Research Article

Assessing the Adoption of Superior Pepper Variety in Increasing the Efficiency: An Evidence of Pepper Farming in West Kalimantan, Indonesia

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Abstract | The pepper commodity as a high-value product has the potential to be developed in West Kalimantan but is hampered by low productivity. The use of local pepper varieties and foot rot disease have caused a decrease in the production and efficiency of pepper farming. Farmers have adopted improved varieties called "Bengkayang pepper." However, no studies have specifically examined the effect of adopting the Bengkayang pepper on the production and efficiency of pepper farming. This research aims to determine the technical, economic, and allocative efficiency of pepper farming and evaluate the effect of Bengkayang pepper in increasing efficiency. The study was conducted in West Kalimantan with a sample of 180 pepper farmers, and data analysis used the Stochastic Frontier Analysis. The study results indicate that the implementation of pepper farming is not entirely efficient. However, adopting the Bengkayang pepper variety has increased the efficiency. The technical, economic, and allocative efficiency for the Bengkayang Pepper variety are 0.81, 0.56, and 0.69, higher than local varieties, 0.77, 0.52, and 0.67, respectively. Inefficiency determinant factors show that education and experience can increase technical efficiency, while cost inefficiency is determined by education, family size, and frequency of extension. Other findings show that farm size, pepper trees, labour, urea fertilizer, fungicide and pepper age positively influence pepper production. This study suggests the participation of government and stakeholders to improve and develop superior varieties and increase farmers' informal education through extension activities and technical training in pepper farming.

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Introduction

Pepper (*Piper nigrum* L) is a vital spice plant extensively utilized across diverse industries. Its applications span various sectors, including the food, soft drinks, and cake industries. Pepper and its processed products are also utilized in the perfume, herbal medicine, and cosmetics industries (Khew *et* *al*., 2022; Saju and Ramadevi, 2023; Suwarto, 2016; Takooree *et al*., 2019). As a plantation commodity, pepper contributes significantly to a country's foreign exchange and job provider (Semuroh and Sumin, 2021). The number of Indonesian pepper exports in 2020 reached US$ 160,388, with an export volume of 58,378 tons (Directorate General of Estate Crops, 2022). Opportunities for developing the pepper commodity in Indonesia remain promising due to its reputation as a high-value product and the expanding areas dedicated to pepper farming (Suwarto, 2016). The availability of land, favorable soil, climate conditions, and product diversification, particularly during declining pepper prices, have heightened farmers' motivation to cultivate pepper.

In contrast, Indonesian statistical data recorded a decrease in productivity in pepper farming by 2.29% per year in 2014-2020. A quite significant productivity decline occurred in 2014-2015, with a drop of 10%, and in 2018, pepper productivity dropped to the lowest value, 789 kg/ha (Directorate General of Estate Crops, 2022). This situation aligns with Indonesia's decline in pepper export volume in 2015-2019 (Directorate General of Estate Crops, 2022). Low production and farmers bargaining positions are also problems in the pepper marketing system in Indonesia (Zarliani *et al*., 2023).

West Kalimantan is recognized as one of the pepper-producing regions in Indonesia, characterized by smallholder plantations managing pepper cultivation. Statistical data records an increase in pepper area in West Kalimantan by 3.8% per year in 2014-2020, followed by a rise in farmer numbers (Central Bureau of Statistics, 2021). However, the increase in farm size and farmer number is not in line with the increase in pepper production, resulting in the decline of pepper productivity in West Kalimantan. Low productivity is the main problem in the pepper industry (Ee and Shang, 2017). Previous studies have gathered several issues regarding the decline of pepper productivity due to plant disease, especially foot rot disease, the use of local varieties, simple cultivation techniques, and the low application of fertilizers (Azri and Hatta, 2021; Ee and Shang, 2017; Suhaendah *et al*., 2020).

Low productivity indicates low farming efficiency, which refers to the quantity of output generated from a specific input. Previous studies have proven that farming activities in developing countries have not achieved efficiency (Asadullah and Rahman, 2009; Ureta *et al*., 2007). Farmers have only achieved efficiency ranging from 60-70% or inefficiency between 30-40% (Akamin *et al*., 2017; Ureta *et al*., 2007). Achieving technical, allocative, and economic efficiency is a significant factor in accelerating the growth of the agricultural sector and, at the same time, increasing farmers' productivity and income.

Pepper farmers in West Kalimantan use a superior pepper variety called Bengkayang pepper. This variety is one of ten pepper varieties developed in Indonesia and issued by the Indonesian Center for Plant Variety Protection and Agricultural License (Meilawati *et al*., 2020; Prayoga *et al*., 2020). The Bengkayang pepper variety is claimed to be tolerant to foot rot and yellowing disease (Prayoga *et al*., 2020) and has higher production. Adopting this superior variety can increase the pepper productivity in West Kalimantan compared to the local variety. Local pepper varieties refer to pepper propagation seedlings cultivated by farmers from previous plants, with conditions and production not yet assured.

The study of farming efficiency is crucial as an indicator of farmers' success in managing their farming activity. Farm sustainability is also reflected in farming efficiency. Technical efficiency in crop production is also essential to pursuing growth in small-scale agricultural output (Omar and Fatah, 2021). The problem of farming efficiency become the main focus in developing countries, including Indonesia, partly due to the low technical, allocative, and economic efficiency. Previous research on farming efficiency has been carried out on food crops (Ali *et al*., 2019; Biswas *et al*., 2023; Mulyani *et al*., 2020), horticulture (Hoque *et al*., 2019, 2021), livestock (Batzios *et al*., 2023; Junaidi *et al*., 2023), and fisheries (Islam *et al*., 2023). In the plantation sector, studies have been recorded regarding the efficiency of coffee (Tamirat and Tadele, 2023) and palm oil (Abdul *et al*., 2022).

This research aims to see the effect of adopting superior varieties of Bengkayang pepper on increasing production and efficiency and assess the technical, economic, and allocative efficiency of pepper farming in West Kalimantan. The novelties offered by this study are: (1) identifying the efficiency of pepper farming as a high-value product that is still promising for farmers, (2) emphasizing the influence of adopting the Bengkayang pepper variety in increasing production and efficiency of pepper farming, as well as including several variables others as predictors of farming efficiency. The findings of this study hold significant value for the government and stakeholders in shaping policy recommendations aimed at advancing the development of Bengkayang pepper varieties, intending to enhance efficiency and productivity in pepper farming.

Materials and Methods

Study area

The research area was decided purposively in West Kalimantan Province with consideration as one of the prominent pepper-producing centres in Indonesia with the most significant farm area and production on Kalimantan Island (Directorate General of Estate Crops, 2022). The selected districts were Bengkayang, Sanggau, and Sambas. One sub-district was chosen within each district: Selebar, Sekayam, and Galing sub-districts (Figure 1). Next, the centre village was chosen, namely the Sahan, Bungkang, and Ratu Sepudak villages. The sample consisted of 180 pepper farmers, selected based on having productive trees. Respondents were chosen using proportional random sampling. The research was carried out between October 2022 and May 2023.

