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The production cost efficiency of bioindustrial agriculture: A case study in Bengkulu province Indonesia

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ABSTRACT

Location-specific bioindustrial agriculture integrating coffee and cattle is a farming system that optimally manages and utilizes all biological resources, including biomass or agricultural waste. The issue of productivity in bioindustrial agriculture is closely related to cost efficiency. This study aims to analyze income and the determinants affecting the cost efficiency of coffee–cattle integrated bioindustrial farming. The research was conducted in Rejang Lebong Regency, Bengkulu Province, Indonesia, which is a center of robusta coffee production. A total of 100 farmers were selected using purposive sampling. Data analysis employed the income function and the stochastic frontier cost function using the Maximum Likelihood Estimation (MLE) method. The results showed that the cost efficiency value of integrated coffee–cattle bioindustrial farming is 12.07% and is still at an inefficient level; this is due to the low adoption rate. Factors that significantly influence cost efficiency are revenue, seed price, NPK fertilizer price, calf price, compost price, and labor wages, while feed prices have no significant effect. Meanwhile, factors that significantly affect cost inefficiency include age, number of family members, coffee farming experience, cattle farming experience, and education. The study recommends collaboration between the government, agricultural extension workers, and farmers to develop extension and training programs on location-specific bioindustrial farming. Increased adoption of this system is expected to improve both income and production cost efficiency.

Contribution/Originality: This study has investigated bioindustrial farming based on the integration of coffee and cattle, practiced widely by farmers in Rejang Lebong, Indonesia. However, adoption rates and production cost efficiency still remain low due to farmers' lack of waste management skills. These findings have implications for farmer training programs by relevant stakeholders.

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1. INTRODUCTION

The challenges of agricultural development are becoming increasingly complex in efforts to enhance food security and sustainably meet the demand for food, feed, and energy. Agriculture in Bengkulu Province continues to face problems of low productivity and poor product quality, with a large amount of agricultural and livestock waste not being optimally utilized. Farming activities remain highly dependent on chemical inputs and have yet to adequately consider production cost efficiency. On the other hand, agricultural land is limited due to land conversion for non-agricultural purposes. As a result, increases in agricultural and livestock production cannot be achieved extensively but must instead rely on intensive methods. Therefore, it is necessary to develop agricultural systems that optimize land use and process agricultural waste so that it can be reused by both crops and livestock, a system known as bioindustrial agriculture.

Bioindustrial agriculture is a farming system that optimally manages and utilizes all biological resources, including biomass or agricultural waste, which are processed to produce a variety of high-value food, feed, fertilizer, and energy products within a harmonious ecosystem (Balitbang, 2015). One approach to developing sustainable bioindustrial agriculture is through crop–livestock integration, which can be applied to different commodities as a representation of diverse regional conditions.

Based on several scientific activities and regular discussions conducted by researchers and onsite farmers since 2024, we found that bioindustrial agriculture in Bengkulu Province was recognized and applied by local farmers and local extension instructors through practicing an integration farming system between palm plantations and cows and buffaloes in North Bengkulu Regency, Central Bengkulu Regency, and South Bengkulu Regency (Kurniati, Putranto, & Jafrizal, 2025). Reported by Pasaribu, Wijaya, and Surya (2017), there was an integration between honey bees and horticultural farming in Rejang Lebong regency and Kepahiang regency. However, those studies indicated that the integration farming system in Bengkulu Province is still mostly applied with traditional and regular farming systems. These earlier applied integration and bioindustrial agricultural systems have not been able to provide a significant contribution to farmers' income in the regencies. Therefore, through this most recent bioindustrial agriculture system introduced by the researchers, a neo-integration system was offered by introducing a touch of closed circular agriculture as a novelty of this recent study. They introduced the processing of unused livestock fecal and urinary waste as natural fertilizer, which does not require the cost of purchasing and making environmentally and financially friendly natural pesticides.

Supported by extensive land, climate, and geographical conditions, Bengkulu Province is dominated by plantation and livestock commodities. Coffee is one of the leading commodities cultivated by farmers. In 2024, coffee production in Bengkulu reached 2.5 tons per hectare with a harvested area of 92,780 hectares. Bengkulu is among the largest robusta coffee-producing regions in Indonesia, with production in 2023 reaching 55,000 tons, or 7.23% of the national total. Rejang Lebong Regency is one of the central coffee-producing areas in the province and is prioritized as a national-scale coffee development region. In Rejang Lebong, robusta coffee is a leading plantation commodity, with a planted area of 30,392 hectares producing 14,826.89 tons (BPS, 2024).

In the livestock sector, beef cattle are the most important ruminants, contributing significantly to meat supply and meeting food needs, particularly animal protein. Cattle are raised by the majority of farmers in Bengkulu Province and serve as a key source of rural household income. In 2024, the cattle population reached 164,780 heads (BPS, 2024).

The objective of this study is to analyze income and the determinants affecting production cost efficiency of location-specific bioindustrial farming based on coffee-cattle integration in Rejang Lebong Regency, Bengkulu Province. The novelty of this study lies in the use of a stochastic frontier cost function to analyze determinants affecting production costs in farming systems that combine two types of production crops and livestock, whereas previously, this function was used only for single-commodity analysis.

