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TECHNICAL EFFICIENCY OF VANNAMEI SHRIMP (*Litopenaeus vannamei*) FARMING IN SOUTH SULAWESI PROVINCE, INDONESIA

EFISIENSI TEKNIS USAHA BUDIDAYA UDANG VANAME (*Litopenaeus vannamei*) DI PROVINSI SULAWESI SELATAN, INDONESIA

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ABSTRACT

Shrimp is one of Indonesia's leading aquaculture commodities, with vannamei shrimp (*Litopenaeus vannamei*) dominating national output and export volume. However, fluctuating shrimp production in Pangkep Regency indicates suboptimal input utilization and technical inefficiency. This study evaluated technical efficiency levels while identifying key drivers of shrimp output and technical inefficiency using Stochastic Frontier Analysis (SFA) with a log-linear Cobb–Douglas specification. Empirical findings demonstrate that shrimp farmers operate with a high mean technical efficiency score of 0.819. Output is significantly affected by fry, feed, labor allocation, saponin, and fertilizer, with fry input emerging as the most sensitive factor. In Addition, technical inefficiency is significantly influenced by farming experience, stocking density, and farmer age. A returns to scale (RTS) value of 1.417 indicates that shrimp farming operates under increasing returns to scale (IRS), signaling substantial opportunities for output expansion. Maintaining rational stocking densities, optimizing input reallocation, and extending technical guidance to older and less experienced producers are recommended.

Keywords: production factors, returns to scale, technical efficiency, technical inefficiency, vannamei shrimp.

ABSTRAK

Udang merupakan salah satu komoditas akuakultur unggulan di Indonesia, dengan jenis udang vaname yang mendominasi produksi serta volume ekspor nasional. Namun, fluktuasi produksi udang di Kabupaten Pangkep mengindikasikan pemanfaatan input belum optimal dan timbulnya masalah inefisiensi teknis. Penelitian ini mengevaluasi tingkat efisiensi teknis serta mengidentifikasi faktor penentu produksi dan inefisiensi menggunakan metode *Stochastic Frontier Analysis* (SFA) berbasis fungsi Cobb–Douglas. Temuan empiris menunjukkan bahwa petambak tergolong efisien secara teknis dengan rerata skor 0,819. Hasil panen dipengaruhi secara signifikan oleh benur, pakan, curahan tenaga kerja, saponin, dan pupuk, dengan benur sebagai variabel yang paling sensitif. Inefisiensi teknis dipengaruhi oleh pengalaman budidaya, padat tebar, dan umur petambak. Nilai *Returns to Scale* (RTS) sebesar 1,417 menunjukkan kondisi *Increasing Returns to Scale* (IRS), mengindikasikan peluang besar untuk peningkatan produksi. Pengaturan padat tebar rasional, optimasi alokasi input, serta perluasan pendampingan teknis bagi petambak berusia tua dan kurang berpengalaman sangat disarankan.

Kata kunci: faktor produksi, skala hasil, efisiensi teknis, inefisiensi teknis, udang vaname.

INTRODUCTION

Aquaculture is one of the strategic sectors supporting Indonesia's fisheries production and export performance. Among aquaculture commodities, vannamei shrimp (*Litopenaeus vannamei*) has become the dominant species due to its rapid growth, high survival rate, and strong market

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demand. Consequently, increasing vannamei shrimp productivity has become one of the priority programs of the Ministry of Marine Affairs and Fisheries (KKP). The rapid development of vannamei shrimp farming has also contributed significantly to national aquaculture production and export performance (Badan Pusat Statistik, 2024), making production efficiency an increasingly important issue for ensuring the sustainability and competitiveness of the sector (Haris, 2019; Lestriadi & Wati, 2021).