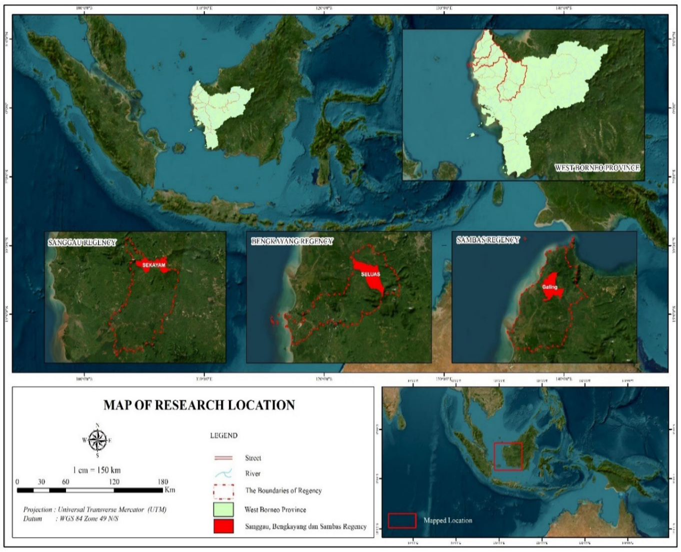

Figure 1: *Location of selected area of pepper farming in West Kalimantan, Indonesia*

Data analysis

Analysis of factors influencing pepper production using the Stochastic Frontier Analysis (SFA) into natural logarithm as follows:

$$Ln\,Y = Ln\,\beta_0 + \beta_1 LnX_1 + \beta C_2 LnX_2 + \beta_3 LnX_3 + \beta_4 LnX_4 + \beta_5 LnX_5 + \beta_6 LnX_6 + \beta_7 LnX_7 + \beta_8 LnX_8 + \beta_9 LnX_9 + e \;...(1)$$

Where Y is production, β_0 is the intercept, β_1–β_9 are the coefficients of each independent variable, X_1 is the farm size, X_2 is the pepper tree, X_3 labor, X_4 is urea fertilizer, X_5 is NPK fertilizer, X_6 is manure, X_7 is a herbicide, X_8 is a fungicide, X_9 is pepper age, and *e* is an *error term*. The formula resolves using the Maximum Likelihood Estimation (MLE) method. The use of the Cobb-Douglas function has been practiced in the agricultural sector, for example, in food crop production (Biswas *et al*., 2023; Tadesse *et al*., 2021; Zhang *et al*., 2020), fisheries (Yang *et al*., 2022), and livestock (Khan *et al*., 2022; Kibona *et al*., 2022). The next stage uses the SFA to measure technical, allocative, and economic efficiency.

Technical efficiency

Measuring the technical efficiency of pepper production uses the following equation (Coelli, 1998):

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{Y_i}{exp\,(X_i, \beta)} = \frac{exp\,(X, \beta, -u_i\,)}{exp\,(X_i, \beta)}\,exp(-u_i)\;...(2)$$

Where TE_i denotes the technical efficiency of the ith farmer, Y_i is output observed of farmer-ith, Y_i^* signifies output frontier estimated, exp($-u_i$) is the expected mean of the inefficiency effect (u_i). Testing of the stochastic frontier efficiency parameter estimator is carried out in two stages, namely (1) estimating the β parameter using the OLS method, (2) estimating all parameters β_0, β_1–β_9, variations of μ_i and v_i simultaneously using the MLE method with the Frontier program version 4.1 (Coelli *et al*., 2005). The parameter test results will provide the following parameter variance estimation values (Aigner *et al*., 2023; Coelli, 1996).

$$\sigma 2 = \sigma_\mu^2 + \sigma_v^2\; dan\; \gamma = \frac{\sigma_\mu}{\sigma_v}\;....(3)$$

Where; σ^2 is the variance of the normal distribution, $\sigma_\mu^{\,2}$ is the variance μ_i, $\sigma_v^{\,2}$ is the variance of v_i. The value of the gamma parameter (γ) is the contribution of technical efficiency to the residual error (ε), with values ranging between zero and one. Parameter values γ that are close to zero indicate that deviations from the frontier increasingly lead to residual effects (error). In contrast, values that approach one indicate that deviations increasingly lead to inefficiency effects (Ogundari and Ojo, 2006).

The technical efficiency obtained is inversely correlated with the technical inefficiency. In this research, the technical inefficiency effect model refers to (Coelli *et al*., 1998). Variables to measure technical inefficiency are assumed to be independent and have a normal N distribution (μ_i, σ^2). Determining the distribution parameter (μ_i) of the technical inefficiency effects uses the formula:

$$\mu i = \text{Ln}\ \delta_0 + d_1 D_1 + \delta_{10} \text{Ln}\ X_{10} + \delta_{11} \text{Ln}\ X_{11} + \delta_{12} \text{Ln}\ X_{12} + \delta_{13} \text{Ln}\ X_{13} + \delta_{14} \text{Ln}\ X_{14} \ \ldots (4)$$

Where μi is the technical inefficiency effect, δ_0 is intercept, δ_{10}-δ_{14} is the coefficent, D_1 Dummy of Bengkayang pepper, X_{10} farmers age, X_{11} education, X_{12} experience, X_{13} family size, and X_{14} frequency of extension. The decision-making criteria are: (1) If $X_i < 0$ = The higher the factor, the lower the inefficiency, and (2) If $X_i > 0$ = The higher the factor, the higher the inefficiency. Technical inefficiency is measured using the MLE method. Data analysis using Frontier software version 4.1.

Economic efficiency

Measuring economic efficiency uses input price information by deriving the dual cost function from the production function. In the SFA model it is formulated:

$$\text{Ln}\ C = \text{Ln}\ \gamma_0 + \gamma_1 \text{Ln}\ P_1 + \gamma_2 \text{Ln}\ P_2 + \gamma_3 \text{Ln}\ P_3 + \gamma_4 \text{Ln}\ P_4 + \gamma_5 \text{Ln}\ P_5 + \gamma_6 \text{Ln}\ P_6 + \gamma_7 \text{Ln}\ P_7 + \gamma_8 \text{Ln}\ Y + (v_i - \mu_i) \ \ldots (5)$$

Where; C is production cost, γ_0 is constant, γ_0-γ_8 is coefficient, P_1 is the price of seed, P_2 is the wage of labor, P_3 is the price of urea fertilizer, P_4 is the price of NPK fertilizer, P_5 is the price of manure, P_6 is the price of herbicide, P_7 is the price of fungicide, Y is the production and $v_i - \mu_i$ is *error term* (μ_j = inefficiency effect).