2. LITERATURE REVIEW

Bioindustrial agricultural based on integration between plants and livestock is generally widely practiced with plantation crops. The purpose of an integrated farming system is to optimally utilize land functions, improve soil quality, increase yields, produce diverse food, and enhance land-use efficiency. The development of livestock using an integrated pattern on plantation lands such as oil palm, coffee, cocoa, and coconut has good prospects (Fyka, Limi, Zani, & Mokodompit, 2019). Plantation crops in an intercropping system are the main component, while grass and livestock grazing on them are the second components. Intercropping is a horizontally diversified part of an integrated farming system. An integrated farming system is a solution to the problem of limited agricultural areas and plantations in Bali (Siswati, 2021). The effective use of agricultural areas and plantations will increase with the integration of livestock, and integrated farming often includes both crop and livestock enterprises (Archer, Franco, Halvorson, & Pokharel, 2018). The approach to integrating livestock with food crops, plantations, and industrial forest plantations is feasible and should be developed technically, economically, and socially to increase the population of beef cattle with low production costs (Kusumo, Priyanti, & Saptati, 2017).

The expansion of coffee plantations and cattle populations also increases the volume of waste biomass, which, if not optimally utilized, can have negative environmental impacts. Coffee husks, which constitute 45–50% of the harvested coffee weight, are abundant. Their nutritional content is sufficient for conversion into livestock feed (Widyotomo & Sukirno, 2013). Meanwhile, an adult cow produces 4–5 tons of fresh manure annually (Howara, 2011). Plant and livestock waste are critical resources not only as organic material to improve crop growth and soil quality but also as sources of animal feed and alternative household energy to replace fossil fuels (Bhati et al., 2024; Hai et al., 2020; Munandar, Gustiar, Yakup, Hayati, & Munawar, 2015).

Smallholder coffee farming is still based on a monoculture system. This system lacks integration between biomass-producing agriculture, biomass processing industries, waste management, water utilization, energy generation, and soil nutrient conservation (Nwaogu & Cherubin, 2024). As a result, it faces various problems, such as: (1) low productivity and product quality, (2) unutilized waste, and (3) dependence on external inputs (Wulandari, Ardana, Massinai, & Hartati, 2020).

A solution to these issues is the development of location-specific bioindustrial agriculture systems. This can be achieved by integrating crops and livestock, while optimally managing and utilizing all biological resources, including agricultural and livestock biomass or waste, within a harmonious ecosystem. More broadly, bioindustrial agriculture involves processing agricultural and livestock resources with the aid of simple industrial technologies to produce various agricultural outputs of higher economic value. Processing is not only aimed at increasing production but also at diversifying agricultural products into functional food sources, thereby improving farmers' economic welfare (Hendayana, 2015).

The fundamental principles of bioindustrial agriculture are minimal waste, minimal imported inputs, processing biomass and waste into new bioproducts, crop–livestock integration, application of technological innovations, and environmental friendliness (Balitbang, 2015; Hida, Rachmina, & Rifin, 2023). The development of bioindustrial agriculture represents sustainable agricultural development that applies small-scale technologies and is both technically and economically feasible (Hendriadi, 2015).

Farmers' income from coffee and cattle can be increased by utilizing cattle manure and urine to produce compost and biourine, which can also be converted into bioenergy in the form of gas (Jaishankar, Janagoudar, Basavaraj, Vasudev, & Siddayya, 2014; Soni, Katoch, & Ladohia, 2014). Meanwhile, crop waste such as coffee husks can be used as animal feed (Dahono, Nuristina, Ekalinda, Agussalim, & Hidayat, 2019). Coffee husks are among the plantation by-products suitable for cattle feed. Pamungkas and Utomo (2008) explained that in each coffee bean processing, husks account for 45%, beans for 40%, mucilage for 10%, and parchment for 5%. According to Muryanto, Subagyo, and Rudi (2011) from 2,000 tons of coffee produced, 10–21.5% can be utilized as livestock feed. Research by Astuti, Sugandi, and Wahyuni (2015) showed that farmers' adoption of coffee cultivation technology is only 40.9%, and the adoption rate of cattle farming management reached only 42.52%, suggesting significant potential to enhance farmers' motivation to adopt both coffee cultivation and cattle farming technologies to improve production.

3. METHODOLOGY

3.1. Scope of the Study

This research employed a survey method conducted in Rejang Lebong Regency, Bengkulu Province. The research location was selected purposively, considering that Rejang Lebong is a center of coffee cultivation covering 30,393 hectares (BPS, 2024). The study was carried out in two sub-districts that serve as central coffee production areas, namely Sindang Beliti Ulu (3,145 hectares) and Selupu Rejang (3,380 hectares). In addition, many coffee farmers in these areas also raise cattle.

3.2. Sample Size and Sampling Procedure

The sampling method used was Accidental Sampling, where selected samples were deemed suitable and qualified as data sources (Sugiyono, 2008). The research sample consisted of farmers who were also cattle raisers. The number of samples was determined based on the opinion of Sukiyono (2018), who stated that if the sampling frame of the population is not clearly known, the minimum number of samples should be at least ten times the number of variables studied. Therefore, 100 coffee farmers in Sindang Beliti Ulu and Selupu Rejang sub-districts were selected as respondents.

3.3. Data Collection

Data were collected through observation and interviews. Primary data were obtained using questionnaires and interviews with farmers, cattle raisers, village officials, agricultural extension workers, and the Department of Agriculture and Animal Husbandry. Secondary data were collected from relevant institutions and agencies that support the research.