According to Statistics Indonesia (Badan Pusat Statistik, 2024), national vannamei shrimp production fluctuated notably between 2016 and 2023. Production declined from 936,221 tons in 2016 to a low of 861,336 tons in 2019, before recovering to a peak of 953,178 tons in 2021 and reaching 941,646 tons in 2023. These fluctuations indicate that national shrimp production has not increased consistently despite the expansion of farming activities. This suggests that improving shrimp production inputs, but also on improving the efficiency with which existing resources are utilized through better farm management and production practices. Technical efficiency reflects farmers' ability to obtain maximum output from a given set of production inputs and has become an important indicator in evaluating the performance of shrimp farming enterprises (Begum et al., 2015; Thach et al., 2021)

Although production fluctuated over this period, the overall trend demonstrates steady growth, indicating that if pond-level cultivation is well-organized and managed, this sector holds substantial potential for stable development. Realizing this potential requires sound input management, including water quality control, disease prevention, efficient feed and nutrition allocation, and proper pond maintenance. Furthermore, increased domestic production directly strengthens Indonesia's shrimp export capabilities. Shrimp remains a premier export commodity facing growing global market demand. Supported by efficient and high-quality cultivation, harvests can meet international export standards in both volume and quality, serving as a strategic foundation for boosting national foreign exchange earnings.

According to the Ministry of Marine Affairs and Fisheries (KKP), South Sulawesi Province represents a strategic center for whiteleg shrimp aquaculture development in eastern Indonesia. Its extensive coastal potential and abundant human resources position South Sulawesi as a rapidly expanding region for enhancing productivity and competitiveness. Table 1 highlights the strategic position of South Sulawesi among Indonesia's top four major shrimp-producing provinces.

Table 1. Comparison of Shrimp Production across Major Shrimp-Producing Provinces (2018–2023)

Province	Production (ton)					
	2018	2019	2020	2021	2022	2023
West Java	121,403	136,808	131,499	178,199	128,776	132,599
East Java	103,494	104,616	114,886	118,953	122,754	118,330
West Nusa Tenggara (NTB)	130,423	156,046	159,013	177,514	186,368	194,648
South Sulawesi	43,820	44,528	49,903	54,875	61,338	66,577

Source: Statistics Indonesia (2024)

The cross-provincial comparison in Table 1 reveals that while South Sulawesi has not yet matched the total output volumes of West Java, East Java, or NTB, its production trajectory displays

consistent year-over-year growth. The rise from 43,820 tons in 2018 to 66,577 tons in 2023 reflects South Sulawesi's accelerating production potential.

Despite its lower production volume compared to West Java, South Sulawesi possesses a critical ecological advantage: superior and more stable water quality. Reports from the Ministry of Environment and Forestry (KLHK) on the Water Quality Index (WQI; *Indeks Kualitas Air*, IKA 2015–2020) classified Java Island as having the poorest water quality nationally. KLHK identified six Java provinces with the lowest IKA scores, with West Java consistently rated in the "poor" category over the five-year evaluation period. Nationally, Indonesia's average IKA reached only 53.53, failing to meet the national target of 55.1. The primary causes, namely high Biochemical Oxygen Demand (BOD), low Dissolved Oxygen (DO), and elevated Fecal Coliform contamination, indicate heavy domestic and industrial pollution in Java. Consequently, shrimp farming in West Java faces severe operational risks, including higher mortality rates, disease outbreaks, increased aeration requirements, and elevated water treatment costs, which ultimately undermine technical efficiency and long-term sustainability.

In contrast, environmental assessments in South Sulawesi indicate favorable water quality conditions for aquaculture. Physical and chemical parameter evaluations show that major water sources in South Sulawesi satisfy Class III water quality standards with a pollution index (PI ≤ 1), categorizing them as unpolluted. Furthermore, BOD levels ranging from 1.8 to 2.8 mg/L indicate lower organic waste loads than in Java. Consequently, while current production levels in South Sulawesi remain relatively modest, its long-term aquaculture sustainability is substantially higher due to better ecological stability, manageable water treatment requirements, and lower disease risks.

South Sulawesi is one of the major vannamei shrimp production areas in Indonesia. Within the province, Pangkep Regency is recognized as an important shrimp farming center. However, shrimp production and productivity in Pangkep remain relatively low and fluctuate over time.

