respondents representing eight Pacific white shrimp (*Litopenaeus vannamei*)

hatchery businesses in Situbondo Regency, namely Hisenor Technology, Banyu Biru Djaya, Delta Windu Purnama, Agape Hatchery, Summa Benur, Raja Benur Prima, Central Pertiwi Bahari, and Pasific Andre Anton. The statistical analysis results of respondent characteristics are presented as follows:

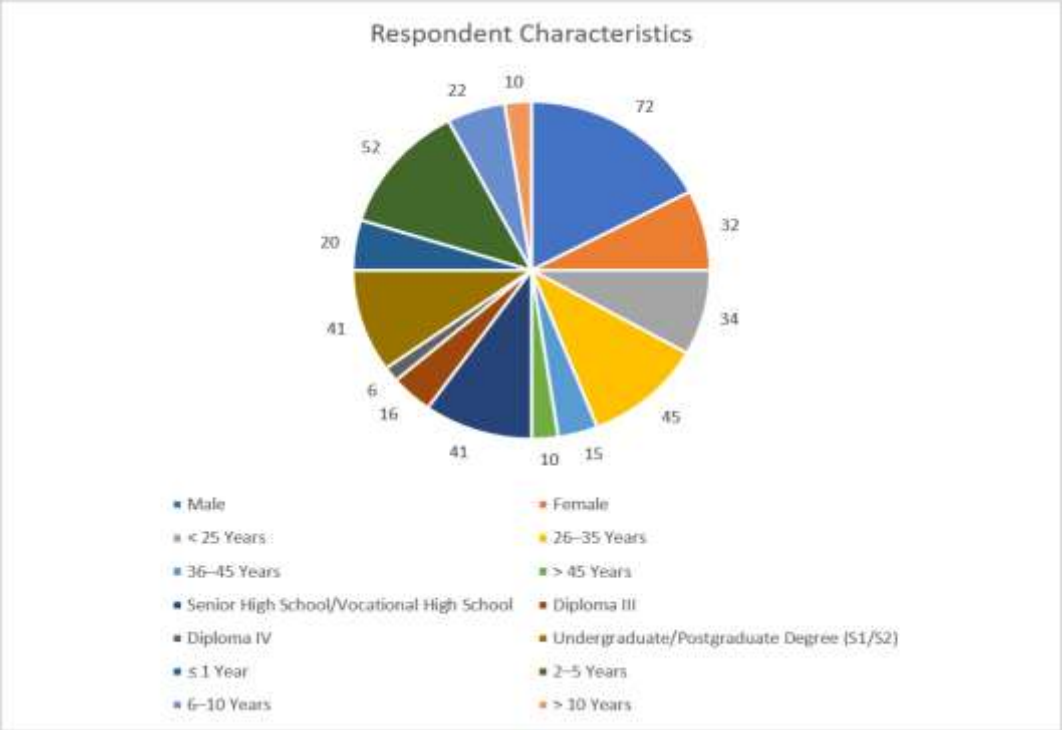


Figure 2. Respondent Characteristics

This study identified respondent characteristics based on gender, age, education level, and working experience. Data were collected through questionnaires from 104 respondents originating from eight Pacific white shrimp hatchery businesses in Situbondo Regency, namely Hisenor Technology, Banyu Biru Djaya, Delta Windu Purnama, Agape Hatchery, Summa Benur, Raja Benur Prima, Central Pertiwi Bahari, and Pasific Andre Anton.

Based on the statistical analysis of respondent characteristics, the majority of respondents were male (69%), while female respondents accounted for 31%. In terms of age distribution, most respondents were between 26 and 35 years old (43%), followed by respondents under 25 years old (33%), 36–45 years old (14%), and above 45 years old (10%). Regarding educational background, the distribution was relatively balanced, with 39% of respondents having completed senior high school/vocational high school education, 39% holding undergraduate or postgraduate degrees (S1/S2), 15% having a Diploma III qualification, and 6% holding a Diploma IV qualification. Regarding work experience, most respondents had worked for 2–5 years (50%), followed by respondents with ≤1 year of experience (19%), 6–10 years of experience (21%), and more than 10 years of experience (10%).