3.4. Data Analysis Techniques

The data analysis techniques used in this research were as follows:

To calculate the income of location-specific bioindustrial farming integrating coffee and cattle, the income function adapted from Siahaan, Harianto, and Pambudy (2025) was used.

$$Y = TR - TC \quad (1)$$

$$TR = Q \times Pq \quad (2)$$

$$TC = FC + VC \quad (3)$$

Where:

Y = Bioindustrial farming income (Rp/year).
TR = Total revenue (Rp/year).
TC = Total cost (Rp/year).
Q = Output quantity (kg, head).
Pq = Output price (Rp/kg, Rp/head).
FC = Fixed cost (Rp/year).

VC = Variable cost (Rp/year).

To calculate the cost efficiency of location-specific bioindustrial farming based on coffee–cattle integration, the Stochastic Frontier Cost Function was used.

The stochastic frontier cost function (Stochastic Frontier Analysis, SFA) is an economic analysis model used to estimate the production cost function by considering stochastic or random technical inefficiency (Nguyen & Pham, 2020). This model separates the error term into two components: one representing measurement error and random disturbances (noise), and the other representing farm-level technical inefficiency. Cost efficiency analysis using SFA is based on a cost frontier that can be expressed as follows (Kumbhakar & Lovell, 2000).

$$Ei \geq c(yi, wi, \beta) \quad (4)$$

Equation 8 shows cost efficiency as the ratio of the minimum possible cost to the actual cost. Since $Ei \geq c(yi, wi, \beta)$, then $CEi \leq 1$. $CEi = 1$ if $xni = xni\ (yi, wi; \beta)$, so what $Ei = \sum n\ wni\ xni\ (yi, wi;\beta)$ reaches the minimum possible value for $c(yi, wi; \beta)$. Conversely, $CEi < 1$ indicates that the minimum cost ratio is lower than the actual cost. Thus, the smaller the value of CEi, the more inefficient the farm is.

The deterministic cost frontier $c(yi, wi;\ \beta)$ ignores the fact that costs may be influenced by random shocks outside the farmer's control. Therefore, the Stochastic Cost Frontier can be written as:

$$E_i \geq c(y_i, w_i; \beta).exp\{v_i\} \quad (5)$$

$[c(y_i, w_i; \beta).exp\{v_i\}]$ is the *stochastic cost frontier*.

The stochastic cost frontier comprises a deterministic component $c(yi, wi;\ \beta)$, which applies to all farms, and a random component $exp(v_i)$, which is unique to each farm. Therefore, the equation for cost efficiency is expressed as:

$$CE_i = \frac{c(y_i, w_i, \beta).\exp\{v_i\}}{E_i} \quad (6)$$

This defines cost efficiency as the ratio of the minimum cost achievable in an environment characterized by exp $\{vi\}$ to the actual cost. The value of $Cei \leq 1$, $CEi = 1$ if and only if $Ei = c(yi, wi, \beta)$. Exp $\{vi\}$. Conversely, $CEi \leq 1$ indicates that the minimum cost is lower than the actual cost.

In this study, the Stochastic frontier was applied, referring to Aigner, Lovell, and Schmidt (1977); Meeusen and van Den Broeck (1977) and Coelli (1996), with the following equation.

$$Ci = C\ (yi, wi) + (vi + ui) \quad (7)$$

Where:

Ci = total production cost of bioindustrial farming.

yi = output produced.

wi = input prices.

vi = random error distribution.

ui = error term (Inefficiency effect).

Cost efficiency analysis was conducted by deriving the dual cost function from the production function (Maulidi, 2025). This method minimizes input cost functions under the constraint of the production function, resulting in the following dual frontier cost function.

$$Ln\ BP = \beta_o + \beta_1 In\ TR + \beta_2 In\ Pnpk + \beta_3 In\ Pbbt + \beta_4 In\ Pkom + \beta_5 In\ Ptk + \beta_6\ PAnk + \beta_6 Ppa + (v_i + \mu_1) \quad (8)$$

Where:

In BP = Production cost of bioindustrial farming (Rp).

In TR = Revenue (Rp/year).

In Pnpk = NPK fertilizer price (Rp/kg)

In Pbbt = Seed price (Rp/plant).

In Pkom = Compost price (Rp/kg).

In Ptk = Labor wage (Rp/HKSP).

In Pank = Calf price (Rp/head).

Ln Ppak = Feed price (Rp/kg).

β_o = Intercept.

$\beta_1 - \beta_7$ = Estimated parameter coefficients.

$V_i + \mu_i$ = *Error term* (μ_i = inefficiency effect in the model).

The distribution parameter of cost inefficiency effects (μi) in this study was formulated as:

$$\mu i = \delta_0 + \delta_1\ Um + \delta_2\ Agt + \delta_3\ PgK + \delta_4 PgS + \delta_5 Pd \quad (9)$$

Where :

μi = Cost inefficiency effect.

Um = Farmer's age (Years).

Agt = Number of family members (Persons).

PgK= Coffee farming experience (Years).

PgS = Cattle farming experience (Years).

Pd = Formal education of farmer (Years).

δ_0 = Intercept

$\delta 1 \ldots \delta_5$ = Estimated parameter coefficients.