Table 2. Vannamei Shrimp Production and Productivity in Pangkep Regency, 2020–2024

Year	Production (ton)	Pond Area (ha)	Productivity (ton/ha)
2020	2,043	11,015	0.18
2021	2,302	11,015	0.21
2022	2,025	11,013	0.18
2023	1,595	11,000	0.14
2024	2,840	10,996	0.26

Source: Fisheries and Marine Affairs Office of Pangkep Regency (2025)

Table 2 shows that vannamei shrimp production in Pangkep fluctuated during 2020–2024 (KKP, 2025), while productivity remained relatively low at approximately 0.18 ton/ha. This indicates that available production resources have not been utilized optimally. Previous studies reported that shrimp production is influenced by production inputs such as fry, feed, labor, fertilizer, and stocking density. Feed and shrimp fry are consistently reported as the most influential inputs affecting shrimp output, while labor and pond management also play important roles in determining production performance (Haris, 2019; Lestriadi & Wati, 2021; Purnamasari et al., 2022). Studies applying stochastic frontier analysis have also shown that differences in input use and farm management are associated with variations in technical efficiency among shrimp farmers (Lestriadi & Wati, 2021;

Purnamasari et al., 2022). Therefore, improving productivity in Pangkep requires not only increasing production inputs but also improving the efficiency with which these inputs are transformed into shrimp output.

Previous studies have applied stochastic frontier analysis to assess technical efficiency in agricultural production systems, including agricultural commodities in South Sulawesi (Arifin et al., 2021). In shrimp farming, Lestriadi & Wati (2021) and Purnamasari et al. (2022) estimated technical efficiency using stochastic frontier analysis, while Haris (2019) focused on the economic efficiency of production inputs. Previous studies have also examined farmers' management practices and their implications for farm performance (Tinaprilla et al., 2022). However, empirical evidence evaluating the comprehensive determinants of production and technical efficiency in vannamei shrimp farming in South Sulawesi remains limited. Existing studies have generally examined production factors or technical efficiency separately, without fully integrating the socioeconomic factors influencing technical inefficiency. Recent evidence from shrimp aquaculture in Vietnam has shown that farmer characteristics and farm management practices are also associated with technical inefficiency across different shrimp production systems (Le et al., 2022).

Therefore, this study aims to analyze the factors affecting vannamei shrimp production, estimate the level of technical efficiency, and identify the socioeconomic and farm-level determinants of technical inefficiency among vannamei shrimp farmers in Pangkep Regency.

RESEARCH METHODS

Sample Preparation

This research was conducted in Pangkajene and Islands (Pangkep) Regency, South Sulawesi Province, Indonesia, which was purposively selected as one of the major vannamei shrimp production centers in the province. The target population comprised active vannamei shrimp farmers in seven major coastal subdistricts: Pangkajene, Labakkang, Bungoro, Ma'rang, Minasatene, Mandalle, and Segeri. Official aquaculture records identified 2,873 registered aquaculture producers, of whom 1,837 (63.9%) cultivated vannamei shrimp. Because most farmers practiced traditional polyculture with milkfish or tilapia, respondents were purposively selected to meet three criteria: (1) being primarily or exclusively engaged in vannamei shrimp farming, (2) having completed at least one production cycle during the study period, and (3) being willing to participate (Etikan, 2016). This selection was intended to reduce measurement bias in input allocation attributable to polyculture systems.

The resulting sample comprised 100 specialized vannamei shrimp farmers, representing nearly the entire identified primary-producer frame in the study area. Thus, the sample provides high coverage of the eligible population, although purposive selection does not completely eliminate potential selection bias. The sample was also considered adequate for the estimated SFA model, which included seven production factors and seven technical inefficiency determinants. Following Coelli et al. (2005), model adequacy was assessed based on the number of observations relative to estimated parameters and the statistical significance and specification tests of the estimated frontier.

Since the study was limited to Pangkep Regency, the findings should not be directly generalized to all vannamei shrimp farmers in South Sulawesi.

Data Types

Primary data were used in this research. Farmers were interviewed directly using a structured questionnaire to obtain primary data. The questionnaire in this study collected data on vannamei shrimp production and production inputs (shrimp fry, feed, total labor, saponin, fertilizer, probiotic application, and lime application), as well as socioeconomic and farm characteristics of farmers, including age, education level, farming experience, stocking density, land ownership status, off-farm income status, and cultivation status.