Jondrow *et al*. (1982) define economic efficiency as the ratio between the observed minimum total costs (C*) with the total actual production costs of farming (C), formulated:

$$\text{Economic Efficiency} = \frac{C^*}{C} = \frac{E(C_i | u_i = 0, Y_i, P_i)}{E(C_i | u_i, Y_i, P_i)} = E[\exp.(u_i/\epsilon] \ \ldots (6)$$

According to Ogundari and Ojo (2006), the cost function can technically be analyzed using frontier 4.1 software, and the cost efficiency value will be obtained. Furthermore, economic efficiency is acquired as the inverse of cost efficiency.

$$\text{Economic efficiency} = \frac{1}{\text{Cost efficiency}} \ \ldots (7)$$

Economic efficiency can be calculated as the product of technical efficiency and allocative efficiency, expressed by the following formula:

$$\text{Allocative efficiency} = \frac{\text{Economic efficiency}}{\text{Technical efficiency}} \ \ldots (8)$$

Results and Discussion

Table 1 provides descriptive statistics of the variables. 53% of farmers have adopted the Bengkayang pepper variety, and the remainder (47%) use local pepper. Bengkayang pepper is one of the superior pepper varieties in Indonesia, originating from Bengkayang Regency, West Kalimantan. This variety has received seed certification from the Ministry of Agriculture of the Republic of Indonesia with No. 466/Kpts/TP.240/7/1993 and No. 10/Permentan/OT.140/1/2013. The Bengkayang pepper variety is claimed to have high production and is resistant to stem rot disease (Prayoga *et al*., 2020). Local pepper is developed independently by farmers or other farmers obtained from previous crops whose quality and production results are not yet guaranteed.

Regarding input use, the average farmer has 800 pepper trees with an average farm size of 0.72 hectares. In other words, a farmer has an average of 1,108 pepper trees in a one-hectare area. This number follows technical recommendations for pepper cultivation, namely 1100-1600 trees per hectare with planting distances ranging from 2.5m x 2.5m to 3m x 3m (Suwarto, 2016). Regarding labor allocation, the most significant labor absorption is for harvest and post-harvest activities. Fertilizers in pepper farming are urea, NPK, and manure. The average use of urea fertilizer is 246.3 kg/year or 340,87 kg/ha/year following the recommended recommendations, namely 200–400 kg/ha/year (Suwarto, 2016). The average use of NPK fertilizer is 658.8 kg/year or 911,82 kg/ha/year, exceeding the recommended recommendation of 400-600 kg/ha/year (Mandiri, 2017). The average use of manure is 1,178.03 kg/year or 1,630.48 kg/ha/year, less than the recommended recommendation, namely 5-10 kg/plant/year or around 5,500-11,000 kg/ha/year (Mandiri, 2017).

Factors affecting pepper farming production

The results of the Cobb-Douglas stochastic frontier production are identified in Table 2. The variables that significantly and positively affect pepper production are the farm size, pepper tree, labor, urea fertilizer, fungicide, and pepper age. The farm size

Table 1: *Description and unit measurement of variables.*

Variables	Description and unit measurement	Mean	Std. dev.
Dependent variables			
Pepper production	Amount of pepper production (kg/year)	549.44	97.56
Independent variables			
Pepper farm characteristic			
Farm size	Pepper farm size (hectare)	0.72	0.21
Pepper age	Age of pepper plants (year)	8.28	1.02
Pepper farm managerial			
Bengkayang pepper variety	Use of Bengkayang pepper (1=use, 0=no)	0.53	0.50
Farmer age	Farmer age (year)	45.91	7.24
Education	Formal education (year)	9.29	2.48
Family size	Number of family members (person)	4.24	0.98
Experience	Farmer experience in pepper farming (year)	15.81	4.37
Frequency of extension	Frequency of extension (time)	1.83	0.61
Input variables			
Pepper tree	Amount of pepper tree (unit/year)	800.22	119.81
Labor	Amount of labor working day (working day/year)	455.75	234.46
Urea fertilizer	Amount of urea fertilizer (kg/year)	246.28	41.65
NPK fertilizer	Amount of NPK fertilizer (kg/year)	658.79	161.81
Manure	Amount of manure (kg/year)	1178.03	288.71
Herbicide	Amount of herbicide (litre/year)	5.03	1.52
Fungicide	Amount of fungicide (kg/year)	3.64	1.08
Price of input variables			
Price of seed	Price of seed fertilizer (IDR/kg)	1.455	330
Price of labor wage	Price of labor wage (IDR/working day)	59,333	8,363
Price of urea fertilizer	Price of urea fertilizer (IDR/kg)	9,284	2,097
Price of NPK fertilizer	Price of NPK fertilizer (IDR/kg)	15,248	4,424
Price of Manure	Price of manure (IDR/kg)	529	191
Price of herbicide	Price of herbicide (IDR/litre)	83,903	8,713
Price of fungicide	Price of fungicide (IDR/kg)	114,628	4,040

Source: *primary data analysis (2023).*

Table 2: *Estimation of stochastic frontier production with the MLE.*

Variable	Expected sign	Coefficient	Std error	t-ratio
Constanta	+/-	3.709***	0.435	8.536
Farm size	+	0.185***	0.029	6.374
Pepper tree	+	0.261***	0.061	4.296
Labor	+	0.029*	0.015	1.878
Urea fertilizer	+	0.148**	0.071	2.092
NPK fertilizer	+	-0.080**	0.033	-2.408
Manure	+	0.013 ns	0.025	0.506
Herbicide	+	-0.012 ns	0.220	-0.563
Fungicide	+	0.051**	0.025	2.029
Pepper age	+	0.254***	0.075	3.383
Sigma-square		0.003***	0.0003	9.460
Gamma		0.999***	0.060	16.578
Log-likelihood MLE		258.522		
LR test		34.38		

*$p < \alpha = 10\%$, ** $p < \alpha = 5\%$, *** $p < \alpha = 1\%$, *Source: primary data analysis (2023).*

positively and significantly affects pepper production at α = 1% with a coefficient of 0.185, which means that increasing farm size by 1% will increase pepper production by 0.185%. Respondent farmers own 0.72 ha of private farm area, so they have full rights to make farming decisions, including the input and technology adoption. The positive influence of farm size on production was discusssed in previous studies (Andaregie *et al*., 2020; Ghimire *et al*., 2023; Mulyani *et al*., 2020; Omar and Fatah, 2021; Osti *et al*., 2017).

The pepper tree positively and significantly affects pepper production at α=1% with a coefficient of 0.261, which means that increasing the number of pepper trees by 1% will increase pepper production by 0.261%. This variable has the highest coefficient value among other significant independent variables, so it is the most responsive variable in increasing pepper production. The number of pepper trees varies, depending on the planting distance and farm size. The planting distance is generally 3m x 3m, with an average number of 800 trees per 0.72 ha, equivalent to 1,107 trees per ha. The positive influence of the number of pepper trees on production was also found in previous studies (Kumar *et al*., 2018; Verma *et al*., 2021; Edison, 2022).

The labor has a positive and significant effect at α= 10% with a coefficient of 0.028, which means that increasing the labor positively and significantly impacts increasing pepper production. The labor generally comes from family members with productive age. Outside labor is usually used in certain activities that require much labor, such as harvest and post-harvest activities. Previous studies also show that increasing labor has a positive effect on production (Osti *et al*., 2017; Andaregie *et al*., 2020; Wijayanti *et al*., 2020; Tadesse *et al*., 2021; Verma *et al*., 2021; Edison, 2022; Ghimire *et al*., 2023).

The urea fertilizer has a positive and significant effect at α = 5% with a coefficient of 0.148, which means that increasing the urea fertilizer positively influences rising production. Pepper is a commodity that requires sufficient nutrition to provide substantial production results. Urea fertilizer is essential to strengthen plant roots and accelerate the growth of new shoots. Previous studies are in line with these results and state a positive response of fertilizer on production (Osti *et al*., 2017; Kumar *et al*., 2018; Chandio *et al*., 2019; Zhang *et al*., 2020; Omar and Fatah, 2021; Verma *et al*., 2021).