The above model parameters were estimated using the Maximum Likelihood Estimation (MLE) method with the Frontier 4.1 software developed by Coelli (1996). Estimation of cost efficiency parameters and inefficiency functions was carried out simultaneously (Battese & Coelli, 1995; Coelli, 1996) in the following form.

$$\sigma^2 \equiv \sigma^2_u + \sigma^2_v \text{ dan } \gamma \equiv \frac{\sigma u}{\sigma v} \quad (10)$$

Where :

σ^2 = Variance of the normal distribution.

σ^2_u = Variance u_i.

σ^2_v = Variance v_i.

4. RESULTS

4.1. Socio-Economic Characteristics of Farmers

Socio-economic factors influence farmers' decision-making in their farming activities (Diaz et al., 2022; Mogaka, Bett, & Karanja Ng'ang'a, 2021). In coffee–cattle integrated bioindustrial farming, the socio-economic factors include respondent characteristics such as age, education level, family size, coffee farming experience, cattle farming experience, coffee land area, and the number of cattle owned by farmers.

Table 1. Socio-Economic Characteristics of farmers.

Variables	Min.	Max.	Average
Age (Years)	27	75	47.26
Education	Elementary	Bachelor	Junior High
Number of family members (Persons)	1	7	3.72
Coffee farming experience (Years)	4	42	13.71
Cattle farming experience (Years)	1	23	7.21
Coffee land area (Ha)	0.4	2.25	1.12
Number of cattle (Heads)	1	5	2.13

Table 1 shows that the minimum age of farmer respondents is 27 years, the maximum is 75 years, and the average is 47.26 years. This age range is considered productive, thus enabling respondents to manage both coffee farming and cattle raising effectively.

Education level influences farming activities since it affects farmers' way of thinking and their ability to absorb technology and information. Based on Table 1, the education level of respondents is relatively low, with most farmers having only attended junior high school. This implies that their mindset tends to be static, making it difficult for them to adopt new technologies and innovations in managing coffee farming and cattle raising.

The average number of family members per household is 3.72. This indicates a relatively limited availability of family labor, which can reduce the adoption rate of location-specific integrated coffee–cattle bioindustrial farming.

Table 1 also shows that the average coffee farming experience is 13.71 years, while the cattle farming experience is 7.21 years. Farmers with greater experience generally possess better knowledge and skills in managing their farms, which can enhance productivity and income. Experience also helps farmers adopt new technologies and manage farming-related risks more effectively.

The minimum land size for coffee farmers is 0.4 ha, the maximum is 2.25 ha, and the average is 1.12 ha. Coffee plantations are often located relatively far from farmers' homes, which hinders the adoption of integrated coffee–cattle bioindustrial farming since cattle are usually raised in barns near farmers' houses. In addition, the number of cattle kept is relatively small, averaging 2.13 heads, meaning that the manure produced is insufficient to meet the needs of the coffee land.

4.2. Income Analysis of Location-Specific Bioindustrial Farming

4.2.1. Coffee Farming Analysis

Coffee farming income was calculated for one harvesting year when the coffee plants were over four years old. The average coffee plantation area is 1.12 hectares, with production calculated in the form of dry coffee beans amounting to 2,041 kg, which is equivalent to 1,832.32 kg/ha/year, at an average price of Rp 57,360/kg. The revenue from coffee farming was Rp 116,840,850/year, obtained by multiplying dry coffee bean production by the coffee price. Meanwhile, the production cost of coffee farming was Rp 40,974,185/year, resulting in a net income of Rp 75,866,665/year.

Table 2. Coffee farming analysis per year.

No.	Variables	Per Year
1.	Production (Kg)	2,041
2.	Price (Rp/Kg)	57,360
3.	Revenue (Rp)	116,840,850
4.	Cost (Rp)	40,974,185
5.	Income (Rp)	75,866,665

Table 2 shows that coffee income was relatively high at Rp 75,866,665 per year due to the relatively high price of coffee at the time of study. Furthermore, the use of manure in coffee farming can reduce the use of chemical fertilizers, thus saving on fertilizer costs.

4.2.2. Cattle Farming Analysis

The income analysis of beef cattle farming is calculated as the difference between revenue and production costs. Revenue from this activity comes from the sale of cattle and by-products in the form of compost. Almost all farmer respondents did not produce bio-urine due to the relatively small number of cattle and the difficulty of collecting urine. The results of the cattle farming income analysis are presented in Table 3.

Table 3. Cattle Farming Analysis per Year.

No.	Variables	Per Years
1	Production	
	- Cattle (heads)	2.12
	- Compost (kg)	1108
2	Price	
	- Cattle (Rp/head)	16,985,000
	- Compost(Rp/kg)	1255
3	Revenue	
	- Cattle (Rp)	33,920,000
	- Compost(Rp)	1,534,000
4	Total Revenue (Rp)	37,679,000
5	Total Cost (Rp)	26,395,000
6	Income (Rp)	11,397,700

Cattle production consists of live cattle with an average of 2.12 heads and 1,108 kg of compost, generating a revenue of Rp 37,679,000 per year and a production cost of Rp 26,395,000. Thus, the net income from cattle farming is Rp 11,397,705 per year.