Cobb–Douglas Production Function Analysis

Quantitative analysis was employed in this study using the Stochastic Frontier Analysis (SFA) approach to estimate the production frontier while separating random error from technical inefficiency (Aigner et al., 1977; Battese & Coelli, 1995). This study provides an integrated assessment by simultaneously examining the determinants of vannamei shrimp production, measuring farmers' technical efficiency, and identifying socioeconomic and farm-specific factors associated with technical inefficiency. The analysis uses farm-level data from Pangkep Regency, one of the important vannamei shrimp farming areas in South Sulawesi, where empirical evidence integrating production determinants and technical inefficiency remains limited.

The production relationship was specified using the Cobb–Douglas stochastic frontier production function because of its simplicity, direct interpretation of production elasticities, and ability to assess Returns to Scale (RTS) from the sum of input elasticities (Cobb & Douglas, 1928; Coelli et al., 2005). The parameters were estimated using Maximum Likelihood Estimation (MLE) following Battese & Coelli (1995), which simultaneously estimates the production frontier and technical inefficiency effects. The stochastic frontier production function is expressed as:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 \ln X_{5i} + \beta_6 \ln X_{6i} + \beta_7 X_{7i} + (v_i - u_i) \quad (1)$$

Description:

Y_i : Shrimp production (kg)
X_1 : Shrimp fry (tails)
X_2 : Feed (kg)
X_3 : Total labor (HOK)
X_4 : Saponin (kg)
X_5 : Fertilizer (kg)
X_6 : Probiotic application (1 = yes; 0 = no)
X_7 : Lime application (1 = yes; 0 = no)
β_0 : Intercept
$\beta_1 - \beta_7$: Estimated coefficients
V_i : Random error (noise effect)
U_i : Technical inefficiency effect

i : Farmer

The stochastic frontier model was estimated in Stata 17 using the maximum likelihood estimation (MLE) procedure. The significance of each production factor was evaluated using the Wald test, while the overall suitability of the stochastic frontier model was assessed using the likelihood ratio (LR) test. The LR test examines whether the stochastic frontier specification provides a significantly better representation of the production process than the conventional production function by testing for technical inefficiency (Coelli et al., 2005).

Technical Efficiency Analysis

Technical efficiency refers to the ability of producers to obtain the maximum possible output from a given set of production inputs and technology (Farrell, 1957) in the stochastic frontier framework. Technical efficiency is measured as the ratio of observed output to the corresponding frontier output. Technical efficiency values range from 0 to 1, where values closer to 1 indicate that producers operate nearer to the production frontier and utilize production resources more efficiently (Coelli et al., 2005). The technical efficiency score for each farmer was estimated from the stochastic frontier model as:

$$TE_i = \frac{Y_i}{Y_i^*} \quad (2)$$

where:

$$TE_i = \exp(-U_i)$$

where TE_i denotes the technical efficiency of farmer *i*, Y_i is the observed output, Y_i^* is the frontier output, and U_i is the technical inefficiency component.

Technical Inefficiency Model

Quantitative analysis used the Stochastic Frontier Analysis (SFA) framework, which is grounded in the concept of technical efficiency (Farrell, 1957) and stochastic production frontier theory (Aigner et al., 1977). The log-linear Cobb–Douglas specification was adopted because its parameters directly represent production elasticities, allow straightforward estimation of Returns to Scale (RTS), and provide a parsimonious functional form for the cross-sectional sample of 100 farmers (Coelli et al., 2005). Production inputs (fry, feed, labor, saponin, fertilizer, probiotic, and lime) were selected based on the aquaculture production process and previous empirical studies of shrimp farming (Boyd & Tucker, 1998; Lestriadi & Wati, 2021; Purnamasari et al., 2022).

Technical inefficiency determinants were estimated simultaneously with the production frontier using the one-step maximum likelihood estimation (MLE) procedure of Battese & Coelli (1995). This approach enables the production frontier and inefficiency effects to be estimated simultaneously, using the following equation:

$$-u_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + \delta_6 Z_{6i} + \delta_7 Z_{7i} + w_i \quad (3)$$

Description:

Z_1 : Age (years)

Z_2 : Education (years)

Z_3 : Farming experience (years)

Z_4 : Stocking density (shrimp/m²)

Z_5 : Land ownership (1 = own; 0 = otherwise)

Z_6 : Off-farm income ($1 =$ yes; $0 =$ no)

Z_7 : Farming status ($1 =$ main occupation; $0 =$ otherwise)

Negative parameter estimates indicate that the corresponding variable reduces technical inefficiency and therefore improves technical efficiency, whereas positive coefficients indicate higher technical inefficiency (Battese & Coelli, 1995).