The NPK fertilizer has a negative and significant effect at α= 5% with a coefficient of -0.080. In contrast to urea fertilizers, NPK fertilizers negatively affect production, which means that increasing the NPK fertilizers can reduce pepper production. It means that the use of NPK fertilizer has exceeded the recommended dose. The average use of NPK fertilizer by respondent farmers is 911,82 kg/ha/year, while the recommended dose is 400-600 kg/ha/year (Suwarto, 2016). Respondent farmers have pepper trees in productive age, using more NPK fertilizer to stimulate and accelerate the growth of flowers and fruit. However, the use of NPK fertilizer becomes excessive and has a negative impact on decreasing production.

The fungicide has a positive and significant effect at α= 10% with a coefficient of 0.051, which means that increasing fungicides has a positive impact on increasing pepper production. The primary disease that attacks pepper plants is foot rot, which is led by *Phytophthora capsici* (Vandana *et al*., 2014). This disease reduces productivity and even causes the death of pepper plants (Vandana *et al*., 2014; Nysanth *et al*., 2022). In several cases, the death rate of pepper trees due to the *Phytophthora capsici* virus reached 100% (Anh *et al*., 2018). Farmers treat pepper plant diseases using fungicides or destroy diseased plants by burning them, then treat the soil with bokashi fertilizer and *Trichoderma* sp. or provide lime to suppress the development of viral pathogens. They used fungicides and biopesticides, which have also proven effective in treating *Phytophthora capsici* infections in pepper plants (Rini and Remya, 2020).

The pepper age has a positive and significant effect at α = 5% with a coefficient of 0.253, which means that increasing the pepper age will increase pepper production. The lifespan of productive pepper plants ranges from 3-8 years (Suwarto, 2016). However, with good maintenance, this plant can still produce up to 15 years of age. Respondents have an average of 8.28 years of pepper trees and are in the productive category, positively impacting the increase of pepper production.

Analysis of technical efficiency and inefficiency

Table 3 displays the results of technical efficiency using the SFA production function. The estimation results describe the respondent farmers best performance at the existing technology level. The gamma (γ) value is 0.9999 and significant at α= 1%, indicating that technical inefficiency variables cause 99.99% of the error variation. The remaining 0.01% is caused by stochastic effect random variables, such as climate risk, natural disasters, pests, and diseases (Coelli *et al*., 2005; Ureta *et al*., 2020).

Table 3: *Estimation of technical inefficiency.*

Variable	Expected sign	Coefficient	Std error	t-ratio
Constanta	+/-	0.589***	0.128	4.586
Bengkayang pepper variety	-	-0.040***	0.009	-4.098
Farmer's age	-	-0.007 ns	0.033	-0.211
Education	-	-0.072***	0.024	-3.048
Experience	-	-0.050**	0.020	-2.513
Family size	-	-0.011 ns	0.023	-0.479
Frequency of extension	-	-0.004 ns	0.015	-0.256

**p < α = 10%, ** p < α = 5%, *** p < α = 1%; Source: primary data analysis (2023).*

The sigma square (σ^2) value is 0.00332 and significant at α= 1%, indicating that the model used is appropriate and the inefficiency error terms (vi and ui) are normally distributed. The Log-likelihood values are 258.522, meaning the model can describe the farming conditions. The LR test value of 34.38 is greater than X^2 in the table (Kodde and Palm, 1986) at α = 1%, and the value of limit 6 is 16.07, indicating that the SFA function can describe the existence of technical efficiency and inefficiency in the pepper farming production.

The analysis results in Table 3 show that farming management and socio-economic variables mainly contribute to technical inefficiency in pepper farming. The influence of farming management variables on farming efficiency was also reported in prior research (Hoque *et al*., 2019, 2021; Ghimire *et al*., 2023; Tamirat and Tadele, 2023).

Bengkayang pepper variety has a negative and significant effect at α = 1% on farming inefficiency, which indicates that using the Bengkayang pepper variety can reduce technical inefficiency or, in other words, increase the technical efficiency. The negative influence of using superior seeds on inefficiency was also reported in previous studies (Ali *et al*., 2019; Hoque *et al*., 2019, 2021; Mulyani *et al*., 2020; Ghimire *et al*., 2023).

The Bengkayang variety has been adopted by 52.77% of respondents, and the remaining 47.23% used local seeds. Farmers obtain Bengkayang pepper variety by buying from seed breeders or getting assistance from the government. This variety is claimed to be tolerant to foot rot and yellowing disease (Prayoga *et al*., 2020). The Bengkayang pepper variety has been proven to produce higher production than local varieties. The study results confirm the earlier research that stated that choosing a suitable seed will be the primary determinant of production (Andaregie *et al*., 2020; Baser and Bozoglu, 2020; Zulfiqar *et al*., 2021; Tadesse *et al*., 2021; Li, 2023). The study by Kumar *et al*. (2021) stated that pepper productivity optimization can be achieved by developing superior varieties that are tolerant to foot rot disease and can adapt to shade. Improved varieties reflect farmers adaptability to information and technology, leading to increased production (Imelda *et al*., 2023).

Socio-economic factors that negatively and significantly influence the inefficiency of pepper farming are education and farming experience, which means that increasing education and experience will decrease inefficiency or increase its technical efficiency. These findings are in line with prior studies which show the influence of education and experience on farming efficiency (Ajapnwa *et al*., 2017; Ali *et al*., 2019; Hoque *et al*., 2019; Andaregie *et al*., 2020; Omar and Fatah, 2021; Ghimire *et al*., 2023; Islam *et al*., 2023; Junaidi *et al*., 2023; Workneh and Kumar, 2023). Based on these results, increasing farming efficiency can be done by increasing informal education, for example, by providing extension and training to farmers.

The different values of technical efficiency in Bengkayang and local pepper are presented in Table 4. Farmers with Bengkayang variety adoption have achieved a technical efficiency value (0.80) of 61.05%, while for local varieties, it is only 29.42%. The average technical efficiency for the adopters of the Bengkayang pepper variety is 0.81, and for local pepper is 0.77. These results indicate that not all pepper farming activities are carried out efficiently. The implementation of farming activities that are not yet fully efficient was also found in various agricultural sectors (Hoque *et al*., 2019; Omar and Fatah, 2021; Workneh and Kumar, 2023). Inefficient farming activities indicate a chance to increase efficiency through better resources and technology. Farming management and better use of resources are determining factors for farming efficiency (Kumar *et al*., 2018).

Table 4: *Distribution of value and criteria technical efficiency.*

Interval	Bengkayang pepper		Local pepper	
	Frequency	%	Frequency	%
0.20-0.39	0	0.00	0	0.00
0.40-0.59	0	0.00	0	0.00
0.60-0.79	37	38.95	60	70.58
0.80-1.00	58	61.05	25	29.42
Total	95	100.00	85	100.00
Min	0.71		0.63	
Max	0.97		0.93	
Mean	0.81		0.77	

Source: *primary data analysis (2023).*

Next, the cost efficiency using the SFA cost function is detailed in Table 5. The analysis obtained a sigma-square (σ^2) value of 0.03896, significant at α = 1%, which means the model and distribution are appropriate. The gamma parameter (γ) 0.94211 indicates that inefficiency factors influence 94.21% of the variation in the error term, while variables outside the model cause 5.79%. In the cost function, the MLE log-likelihood values are 234.42, indicating that the value is better and more precise in describing farming conditions.