Outer Model Evaluation

The measurement model evaluation (outer model) was conducted to determine the validity of indicators in representing each research construct. The

model consisted of six variables, namely Water Quality, Vector Control, Sanitation and Disinfection, Shrimp Health Monitoring, Larval Survival, and Hatchery Productivity. The evaluation was performed by examining the outer loading values of each indicator. An indicator is considered valid when it has an outer loading value greater than 0.70.

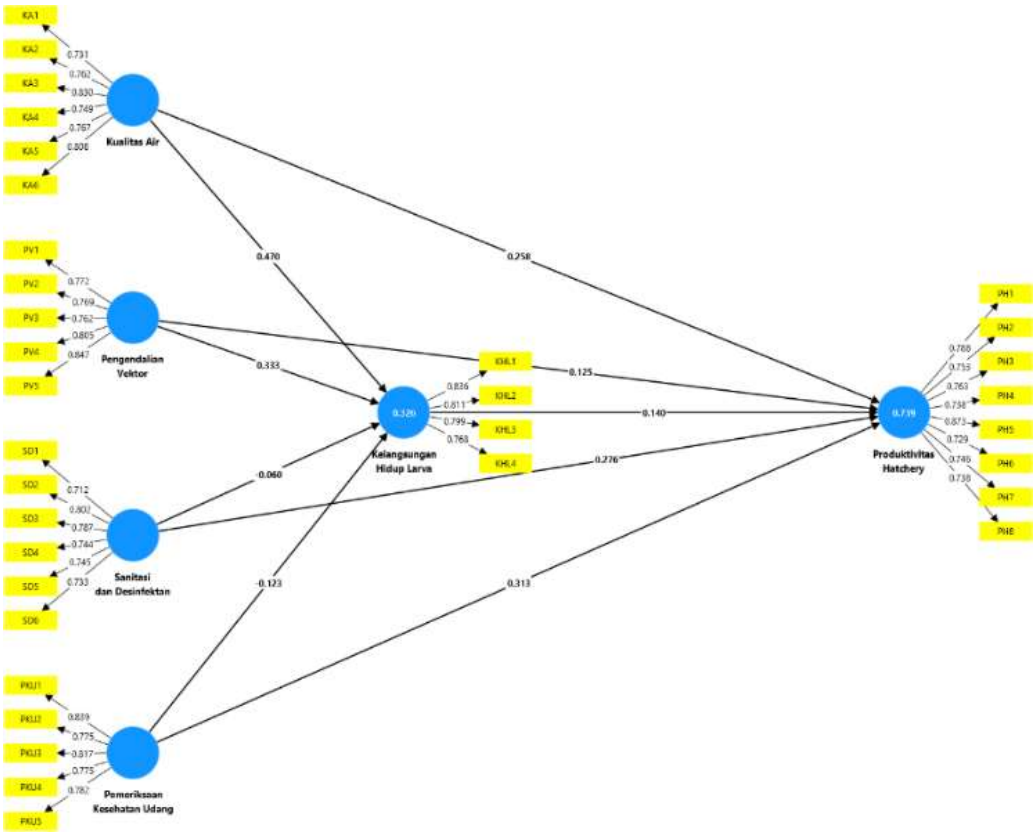


Figure 3. Outer Model

The outer model evaluation was performed to assess the validity and reliability of the measurement instruments for each research construct.

Convergent Validity

Convergent validity testing was conducted by examining the outer loading values and Average Variance Extracted (AVE). Based on the analysis results, all indicators in each construct obtained outer loading values above 0.70, namely Water Quality ranging from 0.731–0.830, Vector Control ranging from 0.762–0.847, Sanitation and Disinfection ranging from 0.712–0.802, Shrimp Health Monitoring ranging from 0.775–0.839, Larval Survival ranging from 0.768–0.836, and Hatchery Productivity ranging from 0.729–0.873. Furthermore, all constructs obtained AVE values above the recommended threshold of 0.50, indicating adequate convergent validity (Hair et al., 2022). These findings confirm that the indicators used in this study were capable of adequately representing their respective latent constructs.