RESULT AND DISCUSSION

Technical Efficiency Levels in Vannamei Shrimp Farming

Pangkajene and Islands Regency (Pangkep) is one of the major vannamei shrimp production centers in South Sulawesi Province, Indonesia. Vannamei shrimp farming in the study area generally comprises 2-3 production cycles per year, with practices ranging from traditional to semi-intensive systems. Each cycle includes pond preparation, post-larvae stocking, grow-out and maintenance, harvesting, and post-harvest handling. Pond preparation generally involves drying and cleaning, followed by applying lime, saponin, and fertilizer based on pond conditions. Ponds are then gradually filled with water before post-larvae stocking. Farmers use PL10, PL12, and PL15 post-larvae, which are acclimatized before stocking. Stocking density varies across production systems and is an important management decision because higher densities increase feed requirements, oxygen demand, and pressure on water quality.

During the grow-out stage, feed is supplied according to shrimp growth and feeding activity, while water quality and shrimp condition are routinely monitored. Probiotics and other disease-control practices may also be applied. In semi-intensive systems, paddle-wheel aerators are used to support dissolved oxygen supply and water circulation, with operating schedules varying according to shrimp growth stage and farm conditions. Harvesting generally occurs at 60–90 days, with shrimp commonly harvested at market sizes of 40–70. These management practices influence the use of production inputs and farmers' ability to achieve efficient production. The present study therefore examines the determinants of vannamei shrimp production using stochastic frontier analysis (SFA) estimated by maximum likelihood estimation (MLE).

The variable indicators used in this production frontier model include Fry (X_1), defined as vannamei shrimp post-larvae (number of individuals); Feed (X_2), defined as the primary food source for shrimp growth (kg); Total Labor (X_3), measured in person-days (HOK); Saponin (X_4), which is a natural pesticide used to eradicate pests and predators during pond preparation (kg); Fertilizer (X_5), used to stimulate natural food availability (kg); Probiotic application dummy (X_6), used to maintain water quality stability; and Lime application dummy (X_7), used for soil and water pH management. The output variable (Y) is the total production of vannamei shrimp per production cycle (kg). Table 3 presents the estimated results of the Cobb-Douglas stochastic production frontier model and shows the contribution of each production input to vannamei shrimp production.

Table 3. Estimation Results of the Cobb-Douglas Production Function (MLE)

Variables	Coefficient	Standard Error	z-ratio	p-value
Intercept	-3.782***	0.756	-5.01	0.000
Fry (X_1)	0.556***	0.088	6.30	0.000
Feed (X_2)	0.197**	0.057	3.43	0.001
Total Labor (X_3)	0.218**	0.078	2.82	0.005
Saponin (X_4)	0.283**	0.093	3.04	0.002
Fertilizer (X_5)	0.163**	0.073	2.23	0.026
Probiotic (Dummy) (X_6)	-0.018	0.196	-0.09	0.927
Lime (Dummy) (X_7)	-0.182	0.231	-0.79	0.430
Sigma Squared (σ²)	1.310			
Gamma (γ)	0.814	0.696	1.17	0.242
Wald Chi-Square (χ^2)	510.39***			0.000
LR Test (χ^2)	19.871***			0.000
Log Likelihood OLS	-89.248			
Log Likelihood MLE	-79.313			

Note: significant at the 1% level (***), significant at the 5% level (**), and significant at the 10% level (*).

An analysis of factors affecting the production of vannamei shrimp farming in Pangkep Regency was conducted to address the production determinants. The production function was analyzed using the Stochastic Frontier model with the maximum likelihood estimation (MLE) method to estimate overall production factors, the intercept, and the two error components (v_i and -u_i). Seven input variables were included in this model: Fry, Feed, Total Labor, Saponin, Fertilizer, Probiotic application, and Lime application.