Table 5: *Estimation of cost inefficiency.*

Variable	Expected sign	Coefficient	Std. error	t-ratio
Constanta	+	3.995**	2.012	1.985
Price of seed	+	0.326***	0.072	4.472
Price of labor wage	+	0.075 ns	0.088	0.857
Price of urea fertilizer	+	0.526***	0.077	6.830
Price of NPK fertilizer	+	0.785***	0.046	16.846
Price of manure	+	0.043 ns	0.028	1.546
Price of herbicide	+	-0.187*	0.103	-1.824
Price of fungicide	+	-0.314*	0.185	-1.697
Production	+	0.306***	0.065	4.669
Function of cost inefficiency				
Constanta		-0.107 ns	0.486	-0.220
Bengkayang pepper variety	-	-0.402**	0.161	-2.487
Farmer's age	-	0.334**	0.139	2.404
Education	-	-0.197**	0.096	-2.051
Experience	-	-0.582ns	0.070	-0.827
Family size	-	-0.662***	0.233	-2.840
Frequency of extension	-	-0.382**	0.157	-2.429
Sigma-square		0.038***	0.012	3.172
Gamma		0.942***	0.019	47.275
Log-likelihood function MLE		234.425		
LR test of the one-side error		51.969		

**p < α =10%, ** p < α = 5%, *** p < α = 1%; Source: primary data analysis (2023).*

The LR test value of 51.96 is greater than X^2 in the table (Kodde and Palm, 1986) at α = 1%, and the value of limit 6 is 16.07, indicating that the SFA cost function can describe the existence of cost efficiency and inefficiency in pepper farming. The stochastic cost function shows that the input prices (seed, urea fertilizer, NPK fertilizer) and production are positive and significant at α = 1%. It indicates that the increase in seed prices, urea fertilizer prices, NPK fertilizer prices, and production caused a rise in production costs. An increase in input price has a high potential to increase input costs because mature trees with ages over three years require more fertilizer than immature trees. Hence, the production costs are more significant (Sulok *et al*., 2018). These results align with the study of Islam *et al*. (2023), stating that high input prices positively correlate with increased production costs.

Further, a study from Biswas *et al*. (2023) also noted that high input prices were a problem in farming efficiency. In studies by Zulfiqar *et al*. (2021), the input cost is the most significant factor in reducing farming efficiency. One of the causes of high input costs is farmers difficulty in accessing inputs, so it is necessary to ensure farmers input access. Prior studies also explained that farmers access to inputs increases farming efficiency (Ajapnwa *et al*., 2017; Junaidi *et al*., 2023). Maintaining input availability is also essential to improving the resilience of smallholder plantations (Andani *et al*., 2022).

The herbicide and fungicide prices have a negative and significant coefficient at α= 10%. It shows that increased prices will reduce the use of herbicides and fungicides, reducing production costs. Herbicides are used to treat weeds, while fungicides are used to treat fungi that cause foot rot disease. Farmers constrained by capital generally deal with weeds mechanically (cutting the weeds). Farmers typically use chemical methods with fungicides or mechanical methods for foot rot disease, such as replanting or replacing infected plants with healthy plants.

Managerial and socio-economic factors that negatively and significantly affect cost inefficiency are Bengkayang pepper variety, education, family size, and frequency of extension. The Bengkayang pepper variety can adapt to the environment, is resistant to disease, and has the potential for high production, which can reduce cost inefficiencies. Regarding farmer education, the higher the education, the more rational farmers are in using inputs to reduce cost inefficiencies. The negative influence of education on cost inefficiency was also reported in prior research (Andaregie *et al*., 2020; Islam *et al*., 2023).

Increasing the family size can reduce cost inefficiencies because the family size reflects the size of the assets owned by the farmers'. Having more family members who can help in farming can reduce labor costs, reducing cost inefficiencies. In line with this study, research from Biswas *et al*. (2023) also stated that the scarcity of human labor could reduce farming efficiency. Studies from Zulfiqar *et al.* (2021) also suggest the importance of involving family labor rather than hiring labor.

The frequency of extension indicates that increasing the frequency of extension will reduce cost inefficiencies. On average, respondent farmers participated in two extension activities organized by Field Agricultural Extension Officers. The extension material is related to cultivation techniques and government programs. Previous studies also reported the importance of extension in farming activities, which stated that farming inefficiencies can be minimized through good extension and market information support (Hoque *et al*., 2021). Mahmood *et al.* (2020) also reported a positive influence between farmer participation in extension activities and cost efficiency. Further, the study by Zozimo *et al.* (2023) also recommended increasing field school activities to increase farming efficiency. Through extension activities and field school activities, it is hoped that farmers can increase knowledge about Good Agricultural Practices (GAP). GAP is needed to increase production and efficiency of farming businesses (International Pepper Community, 2007; Krasachat, 2023; Al-Aziz and Suryani, 2024).

Economic and allocative efficiency analysis

Economic efficiency combines technical and allocative efficiency (Ali *et al*., 2017). Farmers are economically efficient if they can simultaneously achieve technical and allocative efficiency. Allocative efficiency describes the most efficient use of production costs to produce a specific output. The allocative efficiency is a comparison between economic efficiency and technical efficiency. The distribution of economic and allocative efficiency is presented in Table 6.

The research results show that farmers adopting Bengkayang pepper varieties have higher economic and allocative efficiency than local pepper. The Bengkayang pepper variety has achieved an economic efficiency value of 0.6-0.79, as much as 33.68%, while the local variety is only 21.17%. In addition, the Bengkayang pepper varieties have achieved an allocative efficiency value of 0.80, as much as 17.89%, while for local pepper, it is 10.58%.

The distribution values show that the average economic and allocative efficiency of the Bengkayang pepper is 0.56 and 0.69, respectively, higher than the local pepper's 0.52 and 0.67. The Bengkayang variety's lowest economic efficiency was 0.36, and the highest was 0.75. Farmers can reach maximum efficiency by saving 25.33% (1-0.56/0.75). The lowest economic efficiency for local varieties was 0.26, and the highest was 0.74. Farmers can reach maximum efficiency by saving 29.73% (1-0.52/0.74) (Ogundari and Ojo, 2006).

The distribution value of allocative efficiency for the Bengkayang pepper was the lowest at 0.42 and the highest at 0.92. It indicates that, on average, farmers can reach the maximum level of allocative efficiency by saving costs of 25% (1-0.69/0.92). The lowest allocative economic for local pepper was 0.31, and the highest was 0.83. Farmers can reach the maximum allocative efficiency by saving 19.27% (1-0.67/0.83).