4.2.3. Income from Location-Specific Coffee–Cattle Integrated Bioindustrial Farming

The research results show that the income from coffee farming was Rp 75,866,665/year, while the income from cattle farming was Rp 11,397,700/year. Hence, the total income from location-specific integrated coffee–cattle bioindustrial farming amounted to Rp 87,264,370/year. This income is calculated as the sum of coffee and cattle farming income within one year.

Table 4. Income from location-specific coffee–cattle integrated bioindustrial farming (Rp/year).

No.	Type	Coffee (Rp/Year)	Cattle (Rp/Year)	Total
1.	Revenue	116,840,850	37,679,000	154,519,850
2.	Cost	40,974,185	26,395,000	67,255,480
3.	Income	75,866,665	11,397,700	87,264,370

Table 4 shows that coffee farming income is Rp 75,866,665/year and cattle farming income is Rp 11,397,700/year, resulting in bioindustry income of Rp 87,264,370/year. Coffee farming income contributes more to bioindustry income than cattle farming income. In fact, coffee farming is the primary occupation of farmers, while cattle farming is carried out on a small scale around farmers' homes.

4.3. Determinants of Cost Efficiency in Location-Specific Bioindustrial Farming

The results of this study show that the cost efficiency of integrated coffee–cattle bioindustrial farming was 12.07%, with a minimum of 10.57% and a maximum of 35.18%. Referring to efficiency criteria from Ogundari and Ojo (2006), Laha and Kuri (2011) and Nwaru, Okoye, and Ndukwu (2011), this indicates that location-specific integrated coffee–cattle bioindustrial farming remains inefficient.

This inefficiency is due to the low adoption level of coffee–cattle integration in the study area, with an adoption score of 38.57%. Several factors explain this: coffee plantations are relatively far from farmers' homes (on average, 3.5 km), while cattle are raised in barns near the house. None of the farmers keep cattle or build barns in their coffee fields, making it difficult to transport compost to the fields. Moreover, the topography of the coffee plantations is not entirely flat; some are located on slopes and valleys, making it difficult to apply compost. Another limiting factor is the relatively small herd size, averaging 2.12 cattle per farmer, which does not produce enough manure and urine to meet the fertilizer needs of coffee fields averaging 1.13 hectares. According to Azzahrah, Budiraharjo, and Handayani (2023), an adult cow can produce 4–5 tons of fresh manure per year, which can be processed into 2–2.5 tons of compost per head annually. Since 1 hectare of coffee land requires around 4.5 tons of compost, the available manure is insufficient.

Table 5. Stochastic Frontier Cost Function for Coffee–Cattle Bioindustrial Farming.

Variable	Coefficient	Standard Error	t – Ratio
Ln Constant (β0)	5.15	1.17	4.37
Ln Revenue (β1)	-0.92E-08	0.66E-09	-13.91**
Ln Seed Price (β2)	0.617	0.051	11.98**
Ln NPK Fertilizer Price (β3)	0.618E-08	0.95E-09	6.50**
Ln Calf Price (β4)	-0.031	0.057	-0.54**
Ln Compost Price (β5)	-0.231E-10	0.929E-10	-24.90*
Ln Labor Wage (β6)	0.164	0.064	2.55*
Ln Feed Price (β7)	0.908E-10	0.866E-10	1.048
Sigma squared (σ2)	0.417	0.575	7.24
Gamma (γ)	0.609	0.262	4.19
LR test of the one-sided error			3.70

Note : ** Significant at α = 1%, t table α = 1% = 2.373.
* Significant at α = 5%, t table α = 5% = 1.665.

Source : Processed Primary Data, 2025.

Cost efficiency in integrated coffee–cattle bioindustry farming using the stochastic frontier method refers to the analysis of farmers' ability to produce coffee and cattle at minimal cost, while considering factors that cannot be fully controlled. This method separates technical inefficiency from random error factors in coffee and cattle production, thereby allowing the identification of where farmers can improve their cost efficiency.

Cost efficiency was analyzed using the Stochastic Frontier cost function with the Maximum Likelihood Estimation (MLE) model. The results of the analysis on the γ parameter, which is the ratio of the variance of cost efficiency (μi) to the total production variance (εi) among farmers, were found to have a highly significant effect at the 0.01 confidence level. This is also supported by the very significant value obtained from the LR test of the one-sided error. The LR test value obtained for integrated coffee–cattle bioindustry farming was 3.70.

Table 5 shows that the gamma coefficient value is 0.609, which means that 60.9% of the total variation in production costs in the integrated coffee–cattle bioindustry farming is influenced by independent variables such as revenue, seedling price, NPK fertilizer price, calf price, compost price, labor wages, and feed price. Meanwhile, the remaining 39.1% is influenced by inefficiency variables, namely age, number of family members, experience in coffee farming, experience in cattle farming, and farmers' education.

4.4. Determinants of Cost Inefficiency in Location-Specific Bioindustry Farming

Determinants of cost inefficiency were analyzed using the stochastic frontier cost function with the maximum likelihood estimation (MLE) model. In the stochastic production frontier function, inefficiency effects are modeled as a function of socio-economic variables. Table 6 shows that in location-specific bioindustry farming, all variables, namely farmers' age, number of family members, coffee farming experience, cattle farming experience, and education, significantly affect cost inefficiency. Referring to the study of Alabi (2024) it is stated that there is a positive correlation between the level of technical inefficiency and farmers' age, farm scale, and the number of laborers used, and a negative correlation between the technical inefficiency level and producers' experience.