The estimation results in Table 3 show that the overall production function is statistically significant, as indicated by a Wald Chi-Square value of 510.39 ($p < 0.01$). Partial testing (z-test) demonstrates that among the seven production factors, five variables significantly affect vannamei shrimp production. At the 99% confidence level ($\alpha = 1\%$), four factors Fry, Feed, Total Labor, and Saponin significantly influence production. At the 95% confidence level ($\alpha = 5\%$), Fertilizer application significantly affects productivity. Conversely, Probiotic and Lime dummy applications do not exert statistically significant effects on vannamei shrimp production in the field.

The Fry variable has the largest production elasticity with a coefficient of 0.556 ($p < 0.01$). This indicates that a 1% increase in Fry stocking increases vannamei shrimp production by 0.556% *ceteris paribus*. This finding aligns with the research of Nurhidayati et al. (2022) and Thriveni et al. (2022), which identified shrimp seed and other production inputs as important determinants of shrimp production. The elasticity coefficient of shrimp fry is the most dominant compared to other production inputs, indicating that seed is the most sensitive factor in determining harvest output. The selection of high-quality, Specific Pathogen-Free (SPF) fry and precise stocking quantities are crucial for farmers to maximize pond productivity.

The Feed variable significantly affects production at the 1% significance level with an elasticity value of 0.197. Every 1% increase in Feed allocation will increase vannamei shrimp production by 0.197% *ceteris paribus*. This is in line with the research of Lestriadi & Wati (2021) and Haris (2019),

which explained that feed is a vital nutritional input that significantly drives shrimp output. Feed contributes significantly to the growth rate and weight gain of whiteleg shrimp. Controlled feeding management is essential to meet nutritional requirements while avoiding excess feed accumulation that could deteriorate pond water quality. For instance, implementing initial blind feeding combined with routine tray (*anco*) monitoring optimizes feed efficiency (74.6%–77.2%) and maintains a stable FCR of 1.3 (Shilman et al., 2023). Furthermore, optimizing feed allocation through C:N ratio manipulation via carbohydrate addition allows pelleted feed to be reduced by up to 20% without compromising growth performance (Tinh et al., 2023).

Total Labor exhibits a positive and significant effect on vannamei shrimp production at the 1% level ($\alpha = 1\%$) with an elasticity coefficient of 0.218, meaning every 1% increase in labor input increases output by 0.218% *ceteris paribus*. This finding supports Folorunso et al. (2021), who highlighted labor as an essential input affecting aquaculture yields. Labor allocation reflects the intensity of daily farm management, such as water quality monitoring, feeding control, and dike maintenance. The effective utilization of labor directly influences the overall success of shrimp culture management.

Saponin and Fertilizer variables also positively and significantly affect production at the 1% and 5% significance levels, with elasticity values of 0.283 and 0.163, respectively. Every 1% increase in Saponin and Fertilizer usage increases shrimp output by 0.283% and 0.163%, respectively, *ceteris paribus*. Fertilizer stimulates natural food growth during the early culture period, and saponin effectively eradicates predators during pond preparation (Novriadi et al., 2022).

The Probiotic (-0.018) and Lime (-0.182) dummy variables do not significantly influence vannamei shrimp production. Under actual field conditions in Pangkep, chemical/biological treatments often suffer from unstandardized dosages and non-uniform application methods, failing to yield direct production gains. The non-significant effects of the probiotic and lime dummy variables suggest that most farmers in the study area have not implemented biological and chemical treatments according to standardized operational procedures. Unstandardized dosages and ad hoc application without accurate soil and water pH measurements prevent these inputs from generating statistically significant yield improvements.

The estimated Gamma (γ) value is 0.814, indicating that 81.4% of the total error variance is due to technical inefficiency effects (u_i), rather than random noise effects (v_i) such as extreme weather or disease outbreaks. Furthermore, the LR Test value of 19.871 is statistically significant ($p < 0.01$), supporting that the stochastic frontier specification is superior to conventional OLS regression. The MLE log-likelihood value (-79.313) is higher than the OLS log-likelihood value (-89.248), demonstrating that the SFA model provides a better fit to field conditions.