Table 6: *Estimate of economic and allocative efficiencies.*

Interval	Economic efficiency				Allocative efficiency			
	Bengkayang pepper		Local pepper		Bengkayang pepper		Local pepper	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
0.20-0.39	2	2.11	6	7.05	0	0.00	3	3.52
0.40-0.59	61	64.21	61	71.76	26	27.37	9	10.58
0.60-0.79	32	33.68	18	21.17	52	54.74	64	75.29
0.80-1.00	0	0.00	0	0.00	17	17.89	9	10.58
Total	95	100.00	85	100.00	95	100.00	85	100.00
Minimum	0.36		0.26		0.42		0.31	
Maximum	0.75		0.74		0.92		0.83	
Mean	0.56		0.52		0.69		0.67	

Source: *primary data analysis (2023).*

Conclusions and Recommendations

The study concludes that adopting Bengkayang pepper positively influences production, technical, economic, and allocative efficiency in pepper farming. Other factors contributing to increased pepper production include farm size, number of pepper trees, labor, urea fertilizer, and fungicides. Despite generally low-efficiency levels in pepper farming in West Kalimantan, adopting Bengkayang Pepper has been proven to enhance efficiency. This is evidenced by higher technical, economic, and allocative efficiency values for Bengkayang Pepper than local pepper. Opportunities to enhance the efficiency of pepper farming remain open through interventions in various factors. Identifying influential factors reveals that education and experience can mitigate technical inefficiency, while education, family size, and frequency of extension services can reduce cost inefficiencies. However, the study results underscore the importance of adopting superior varieties such as Bengkayang pepper among pepper farmers. This adoption positively influences production efficiency and contributes to improvements in technical, economic, and allocative efficiency, ultimately enhancing overall farm profitability and sustainability. Therefore, promoting the adoption of superior pepper varieties emerges as a critical strategy for maximizing efficiency and productivity in pepper farming.

The government plays a vital role in supporting the development of superior pepper varieties and promoting cultivation techniques aligned with Good Agricultural Practices (GAP) to enhance production and efficiency in pepper farming. Additionally, efforts to increase farmers capacity through extension services and training activities are essential. These initiatives aim to enhance farmers skills in input usage and decision-making related to farming practices, thereby improving overall farm management and efficiency. Furthermore, optimizing inputs such as urea fertilizer and fungicides according to recommended dosages is vital. By adhering to proper application rates, farmers can maximize the benefits of these inputs and potentially boost pepper production while minimizing costs and environmental impact.

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Novelty Statement

Previous research on farming efficiency has predominantly focused on food crops, horticulture, livestock, and fisheries, with limited attention to the plantation sector. This study introduces two novel aspects: firstly, it examines the efficiency of pepper farming, a high-value product in agriculture; secondly, it emphasizes the impact of adopting the Bengkayang pepper variety on enhancing both production and efficiency in pepper farming.

Author's Contributions

Rakhmad Hidayat: Research framework, methodology, collect data, data tabulation and analysis, results interpretation, manuscript writing, review and editing.
Dwidjono Hadi Darwanto: Research framework, methodology, questionnaire, data analysis, manuscript writing and review.
Lestari Rahayu Waluyati and Jangkung Handoyo Mulyo: Research framework, methodology, questionnaire, manuscript review and editing.
All authors read and approved the final manuscript

Conflict of interest
The authors have declared no conflict of interest.

References

Abdul, I., D.W. Sari, T. Haryanto and T. Win. 2022. Analysis of factors affecting the technical inefficiency on Indonesian palm oil plantation. Sci. Rep., 12(3381): 1–9. https://doi.org/10.1038/s41598-022-07113-7

Aigner, D., C.A.K. Lovell and P. Schmidt. 2023. Reprint of: Formation and estimation of stochastic frontier production function models. J. Econ., 234: 15–24. https://doi.org/10.1016/j.jeconom.2023.01.023

Akamin, A., J.C. Bidogeza, J.R. Minkoua and V.A. Sefa. 2017. Efficiency and productivity analysis of vegetable farming within root and tuber-based systems in the humid tropics of Cameroon. J. Integr. Agric., 16(8): 1865–1873. https://doi.org/10.1016/S2095-3119(17)61662-9

Al-Aziz, F.N. and E. Suryani. 2024. System dynamics modeling to increase the productivity of chili pepper through good agricultural practices in East Java. Proc. Comp. Sci., 234: 733–740. https://doi.org/10.1016/j.procs.2024.03.094

Ali, I., H.X. Xi, I. Khan, H. Ali, K. Baz and S.U. Khan. 2019. Technical efficiency of hybrid maize growers: A stochastic frontier model approach. J. Integr. Agric., 18(10): 2408–2421. https://doi.org/10.1016/S2095-3119(19)62743-7

Ali, Q., M. Ashfaq, M.T.I. Khan, K. Bakhsh and M. Waseem. 2017. An efficiency analysis of off-season tomato production in Punjab: A data envelopment analysis approach. Pak. J. Life Soc. Sci., 15(3): 169–177.

Ajapnwa, A., J.C. Bidogeza, N.J. Minkoua and V. Afari-Sefa. 2017. Efficiency and productivity analysis of vegetable farming within root and tuber-based systems in the humid tropics of Cameroon. J. Integr. Agric., 16: 1865–1873. https://doi.org/10.1016/S2095-3119(17)61662-9

Andani, A., I. Irham, J. Jamhari and A. Suryantini. 2022. Multifaceted social and environmental disruptions impact on smallholder plantations resilience in Indonesia. Sci. World J., 2022: 1–17. https://doi.org/10.1155/2022/6360253

Andaregie, A., A. Worku and T. Astatkie. 2020. Analysis of economic efficiency in charcoal production in Northwest Ethiopia: A cobb-douglas production frontier approach. Trees For. Peop., 2: 1–7. https://doi.org/10.1016/j.tfp.2020.100020

Anh, T.T., T.B. Linh, N.V. Phong, T.L.T. Bien, T.T.N. Tram and L.D. Don. 2018. Expression of proteins related to *Phytophthora capsici* tolerance in black pepper (*Piper nigrum* L.). Int. J. Agric. Innov. Res., 6(4): 75–79. https://ijair.org/administrator/components/com_jresearch/files/publications/IJAIR_2674_FINAL.pdf

Asadullah, M.N. and S. Rahman. 2009. Farm productivity and efficiency in rural Bangladesh: The role of education revisited. Appl. Econ., 41(1): 17–33. https://doi.org/10.1080/00036840601019125

Azri and M. Hatta. 2021. Effect of shade covers and foliar fertilizer on the growth of pepper seeds. IOP Conf. Ser. Earth Environ. Sci., 807: 1–6. https://doi.org/10.1088/1755-1315/807/4/042011

Baser, U. and M. Bozoglu. 2020. Chestnut blight and technical efficiency in chestnut production: Case study of Aydin Province, Turkey. Sci. Hortic., 263: 1–7. https://doi.org/10.1016/j.scienta.2019.109048

Bashir, M.K. and Y. Mehmood. 2010. Institutional credit and rice productivity: A case study of District Lahore, Pakistan. China Agric. Econ. Rev., 2(4): 412–419. https://doi.org/10.1108/17561371011097722

Batzios, A., A. Theodoridis, T. Bournaris and A. Semos. 2023. Technical indicators and economic performance of dairy goat farms in Greece: An efficiency analysis. Livest. Sci., 271: 1–8. https://doi.org/10.1016/j.livsci.2023.105210

Biswas, R., M.M.U. Molla, M.F. Alam, M. Zonayet and R.A. Castanho. 2023. Profitability analysis and input use efficiency of maize cultivation in selected areas of Bangladesh. Land, 12(23): 1–23. https://doi.org/10.3390/land12010023

Central Bureau of Statistics, 2021. Kalimantan Barat Provinces in Figures 2021. In: Central bureau of statistics. Badan Pusat Statistik Kalimantan Barat.