Table 6. Cost inefficiency in location-specific bioindustry farming.

Variable	Coeffcient	Standard Error	t – Ratio
Constant (σo)	0.0108	9.960	0.0109
Age (σ1)	- 2.610	2.987	-8.738*
Number of family members (σ2)	-0.000002	0.000004	-7.357*
Coffee farming experience (σ3)	1.197	2.104	5.689*
Cattle farming experience (σ4)	0.000020	0.000022	8.988*
Education (σ5)	0.0419	0.0513	8.180*

Note: * Significant at α = 5%, t table α = 5% = 1.665.

The variable of farmers' age has a significant negative effect on bioindustry farming cost inefficiency. This indicates that as farmers get older, cost inefficiency increases. This result aligns with the study of Islam, Mitra, and Khan (2023), which noted that farmers' age and education affect technical inefficiency in fishpond farming in Bangladesh.

The number of family members has a significant negative effect on cost inefficiency in integrated coffee–cattle bioindustry farming, indicating that a larger family size reduces cost inefficiency. The average family size of farmers is relatively small, 3.72 persons, which sometimes does not meet the labor needs of integrated coffee–cattle bioindustry farming. This finding is supported by Sidabutar, Sitepu, and Hermanto (2024), who found that family size has a significant negative effect on cost inefficiency in shellfish farming in North Sumatra.

Coffee farming experience shows a significant effect on cost inefficiency in location-specific integrated coffee–cattle bioindustry farming. The average coffee farming experience of farmers is relatively long, 13.71 years, since coffee farming is their main occupation.

The variable of cattle farming experience also shows a significant effect on cost inefficiency in integrated coffee–cattle bioindustry farming. Farmers in the study area mainly work as coffee farmers, with cattle raising as a side occupation. Their cattle farming experience is relatively recent, averaging 7.21 years, far below their coffee farming experience.

Education has a significant effect on bioindustry farming cost inefficiency, where the higher the education level, the more rational farmers are in managing their farming activities. This finding aligns with Hasanah, Fauziyah, and Suprapti (2025), who reported that farmers' education and age affect cost inefficiency in corn farming.

5. DISCUSSION

The income from integrated coffee–cattle bioindustrial farming amounted to Rp 87,264,370 per year, or the equivalent of Rp 7,272,030 per month. Of this income, 87% came from coffee farming and 13% from cattle farming. Compared to the Regional Minimum Wage (UMR) of Bengkulu Province in 2025, which is Rp 2,670,039 per month (BPS, 2024), the farmers' income is far above the minimum wage. This indicates that the farmers' standard of living is already decent and relatively prosperous.

This finding is consistent with Parulian, Munthe, and Haloho (2019) who reported an increase in farmers' income from integrated coffee–cattle systems in Samosir Regency, North Sumatra, as well as studies by Ramana et al. (2025) which state that crop–livestock integration can enhance farmers' income.

However, in this bioindustrial farming system, coffee farming still dominates income. This is because coffee farming is the main occupation of farmers, while cattle farming is only a side activity at home. All farmers raise cattle in barns located near their houses, far from coffee plantations, and none keep cattle or build barns within the coffee fields. This is due to the fact that coffee fields are not managed or visited daily, whereas cattle must be fed every day, making it impractical to raise cattle in the coffee plantations.

The research also indicates that the adoption rate of location-specific integrated coffee–cattle bioindustrial farming is relatively low, at 38.57%. This low adoption rate is caused by the small number of cattle raised, averaging only 2.12 heads, which produces insufficient manure for composting. Moreover, none of the farmers process bio-urine due to difficulties in collecting it, as the barns are still simple and not suitable for urine storage. Overall, the limited development of cattle farming is due to a lack of capital and technology, which results in suboptimal productivity. This is supported by Nainggolan, Azhari, Sihombing, Wijaya, and Basriwijaya (2025) who state that beef cattle management in Perbaungan District, Sumatra, is still not optimal, leading to low farmer income.

Additionally, farmers do not process coffee husk waste into cattle feed due to limited labor and waste management skills. Moreover, cattle tend to dislike coffee husks because they contain tannins, which in large amounts can disrupt digestion. Muryanto et al. (2011) explained that tannins can bind and precipitate protein; therefore, to reduce tannin content, coffee husk waste needs to be fermented before being fed to cattle. So far, farmers only pile up the waste and allow it to decompose, after which it is used as fertilizer for coffee plants or as a planting medium for ornamental plants.

The low adoption rate of coffee–cattle integration can also be attributed to limited farmer awareness of its benefits, high initial investment costs (for cattle, barns, feed, and infrastructure), land constraints, and inadequate technical support. Many coffee farmers do not yet fully understand the benefits of integration, such as improved soil fertility, reduced use of chemical fertilizers, and additional income from livestock by-products. Moreover, bioindustrial farming with integrated systems requires upfront costs for purchasing livestock, constructing barns, and feed provision. Farmers with limited capital are often reluctant to bear such costs. Integration also requires sufficient land for coffee plants, livestock housing, and grazing areas, which is limited in the study location. Bell and Moore (2012) and Bell, Moore, and Kirkegaard (2014) also noted similar constraints in Australia, where integration adoption was limited due to shortages of labor and capital.