Technical Efficiency Levels of Vannamei Shrimp Cultivation Business

The estimated technical efficiency scores indicate how closely vannamei shrimp farmers operate to the stochastic production frontier. Table 4 presents the distribution of farmers according to their technical efficiency levels.

Table 4. Distribution of Technical Efficiency Levels in Vannamei Shrimp Farming

No	Technical Efficiency	Percentage
1	< 0.50	9%
2	0.50 – 0.69	11%
3	0.70 – 0.89	32%
4	0.90 – 1.00	48%
	Total	100%
	Max.	0.999
	Min.	0.225
	Mean	0.819

Technical efficiency ranges between zero (0) and one (1). According to Coelli et al. (2005), a farming business is more efficient if its technical efficiency value is close to one (1) and inefficient if it is close to zero (0). A farm is generally considered technically efficient if its score exceeds 0.70. As demonstrated in Table 4, the majority of vannamei shrimp farmers in Pangkep Regency are technically efficient, achieving an average technical efficiency score of 0.819 (81.9%). This indicates that, given the observed input levels and production technology, the farmers operate at approximately 81.9% of the estimated stochastic production frontier. The remaining 18.1% represents a relative technical efficiency gap from the estimated frontier and should not be interpreted as a guaranteed increase in output that can be achieved without additional analysis.

The lowest technical efficiency recorded among vannamei shrimp farmers is 0.225, while the highest is 0.999. Table 4 shows that 48% of farmers (48 people) achieved high efficiency scores between 0.90 and 1.00, operating close to the production frontier. Another 32% (32 people) achieved scores between 0.70 and 0.89. Only 20% of farmers (20 people) recorded technical efficiency scores below 0.70. Compared with small-scale shrimp farms across Indonesia reported by Hukom et al. (2022), which had a mean efficiency of 0.44, vannamei shrimp farming in Pangkep Regency operates at a substantially higher average technical efficiency level. This implies that vannamei shrimp farmers in Pangkep can still increase production by 18.1% using existing inputs and technology simply by optimizing managerial practices.

Factors Affecting Technical Inefficiency of Whiteleg Shrimp Farming Business

The characteristics of respondents in the vannamei shrimp farming business in Pangkep Regency, South Sulawesi Province, include the age of the farmer, farming experience, formal education level, stocking density, land ownership status, off-farm income status, and cultivation status, which can be seen in Table 5.

Table 5. Characteristics of Respondents in the Vannamei Shrimp Farming Business

No	Variables	Description	Maximum	Minimum	Mean	SD
1	Age	Age of shrimp farmers (years)	69.00	25.00	48.35	9.10
2	Experience	Experience of shrimp farmers (years)	30.00	2.00	8.72	6.23
3	Education	Formal education of shrimp farmers (years)	19.00	0.00	10.42	3.52
4	Stocking density	Stocking density of shrimp fry (shrimp/m²)	243.75	0.15	9.57	28.83
5	Land Ownership	Land ownership status: owned (1) or non-owned (0)	1.00	0.00	0.91	0.29

6	Non-farm income	Off-farm employment: present (1) or absent (0)	1.00	0.00	0.26	0.44
7	Cultivation status	Shrimp farming is the primary occupation (1) or secondary (0)	1.00	0.00	0.79	0.41

The factors affecting the technical inefficiency of the vannamei shrimp farming business in Pangkep Regency, South Sulawesi Province, were analyzed using the one-step Stochastic Frontier Analysis (SFA) inefficiency effects model. The results of the estimated technical inefficiency model for vannamei shrimp farming are presented in Table 6.

Table 6. Estimation Results of Factors Affecting Technical Inefficiency ($-u_i$)

Inefficiency Variables (Zi)	Coefficient	Standard Error	z-ratio	p −value
Intercept	0.064	4.588	0.01	0.989
Age (Z_1)	0.100*	0.052	1.94	0.053
Education (Z_2)	-0.103	0.103	-0.99	0.320
Experience (Z_3)	-0.767**	0.357	-2.15	0.032
Stocking density (Z_4)	0.021*	0.011	1.90	0.058
Land ownership (Z_5)	0.146	1.362	0.11	0.914
Non-Farm Income Dummy (Z_6)	-1.271	2.436	-0.52	0.602
Cultivation Status Dummy (Z_7)	-2.439	2.672	-0.91	0.361

Note: significant at the 5% level (**), and significant at the 10% level (*).