Chandio, A.A., Y. Jiang, A.T. Gessesse and R. Dunya. 2019. The nexus of agricultural credit, farm size and technical efficiency in Sindh, Pakistan: A stochastic production frontier approach. J. Saudi Soc. Agric. Sci., 18: 348–354. https://doi.org/10.1016/j.jssas.2017.11.001

Coelli, J., D.S.P. Rao, C.J. O'Donnell and G.E. Battese. 2005. An introduction to efficiency and productivity analysis (2nd Ed). Kluwer Academic Publisher.

Coelli, T.J., 1996. Centre for efficiency and productivity analysis. CEPA Working Papers, 7: 1–33.

Coelli, T.J., D.S.P. Rao and G.E. Battese. 1998. An introduction to efficiency and productivity analysis. In: An introduction to efficiency and productivity analysis. Springer Science+Business Media, LLC. https://doi.org/10.1007/978-1-4615-5493-6

Directorate General of Estate Crops, 2022. Statistic of national leading estate crops comodity 2020-2022. Directorate General of Estate Crops, Ministry of Agriculture.

Edison, 2022. The determinants of farmers' technical efficiency in corn production: Empirical evidence from Jambi Province. IOP Conf. Ser. Earth Environ. Sci., 1097: 1–10. https://doi.

org/10.1088/1755-1315/1097/1/012010
Ee, K.P. and C.Y. Shang. 2017. Novel farming innovation for high production of black pepper (*Piper nigrum* L.) planting materials. J. Agric. Sci. Technol., 7: 301–308. https://doi.org/10.17265/2161-6264/2017.05.001
Ghimire, B., S.C. Dhakal, S. Marahatta and R.C. Bastakoti. 2023. Technical efficiency and its determinants on lentil (*Lens culunaris*) production in Nepal. Farm. Syst., 1: 1–10. https://doi.org/10.1016/j.farsys.2023.100045
Hoque, F., S. Afrin, A. Akter, M. Khatun, T.H. Beg, T. Afrin and K. Yoezer. 2021. Measuring technical efficiency of the cauliflower cultivation in Bangladesh: A case study on Dhaka district. J. Appl. Hortic., 23(1): 54–58. https://doi.org/10.37855/jah.2021.v23i01.11
Hoque, F., A. Akter and S. Rungsuriyawiboon. 2019. Measuring technical efficiency of bottle gourd and brinjal farming in Dhaka district of Bangladesh: Stochastic frontier approach. J. Appl. Hortic., 21(3): 282–288. https://doi.org/10.37855/jah.2019.v21i03.31
Imelda, J.H. Mulyo, A. Suryantini and Masyhuri. 2023. Understanding farmers risk perception and attitude: A case study of rubber farming in West Kalimantan, Indonesia. AIMS Agric. Food, 8(1): 164–186. https://doi.org/10.3934/agrfood.2023009
International Pepper Community, 2007. Good agricuture practice (GAP) pepper (*Piper nigrum* L). International Pepper Community.
Islam, S., S. Mitra and M.A. Khan. 2023. Technical and cost efficiency of pond fish farms: Do young educated farmers bring changes? J. Agric. Food Res., 12: 1–9. https://doi.org/10.1016/j.jafr.2023.100581
Jondrow, J., C.A.K. Lovell, I.S. Materov and P. Schmidt. 1982. On the estimation of technical inefficiency in the stochastic frontier production function model. J. Econom. 19(2–3): 233–238. https://doi.org/10.1016/0304-4076(82)90004-5
Junaidi, E., Jamhari and Masyhuri. 2023. Comparative analysis of contract farming effect on technical efficiency of Broiler Chicken farms in Indonesia. J. World's Poult. Res., 13(2): 223–232. https://doi.org/10.36380/jwpr.2023.25
Khan, N.A., M. Ali, N. Ahmad, M.A. Abid and S.K. Brandt. 2022. Technical efficiency analysis of layer and broiler poultry farmers in Pakistan. Agriculture, 12: 1–21. https://doi.org/10.3390/agriculture12101742
Khew, C.Y., C.M.M. Koh, Y.S. Chen, S.L. Sim and Z.J.A. Mercer. 2022. The current knowledge of black pepper breeding in Malaysia for future crop improvement. Sci. Hortic., 300: 1–10. https://doi.org/10.1016/j.scienta.2022.111074
Kibona, C.A., Z. Yuejie and L. Tian. 2022. Factors that influence beef meat production in Tanzania. A Cobb-Douglas production function estimation approach. PLoS One, 17(8): 1–13. https://doi.org/10.1371/journal.pone.0272812
Kodde, D.A. and F.C. Palm. 1986. Wald criteria for jointly testing equality and inequality restrictions. Econometrica, 54(5): 1243–1248. https://doi.org/10.2307/1912331
Krasachat, W., 2023. The effect of good agricultural practices on the technical efficiency of chili production in Thailand. Sustainability, 15(866): 1–25. https://doi.org/10.3390/su15010866
Kumar, A., A.K. Rohila and V.K. Pal. 2018. Profitability and resource use efficiency in vegetable cultivation in Haryana: Application of cobb-douglas production model. Indian J. Agric. Sci., 88(7): 153–157. https://doi.org/10.56093/ijas.v88i7.81601
Kumar, B.M., B. Sasikumar and T.K. Kunhamu. 2021. Agroecological aspects of black pepper (*Piper nigrum* L.) cultivation in Kerala: A review. Agrivita, 43(3): 648–664. https://doi.org/10.17503/agrivita.v43i3.3005
Li, C., 2023. Climate change impacts on rice production in Japan: A cobb-douglas and panel data analysis. Ecol. Indic., 147: 1–11. https://doi.org/10.1016/j.ecolind.2023.110008
Mahmood, N., M. Arshad, H. Kächele, A. Ullah and K. Müller. 2020. Economic efficiency of rainfed wheat farmers under changing climate: Evidence from Pakistan. Environ. Sci. Pollut. Res., 27: 1–16. https://doi.org/10.1007/s11356-020-09673-5
Mandiri, T.K. 2017. Rahasia Sukses Bertanam Lada. Nuansa Aulia. Nuansa Aulia, Indonesia.
Meilawati, N.L.W., M. Susilowati and N. Bermawie. 2020. Phyllogenetic of nine superior black pepper (*Piper nigrum* L.) varieties based on morphological and molecular markers. IOP Conf. Ser. Earth Environ. Sci., 418: 1–11. https://doi.org/10.1088/1755-1315/418/1/012056
Mulyani, A., D.H. Darwanto, S. Widodo and

Masyhuri. 2020. Production efficiency of Inpago Unsoed-1 and Situbagendit rice farming in Central Java, Indonesia. Biodiversitas, 21(7): 3276–3286. https://doi.org/10.13057/biodiv/d210751

Nysanth, N.S., S. Divya, C.B. Nair, A.B. Anju, R. Praveena and K.N. Anith. 2022. Biological control of foot rot (Phytophthora capsici Leonian) disease in black pepper (*Piper nigrum* L.) with rhizospheric microorganisms. Rhizosphere, 23: 1–10. https://doi.org/10.1016/j.rhisph.2022.100578

Ogundari, K. and S.O. Ojo. 2006. An examination of technical, economic and allocative efficiency of small farms: The case study of Cassava farmers in Osun State of Nigeria. J. Cent. Eur. Agric., 7(3): 423–432.