Reliability Test

Reliability testing was performed using Cronbach's Alpha and Composite Reliability (CR). As presented in Table 1, all constructs obtained Cronbach's Alpha values above 0.70 and Composite Reliability values ranging from 0.70 to 0.95, indicating strong internal consistency and the absence of excessive indicator redundancy(12). Therefore, all measurement constructs used in this study were considered reliable and appropriate for structural model analysis.

Table 1. Reliability Test

Variable	Cronbach's Alpha	Composite Reliability
Water Quality	0,868	0,880
Vector Control	0,853	0,881
Sanitation and Disinfection	0,850	0,858
Shrimp Health Monitoring	0,858	0,866
Larval Survival	0,819	0,822
Hatchery Productivity	0,900	0,906

Discriminant Validity

Discriminant validity testing was conducted using the Heterotrait-Monotrait Ratio (HTMT). Discriminant validity assesses whether theoretically distinct constructs are empirically different from one another within the model. In other words, this evaluation ensures that each construct measures a unique aspect of the theoretical framework without excessive overlap with other constructs. The HTMT value provides a robust measure for evaluating discriminant validity, where values below 0.85 or, under a more lenient criterion, below 0.90 indicate that constructs are sufficiently distinct from one another.

Table 2. Discriminant Validity

Variable	LS	WQ	SHM	VC	HP	SD
Larval Survival						
Water Quality	0.572					
Shrimp Health Monitoring	0.406	0.785				
Vector Control	0.515	0.474	0.642			
Hatchery Productivity	0.546	0.795	0.822	0.624		
Sanitation and Disinfection	0.263	0.530	0.556	0.460	0.692	

Discriminant validity testing using the Heterotrait-Monotrait Ratio (HTMT) was conducted to ensure that each construct in the model represented a distinct concept. Based on the analysis results, all HTMT values among variables were below the threshold of 0.90. The highest HTMT values were found in the relationship between Shrimp Health Monitoring and Hatchery Productivity (0.822), followed by Water Quality and Hatchery Productivity (0.795).

These findings indicate that there was no excessive overlap among constructs. Therefore, the variables Larval Survival, Water Quality, Shrimp Health Monitoring, Vector Control, Hatchery Productivity, and Sanitation and

Disinfection fulfilled the criteria for discriminant validity and were appropriate for further structural model testing.

Inner Model Evaluation

The inner model evaluation was conducted to examine the relationships among latent variables within the research model. This analysis aimed to determine the effects of Water Quality, Vector Control, Sanitation and Disinfection, and Shrimp Health Monitoring on Larval Survival and Hatchery Productivity.