The factors affecting technical inefficiency were estimated simultaneously with the production frontier using the one-step MLE method (Battese & Coelli, 1995). In the inefficiency model, a negative coefficient sign indicates a reduction in technical inefficiency (a positive effect on technical efficiency), whereas a positive coefficient indicates an increase in technical inefficiency.

As shown in Table 6, three variables significantly affect technical inefficiency: Farming Experience, Stocking Density, and Age. Farming Experience has a negative and statistically significant coefficient ($-0.767; p = 0.032$) at the 5% significance level. This indicates that farmers with more experience achieve lower levels of technical inefficiency. Experienced farmers possess better practical intuition in managing feeding regimes, recognizing early disease symptoms, and handling water quality fluctuations, consistent with findings by Duy et al. (2023). The negative effect of farming experience on technical inefficiency indicates that more experienced producers possess better practical intuition and technical competence in handling water quality fluctuations, recognizing early disease symptoms, and adjusting daily feeding rates.

Stocking Density exhibits a positive and statistically significant coefficient ($0.021; p = 0.058$) at the 10% significance level, demonstrating that stocking density beyond the optimal carrying capacity increases technical inefficiency. High stocking density intensifies competition for feed and space while suppressing individual growth performance (Hardianto et al., 2024; Irani et al., 2023). Furthermore, excessive density degrades overall water quality through dissolved oxygen depletion, ultimately elevating mortality risks (Mohammed et al., 2024).

Farmer's Age has a positive coefficient ($0.100; p = 0.053$), significant at the 10% level. This indicates that older farmers tend to experience higher technical inefficiency. A similar relationship between farmer age and technical inefficiency was reported by Begum et al. (2015) in shrimp farming. The positive association between farmer age and inefficiency implies that older producers are

generally less responsive to modern aquaculture innovations and face physical constraints compared to younger farmers. The other explanatory variables, Education (-0.103), Land Ownership (0.146), Non-Farm Income (-1.271), and Primary Cultivation Status (-2.439) have no statistically significant effect on technical inefficiency. These results indicate that practical field experience and appropriate stocking management are the primary drivers of technical efficiency among vannamei shrimp farmers in Pangkep Regency.

Returns to Scale (RTS)

The Returns to Scale (RTS) value was calculated as the sum of the elasticity coefficients of continuous production inputs, yielding an RTS of 1.417. Since RTS > 1, the production exhibits Increasing Returns to Scale (IRS), indicating that a proportional increase in these inputs is associated with a more-than-proportional increase in estimated output. However, the feasibility of increasing production scale requires further cost-benefit analysis considering input and output prices.

CONCLUSION AND SUGGESTION

Conclusion

The results showed that vannamei shrimp farming in Pangkep Regency, South Sulawesi Province, is technically efficient. This can be proven by the average level of technical efficiency attained by farmers, which stands at 0.819. This indicates that farmers still have the potential to improve optimal production by 18.1% by focusing on factors that significantly influence vannamei shrimp production in Pangkep Regency, South Sulawesi Province. Factors affecting shrimp production include fry, feed, total labor, saponin, and fertilizer. Conversely, probiotic and lime application do not influence vannamei shrimp production. Furthermore, the research results indicate that experience, stocking density, and age are the main determinants affecting technical inefficiency. Vannamei shrimp farmers in Pangkep Regency are relatively technically efficient, and as a whole, they have allocated inputs and resources appropriately.

Suggestion

Empirical results indicate that shrimp fry have the highest production elasticity among continuous inputs, followed by saponin, labor, feed, and fertilizer. Farmers should prioritize quality fry selection and optimize feed management to prevent water quality deterioration. Technical inefficiency estimates show that farming experience reduces inefficiency, whereas farmer age and higher stocking density are associated with greater inefficiency. Extension programs should target older and less-experienced producers with tailored guidance. Technically efficient farms (TE ≥ 0.70) provide an empirical benchmark of 7.78 shrimp/m² for stocking density. Because SFA measures frontier efficiency rather than exact point optima, further bio-economic analysis is recommended to identify technically and economically optimal input ratios.

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