Technical support is also critical. Farmers need training on proper cattle husbandry, feed management, and livestock health, but such support is often lacking. Even when extension programs exist, they may not be effective in changing farmers' behavior (Nurida, Evahelda, & Sitorus, 2024). Extension materials may be irrelevant to local conditions, or the delivery method may fail to attract farmers' interest.

Addressing these issues requires integrated efforts from the government, research institutions, and farmer organizations (Haerat, Ansari, & Fatmawati, 2022). Strengthening farmers' understanding through effective extension, improving access to financing, and providing continuous technical support are essential to increase adoption levels of coffee-cattle integration.

In this study, coffee and cattle production are expressed as combined revenue from coffee and cattle, since it is not possible to combine the production of two commodities with different units. Partially, the revenue variable has a very significant negative effect on bioindustry coffee–cattle farming production costs. This indicates that an increase in revenue will reduce the production costs of location-specific bioindustry farming. The revenue variable is used as an expression of coffee and cattle production, where the higher the revenue, the higher the production of coffee and cattle. By increasing productivity (output per unit input), farmers can produce more output with the same or even lower costs, thereby reducing production costs per unit. This is supported by Kavitha, Samuel, Rao, Goverdhan, and Chary (2024) who stated that integrated farming generates higher production because the combination of crops and livestock is more efficient in the use of production factors, thus reducing production costs.

In addition, higher revenue enables farmers to reinvest in more efficient equipment and technology, such as modern agricultural machinery or improved irrigation systems, which reduces the use of fertilizers, pesticides, and labor, ultimately lowering unit production costs. Increased revenue may also allow farmers to expand their farm scale. Larger-scale farming tends to be more efficient in terms of production costs because fixed costs (such as land rent and equipment depreciation) can be spread over a larger production volume (Qi et al., 2023).

The results of the stochastic frontier cost function analysis indicate that all independent variables significantly affect bioindustry farming production costs, except for feed price, which has no significant effect. The study findings reveal that the seedling price variable has a highly significant positive impact on production costs. This suggests that an increase in coffee seedling prices will lead to higher production costs for integrated coffee–cattle bioindustry farming. Coffee seedlings are a crucial component in the coffee cultivation process (Nirmala & Hardjanto, 2022). An increase in seedling prices directly raises the costs that farmers or coffee producers must bear. As the initial raw material in coffee cultivation, rising seedling prices increase the initial investment required to start or expand coffee farms. In the study area, coffee seedling prices are relatively uniform, ranging from Rp 2,500 to Rp 3,000 per plant. The seedlings purchased are generally Robusta coffee varieties obtained from local farmers. Higher coffee seedling prices may disproportionately impact smallholder farmers with limited capital, who may struggle to purchase high-quality seedlings at increased prices, ultimately affecting coffee productivity.

The NPK fertilizer price variable has a significant positive effect on bioindustry farming production costs, which indicates that as the price of NPK fertilizer increases, production costs in integrated coffee–cattle bioindustry farming will also rise. When NPK fertilizer prices increase, farmers must spend more to purchase fertilizer. This increase directly raises the overall production costs of coffee. NPK fertilizer (Nitrogen, Phosphorus, Potassium) is one of the most widely used fertilizers in coffee cultivation. This fertilizer provides essential nutrients needed by coffee plants to grow, fruit, and produce high-quality coffee beans. Nitrogen helps in chlorophyll formation, which is essential for photosynthesis, and stimulates shoot and leaf growth. Phosphorus plays a role in root growth, flower and fruit formation, and improving coffee bean quality. Potassium helps in water and nutrient transport, increases plant resistance to disease and drought stress, and improves fruit quality (Rohani, Prayogo, Suprayogo, & Wicaksono, 2024).

In the study area, all farmers use NPK fertilizer in coffee farming, although a small number of farmers combine it with cattle compost. The price of NPK fertilizer ranges between Rp 16,000 and Rp 17,500 per kg. Farmers use NPK fertilizer because chemical fertilizers show results more quickly than organic cattle compost, whose effects are only visible in the next planting season. Furthermore, NPK fertilizer is easier for farmers to obtain from agricultural shops, while cattle compost requires time for processing.

The calf price variable has a significant negative effect on bioindustry farming production costs. This indicates that the higher the calf price, the lower the production costs. This result aligns with (Mukhlis, Hendriani, Sari, & Sari, 2022) Mukhlis, Hendriani, Sari, and Sari (2022), who reported that calf prices affect cattle farming income in Harau, West Sumatra. The cattle raised by farmers are beef cattle, fattened for 8–12 months and sold during Eid al-Adha. Because the fattening period is relatively short, calves purchased are already over 1 year old, with relatively high prices ranging from Rp 9,500,000 – Rp 11,000,000 per head. The cattle farming system is relatively non-intensive, with many animals being released to graze in fields or farms. This reduces feed costs, and with a relatively short fattening period, feed and veterinary costs can also be minimized. The study results show that the compost price variable has a significant negative effect on integrated farming production costs. This indicates that the higher the compost price, the lower the production costs. Compost has a significant relationship with farming production costs. The use of compost can reduce the purchase of chemical fertilizers, which tend to be more expensive, thereby lowering overall production costs. The research found that the use of compost on rice crops reduced chemical fertilizer costs by 27.75%. This is also consistent with Harjadi et al. (2023) who reported that compost prices significantly affect cost efficiency in vegetable farming at Mount Ciremai National Park, West Java. In addition, compost improves soil quality and crop yields, which can ultimately increase farmers' income.