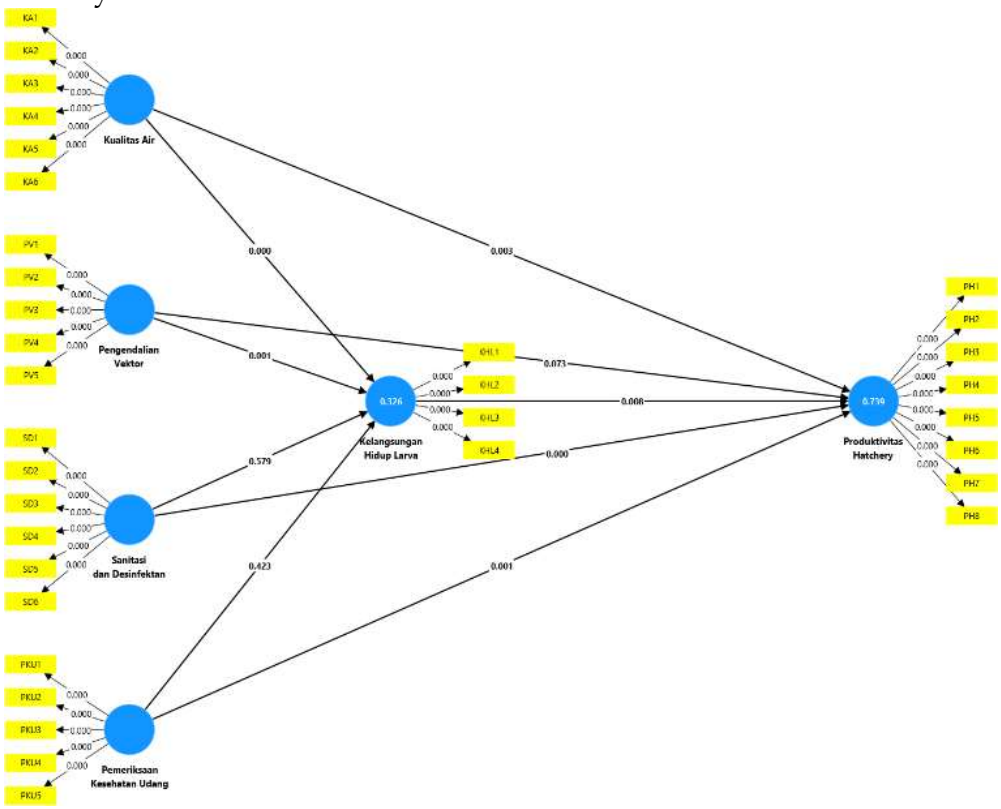


Figure 4. Inner Model

R – Square Test

The evaluation of R-square values was conducted to determine the ability of independent variables to explain dependent variables within the research model. The R-square value indicates the contribution of exogenous constructs in explaining endogenous constructs, while the adjusted R-square value represents the explanatory capability of the model after considering the number of predictors. A higher R-square value indicates a greater ability of the model to explain variations in endogenous variables (Hair et al., 2022).

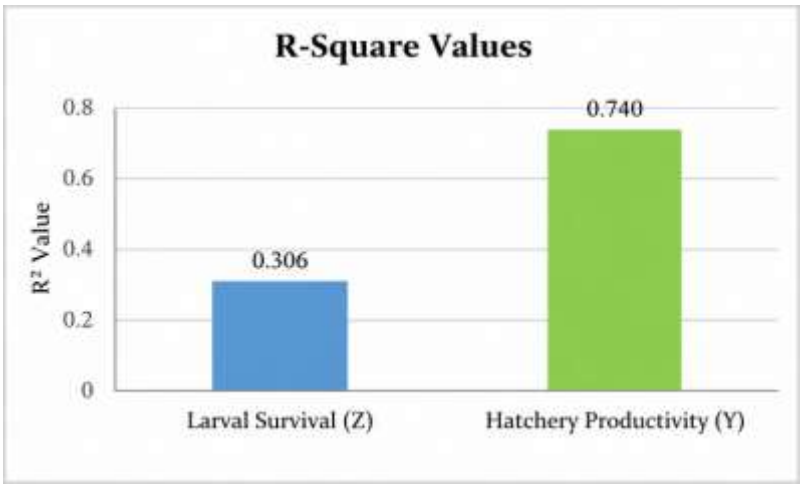


Figure 5. R – Square

Based on the analysis results, the Larval Survival variable obtained an R-square value of 0.326 and an adjusted R-square value of 0.299. This indicates that Water Quality, Vector Control, Sanitation and Disinfection, and Shrimp Health Monitoring were able to explain 32.6% of the variance in Larval Survival, while the remaining percentage was explained by other factors outside the research model. Meanwhile, the Hatchery Productivity variable obtained an R-square value of 0.739 and an adjusted R-square value of 0.726, indicating that the model was able to explain 73.9% of the variance in Hatchery Productivity. These findings indicate that the model has strong explanatory capability for Hatchery Productivity, while its explanatory capability for Larval Survival is categorized as moderate.

Effect Size (f – square)

Effect size evaluation or f-square analysis was conducted to determine the contribution magnitude of each independent variable toward dependent variables within the research model. The f-square value is used to assess whether the effect of a variable is categorized as very weak, weak, moderate, or strong. Generally, an f-square value of 0.02 indicates a small or weak effect, 0.15 indicates a moderate effect, and 0.35 indicates a large or strong effect (Hair et al., 2022).