Omar, Z. and F.A. Fatah. 2021. Determinants of technical efficiency among coconut smallholder production in Johor, Malaysia: A cobb douglas stochastic frontier production approach. IOP Conf. Ser. Earth Environ. Sci., 757: 1–11. https://doi.org/10.1088/1755-1315/757/1/012013

Osti, R., M. Rizwan, A.K. Assefa, D. Zhou and D. Bhattarai. 2017. Analysis of resource-use efficiency in monsoon and spring rice production in Nepal. Pak. J. Nutr., 16(5): 314–321. https://doi.org/10.3923/pjn.2017.314.321

Prayoga, G.I., Ropalia, S.N. Aini, E.D. Mustikarini and Y. Rosalin. 2020. Diversity of black pepper plant (*Piper nigrum*) in Bangka Island (Indonesia) based on agro-morphological characters. Biodiv., 21(2): 652–660. https://doi.org/10.13057/biodiv/d210230

Rini, C.R. and J. Remya. 2020. Management of *Phytophthora capsici* infection in black pepper (*Piper nigrum* L.) using new generation fungicides and biopesticide. Int. J. Agric. Environ. Biotechnol., 13(1): 71–74. https://doi.org/10.30954/0974-1712.1.2020.8

Saju, K. and V. Ramadevi. 2023. A study on the challenges in marketing in the Covid-19 affected economy by the black pepper growing farmers and recommendations with reference to Kerala. E3S Web Conf., 449: 1–11. https://doi.org/10.1051/e3sconf/202344909014

Semerci, A., 2012. Productivity analysis of sunflower cultivations in Turkey. Bulg. J. Agric. Sci., 18(6): 873–882.

Semuroh, J. and Sumin, V., 2021. Factors affecting the intention of sustainable agriculture practices among pepper farmers in Sarawak, Malaysia. Food Res., 5(4): 92–100. https://doi.org/10.26656/fr.2017.5(S4).005

Suhaendah, E., E. Fauziyah and G.E.S. Manurung. 2020. The development of pepper (*Piper nigrum* L.) foot rot disease on agroforestry. IOP Conf. Ser. Earth Environ. Sci., pp. 1–11. https://doi.org/10.1088/1755-1315/533/1/012042

Sulok, K.M.T., O.H. Ahmed, C.Y. Khew and J.A.M. Zehnder. 2018. Introducing natural farming in black pepper (*Piper nigrum* L.) cultivation. Int. J. Agron., 2018: 1–7. https://doi.org/10.1155/2018/9312537

Suwarto, 2016. Lada Produksi 2 ton/ha. Penebar Swadaya. Indonesia.

Tadesse, B., Y. Tilahun, T. Bekele and G. Mekonen. 2021. Assessment of challenges of crop production and marketing in Bench-Sheko, Kaffa, Sheka, and West-Omo zones of Southwest Ethiopia. Heliyon, 7: 1–14. https://doi.org/10.1016/j.heliyon.2021.e07319

Takooree, H., M.Z. Aumeeruddy, K.R.R. Rengasamy, K.N. Venugopala, R. Jeewon, G. Zengin and M.F. Mahomoodally. 2019. A systematic review on black pepper (*Piper nigrum* L.): From folk uses to pharmacological applications. Crit. Rev. Food Sci. Nutr., 59(S1): S210–S243. https://doi.org/10.1080/10408398.2019.1565489

Tamirat, N. and S. Tadele. 2023. Determinants of technical efficiency of coffee production in Jimma Zone, Southwest Ethiopia. Heliyon, 9: 1–11. https://doi.org/10.1016/j.heliyon.2023.e15030

Ureta, B.E.B., D. Higgins and A. Arslan. 2020. Irrigation infrastructure and farm productivity in the Philippines: A stochastic meta-frontier analysis. World Dev., 135: 1–15. https://doi.org/10.1016/j.worlddev.2020.105073

Ureta, B.E.B., D. Solís, V.H.M. López, J.F. Maripani, A. Thiam and T. Rivas. 2007. Technical efficiency in farming: A meta-regression analysis. J. Prod. Anal., 27: 57–72. https://doi.org/10.1007/s11123-006-0025-3

Vandana, V.V., S. Bhai and S. Azeez. 2014. Biochemical defense responses of black pepper (*Piper nigrum* L.) lines to *Phytophthora capsici*. Physiol. Mol. Plant Pathol., 88: 18–27. https://doi.org/10.1016/j.pmpp.2014.06.003

Verma, D.K., H. Singh and G.L. Meena. 2021. Factors affecting production of cereal crops in Rajasthan: The cobb-douglas analysis. Econ. Aff., 66(2): 195–200. https://doi.org/10.46852/0424-2513.2.2021.3

Wijayanti, I.K.E., D. Hadidarwanto and A. Suryantini. 2020. Stochastic frontier analysis on technical efficiency of strawberry farming in Purbalingga regency Indonesia. J. Tekno Sains, 9(2): 91–180. https://doi.org/10.22146/teknosains.40944

Workneh, W.M. and R. Kumar. 2023. The technical efficiency of large-scale agricultural investment in Northwest Ethiopia: A stochastic frontier approach. Heliyon, 9: 1–10. https://doi.org/10.1016/j.heliyon.2023.e19572

Yang, T.Y., T.F. Chiang and W.H. Liu. 2022. Small-scale fishers catch production in Taiwanese coastal areas. Mar. Policy, 143: 1–6. https://doi.org/10.1016/j.marpol.2022.105182

Zarliani, W.O., Al-Muzuna and S. Sugianto. 2023. Behavior and marketing analysis of Pepper (*Piper nigrum* L.): A comparative study of farmers, trading districts and retailers in Southeast Sulawesi, Indonesia. Caraka Tani J. Sustain. Agric., 38(1): 14–25. https://doi.org/10.20961/carakatani.v38i1.59193

Zhang, Q., W. Dong, C. Wen and T. Li. 2020. Study on factors affecting corn yield based on the cobb-douglas production function. Agric. Water Manage., 228: 1–11. https://doi.org/10.1016/j.agwat.2019.105869

Zozimo, T.M., G. Kawube and S.W. Kalule. 2023. The role of development interventions in enhancing technical efficiency of sunflower producers. J. Agric. Food Res., 14: 1–7. https://doi.org/10.1016/j.jafr.2023.100707

Zulfiqar, F., J. Shang, M. Nasrullah and M. Rizwanullah. 2021. Allocative efficiency analysis of wheat and cotton in district Khanewal, Punjab, Pakistan. Geo J., 86: 2777–2786. https://doi.org/10.1007/s10708-020-10228-x