Compost enhances soil fertility by providing essential nutrients for plants and improving soil structure (Chadwick et al., 2015). Fertile soil produces healthier and more productive crops, which ultimately improve yields (Bieluczyk et al., 2020). Although there are initial costs for purchasing or making compost, long-term use of compost can provide savings on chemical fertilizer costs.

The labor wage variable has a significant positive effect on bioindustry farming production costs, indicating that rising labor wages increase bioindustry farming production costs. This is consistent with Grinnell, van der Linden, Azhar, Nobilly, and Slingerland (2022) who stated that labor wages significantly affect cost efficiency in cattle–oil farm integration in Malaysia. Furthermore, an increase in labor costs in bioindustry farming for processing agricultural products and waste. Labor wages in the study area range from Rp 80,000 to Rp 110,000 per working day. In this research analysis, although family labor is not paid in real terms, it is still considered an implicit cost. The labor used by farmers works simultaneously in both coffee and cattle farming. Most labor comes from within the family, but during coffee harvest season, some farmers also hire workers for coffee picking.

Meanwhile, the feed price variable has no effect on bioindustry farming production costs. This is consistent with Buza, Holden, White, and Ishler (2014) who stated that feed price has no significant effect on dairy cattle farming, with income feed per cost being more important. In the study area, most farmers feed their cattle with grass, and a small number combine it with tofu waste. Many farmers raise cattle by releasing them in fields or on the edges of their yards from morning to evening, and at night, the cattle are brought into pens. With this system, cattle forage for their own feed in the field, so farmers do not need to prepare or gather feed daily. This is why feed prices do not affect production costs. Moreover, cattle farming is a side activity for farmers, while the main occupation remains coffee farming and other horticultural crops.

In the study area, the average age of respondent farmers is 47.26 years, which falls into the older age group, although still within the productive age category. Older farmers may have more experience, but they may be less adaptive to new technologies, which hampers efficiency and increases costs. Farmers may be less familiar with or reluctant to adopt modern technologies that could improve efficiency. The lack of technology adoption can cause inefficiency in production processes. Age can also affect farmers' physical condition and health. As farmers grow older, their physical strength and management capacity in farming decline (Handayani, Lestari, Aryani, & Kristina, 2023). Older workers may have lower productivity or require more rest, which impacts production costs and ultimately leads to inefficiency in bioindustry farming.

Cost efficiency can be influenced in two opposing ways: a larger number of dependents increases household consumption costs, but it also provides internal labor, reducing the need to hire external workers, which theoretically can lower production costs. However, in general, more family members tend to increase the financial burden to meet daily needs, which can reduce cost efficiency since more resources must be allocated for consumption (Wuepper, Wimmer, & Sauer, 2020). Farmers with sufficient capital may hire external labor, while those with limited capital rely solely on family labor, making coffee and cattle farming less efficient.

Experienced farmers are more capable of managing production factors optimally, mastering better production techniques, and having a deeper understanding of coffee farming processes (Ho, Hoang, & Wilson, 2021). Such experience allows farmers to allocate resources more precisely, reduce waste, and increase productivity, which ultimately lowers per-unit production costs. With more experience, farmers can adopt best practices that lead to higher production with the same or even fewer inputs for the same output.

The number of cattle raised is also small and tends to be managed less intensively. Because of the small herd size, farmers rarely collect urine since cattle are often released outside the pen. However, feces are usually collected and processed into compost for plants. Due to the less intensive farming system (Navichoc, Alamneh, Batistic, Dietz, & Kilian, 2024) and small herd size, cost inefficiency in production occurs.

Education has the potential to improve cost efficiency by encouraging rational thinking and technology adoption. However, its effectiveness also depends on how education is combined with practical experience and farmers' ability to apply knowledge effectively in farming. The average education level of respondent farmers is junior high school, categorized as low. Low education among farmers causes cost inefficiency because of their limited knowledge and skills in combining and using production factors optimally. This leads to inefficient use of inputs such as fertilizers and pesticides, as well as tools (Tran, Tran, Pham, & Nguyen, 2023). Farmers with lower education levels are less able to adopt integrated coffee–cattle bioindustry practices, which results in higher production costs.

6. CONCLUSION AND RECOMMENDATION

The research findings indicate that the coffee–cattle bioindustry farming is not yet efficient because farmers face difficulties in implementing integration due to the relatively long distance between coffee plantations and farmers' homes, as well as the relatively small number of cattle owned. These conditions make it difficult for farmers to process cattle waste for be in coffee farming. On the other hand, farmers have also not processed coffee waste into cattle feed due to limited resources and knowledge.

The policy implications, such as recommendations given, are that the government, in collaboration with agricultural extension officers and farmers, should design extension programs and training on bioindustry farming based on coffee and cattle. Additionally, the government and other policymakers should focus on creating bioindustry farming; it should include farm and livestock management, appropriate technology for processing livestock waste into organic fertilizer or training on compost processing, and processing agricultural waste into animal feed. In the future, research needs to be conducted on the downstreaming of bioindustrial agricultural products so that bioindustrial agriculture can be carried out comprehensively from upstream to downstream.

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