Table 3. f – square

Relationship	f-square	Description
Water Quality → Larva Survival	0,168	Moderate
Vector Control → Larva Survival	0,106	Weak
Sanitation and Disinfection → Larva Survival	0,004	Very Weak
Shrimp Health Monitoring → Larva Survival	0,010	Very Weak
Water Quality → Hatchery Productivity	0,113	Weak
Vector Control → Hatchery Productivity	0,035	Weak
Sanitation and Disinfaction → Hatchery Productivity	0,206	Moderate
Shrimp Health Monitoring → Hatchery Productivity	0,159	Moderate
Larva Survival → Hatchery Productivity	0,051	Weak

Based on the analysis results, the effect of Water Quality on Larval Survival obtained an f-square value of 0.168, which was categorized as moderate. Vector Control on Larval Survival obtained a value of 0.106, categorized as weak, while Sanitation and Disinfection and Shrimp Health Monitoring on Larval Survival obtained values of 0.004 and 0.010, respectively, indicating very weak effects.

Regarding the relationships with Hatchery Productivity, Water Quality obtained an f-square value of 0.113 and Vector Control obtained 0.035, both categorized as weak effects. Meanwhile, Sanitation and Disinfection obtained a value of 0.206, and Shrimp Health Monitoring obtained 0.159, indicating moderate effects. The effect of Larval Survival on Hatchery Productivity obtained an f-square value of 0.051, which was categorized as weak.

These findings indicate that the largest contributions within the model were observed in the effects of Sanitation and Disinfection on Hatchery Productivity and Water Quality on Larval Survival.

Direct Effect

Direct effect testing was conducted to determine the direct relationships among variables within the research model. A relationship between variables was considered significant when the T-statistic value was greater than 1.96 and the P-value was less than 0.05. The original sample value indicates the direction and magnitude of the relationship, where positive values represent a direct relationship, while negative values indicate an inverse relationship.

Table 4. Direct Effects

Relationship	Original Sample (O)	T Statistics (|O/STDEV|)	P Values	Decision
Water Quality → Larval Survival	0,470	4,243	0,000	Significant
Vector Control → Larval Survival	0,333	3,430	0,001	Significant
Sanitation and Disinfection → Larval Survival	-0,060	0,555	0,579	Not Significant
Shrimp Health Monitoring → Larval Survival	-0,123	0,802	0,423	Not Significant
Water Quality → Hatchery Productivity	0,258	3,019	0,003	Significant
Vector Control → Hatchery Productivity	0,125	1,795	0,073	Not Significant
Sanitation and Disinfection → Hatchery Productivity	0,276	4,577	0,000	Significant
Shrimp Health Monitoring → Hatchery Productivity	0,313	3,311	0,001	Significant

Relationship	Original Sample (O)	T Statistics (|O/STDEV|)	P Values	Decision
Larval Survival → Hatchery Productivity	0,140	2,658	0,008	Significant

Based on the analysis results, Water Quality had a positive and significant effect on Larval Survival with a coefficient value of 0.470, T-statistic of 4.243, and P-value of 0.000. Vector Control also had a positive and significant effect on Larval Survival with a coefficient value of 0.333, T-statistic of 3.430, and P-value of 0.001. Meanwhile, Sanitation and Disinfection and Shrimp Health Monitoring did not significantly affect Larval Survival because their P-values were greater than 0.05. Regarding Hatchery Productivity, Water Quality, Sanitation and Disinfection, Shrimp Health Monitoring, and Larval Survival showed positive and significant effects with P-values of 0.003, 0.000, 0.001, and 0.008, respectively. However, Vector Control did not significantly affect Hatchery Productivity because its P-value was 0.073. These findings indicate that hatchery productivity is directly influenced more strongly by water quality management, sanitation and disinfection practices, shrimp health monitoring, and larval survival.

Indirect Effect

Indirect effect testing was conducted to determine the role of Larval Survival as a mediating variable in the relationship between biosecurity variables and Hatchery Productivity. An indirect effect was considered significant when the T-statistic value exceeded 1.96 and the P-value was below 0.05. The original sample value indicates the direction and magnitude of the indirect relationship through the mediating variable.

Table 5. Indirect Effects

Relationship	Original Sample (O)	T Statistics (|O/STDEV|)	P Values	Decision
Water Quality → Larval Survival → Hatchery Productivity	0,066	2,176	0,030	Significant
Vector Control → Larval Survival → Hatchery Productivity	0,047	2,063	0,039	Significant
Sanitation and Disinfection → Larval Survival → Hatchery Productivity	-0,008	0,548	0,584	Not Significant
Shrimp Health Monitoring → Larval Survival → Hatchery Productivity	-0,017	0,752	0,452	Not Significant

Based on the analysis results, Water Quality had a positive and significant indirect effect on Hatchery Productivity through Larval Survival, with a coefficient value of 0.066, T-statistic of 2.176, and P-value of 0.030. Vector Control also demonstrated a positive and significant indirect effect on Hatchery Productivity through Larval Survival, with a coefficient value of 0.047, T-statistic

of 2.063, and P-value of 0.039. Meanwhile, Sanitation and Disinfection and Shrimp Health Monitoring did not have significant indirect effects on Hatchery Productivity through Larval Survival because their P-values were greater than 0.05, namely 0.584 and 0.452, respectively. These findings indicate that Larval Survival acts as a mediating variable in the relationship between Water Quality and Vector Control with Hatchery Productivity. However, Larval Survival does not mediate the relationship between Sanitation and Disinfection or Shrimp Health Monitoring and Hatchery Productivity

DISCUSSION

The Influence of Biosecurity Component on Larval Survival and Hatchery Productivity

The findings indicate that water quality had a positive and significant effect on larval survival and hatchery productivity, suggesting that effective water management supports both biological and production outcomes. This is particularly relevant to hatcheries in Situbondo Regency, where seawater is used as the primary rearing medium and requires filtration, sterilization, and regular monitoring of temperature, pH, salinity, dissolved oxygen, and ammonia. Maintaining suitable water conditions helps minimize environmental stress and infection risks that may compromise larval development and survival. These findings are consistent with (Boyd, 2020), who emphasizes the importance of water quality for aquatic organism health and production, and (Akmal et al., 2020), who discuss closed-system water management in shrimp farming. Vector control also had a positive and significant effect on larval survival, although its direct effect on hatchery productivity was not significant. This pattern suggests that controlling potential disease carriers and transmission pathways primarily supports larval protection. Access restrictions, footbaths, protective nets, equipment separation, and control of personnel and material movement can help reduce opportunities for cross-contamination between rearing units. However, productivity also depends on other biological and operational factors, which may explain why the direct relationship with vector control was not statistically significant. These findings support biosecurity principles emphasizing the prevention of pathogen introduction and transmission within production systems (FAO, 2020; WOAH, 2021).

Sanitation and disinfection had a positive and significant effect on hatchery productivity but did not significantly affect larval survival, suggesting that their contribution may occur through facility cleanliness, production continuity, and contamination prevention across production cycles. The nonsignificant relationship with survival may reflect the influence of other conditions, such as water quality, stocking density, environmental stress, or limited variation in sanitation practices, although these explanations require further investigation. Shrimp health examination similarly had a positive and significant effect on productivity but no significant effect on survival. Visual assessment, mortality recording, and laboratory testing provide information for detecting health problems, but their contribution to survival depends on subsequent corrective actions, including isolation of affected batches and improvements to rearing conditions. These activities may also support output

quality and production decisions, consistent with the importance of health assessment in aquatic biosecurity (FAO, 2020; WOAH, 2021). Larval survival itself had a positive and significant effect on hatchery productivity, indicating that maintaining larvae throughout development contributes to the availability of postlarvae for harvest and marketing. Overall, the findings demonstrate complementary relationships among biosecurity components: water quality and vector control were significantly associated with larval survival, while water quality, sanitation and disinfection, shrimp health examination, and larval survival were significantly associated with productivity. Hatcheries in Situbondo should therefore implement these practices consistently as an integrated management system to support larval protection, postlarvae quality, production efficiency, and operational sustainability.

The Mediating Role of Larval Survival in the Relationship between Biosecurity Component and Hatchery Productivity

The findings indicate that water quality and vector control had significant positive indirect effects on hatchery productivity through larval survival. Water quality was also significantly associated with productivity directly, suggesting that its contribution involves both favorable production conditions and improved survival. In Pacific white shrimp hatcheries in Situbondo Regency, filtration, sterilization, and monitoring of temperature, pH, salinity, dissolved oxygen, and ammonia help maintain suitable conditions for larval development. Better survival subsequently supports the availability of postlarvae for harvest and marketing. This interpretation is consistent with (Boyd, 2020), who emphasizes the importance of water quality for aquatic organism health and production, and (Akmal et al., 2020), who discuss closed-system water management in shrimp farming. Vector control, meanwhile, showed a significant indirect relationship with productivity despite its nonsignificant direct relationship. Access restrictions, equipment separation, footbaths, and protective barriers may reduce opportunities for pathogen introduction and cross-contamination, thereby supporting larval survival. This reasoning aligns with biosecurity principles concerning the prevention of pathogen entry and transmission (FAO, 2020; WOAH, 2021). Together, these results identify larval survival as a significant pathway connecting environmental management and vector control with hatchery productivity.

Sanitation and disinfection and shrimp health examination did not show significant indirect effects on hatchery productivity through larval survival, although both had significant positive direct relationships with productivity. This pattern suggests that their contributions may involve operational continuity and output quality through pathways other than survival. Sanitation and disinfection help maintain clean facilities and control contamination between production cycles, while health examination provides information for disease detection and production decisions (FAO, 2020; WOAH, 2021). The absence of significant mediation may reflect limited differences in sanitation practices or the influence of other survival-related factors, but these explanations require further investigation. Similarly, visual assessment, mortality recording, and laboratory testing do not automatically improve survival unless followed by appropriate

corrective actions, such as batch isolation or improvements to rearing conditions. Overall, the results distinguish complementary roles among biosecurity components: water quality and vector control were linked to productivity through larval survival, whereas sanitation and disinfection and shrimp health examination were linked directly to productivity without significant mediation. Integrated biosecurity management should therefore combine environmental control and pathogen prevention with consistent sanitation and health assessment to support larval survival and hatchery production.

CONCLUSIONS AND RECOMMENDATIONS

Biosecurity implementation in Pacific white shrimp hatcheries in Situbondo Regency plays an important role in improving larval survival and hatchery productivity. Water quality was identified as a key factor because it influenced larval survival and hatchery productivity both directly and indirectly through survival rate. Vector control affected larval survival and indirectly supported hatchery productivity through improved survival rates. Meanwhile, sanitation and disinfection as well as shrimp health monitoring contributed more directly to increasing hatchery productivity but did not influence productivity through larval survival.

Therefore, Pacific white shrimp hatcheries in Situbondo Regency are recommended to prioritize routine water quality management, strict vector control, consistent sanitation and disinfection procedures, and regular shrimp health monitoring. Future studies are recommended to incorporate additional variables such as feed management, broodstock quality, stocking density, workforce competence, and technological monitoring systems to provide a more comprehensive explanation of hatchery productivity.

ADVANCED RESEARCH

This study has several limitations. Its cross-sectional design captures relationships at a single observation period and therefore cannot establish causal relationships or changes across production cycles. The purposive sample of 104 respondents from eight hatcheries in Situbondo Regency also limits the generalizability of the findings to other locations and production systems. Questionnaire-based measurements may be subject to respondent perceptions and reporting bias, while responses from personnel within the same hatchery may share organizational influences. Furthermore, the model explained 32.6% of the variance in larval survival, indicating that substantial variation remains unexplained.

Future research should employ longitudinal designs across multiple production cycles and include hatcheries from different regions. Questionnaire data should be complemented with measured water parameters, laboratory results, actual survival rates, and production records. Additional variables, including feed management, broodstock quality, stocking density, workforce competence, and monitoring technology, could improve the model's explanatory capacity. Multilevel analysis could also account for respondents nested within

hatcheries, while intervention studies could provide stronger evidence concerning the effectiveness of specific biosecurity practices.

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