Accepted manuscript

Akbar, A., A. Rumallang, C. Rahmawati, and M.A. Rusman. 2024. Efficiency analysis of farming tomato (*Solanum lycopersicum* L.) in the highlands using a frontier stochastic analysis: evidence from Gowa, Indonesia. Revista Colombiana de Ciencias Hortícolas 18(3), e18355. Doi: https://doi.org/10.17584/rcch.2024v18i3.18355

Efficiency analysis of farming tomato (*Solanum lycopersicum* L.) in the highlands using a frontier stochastic analysis: evidence from Gowa, Indonesia

Análisis de la eficiencia del cultivo de tomate (*Solanum lycopersicum* L.) en tierras de montaña mediante un análisis estocástico de frontera: evidencia de Gowa, Indonesia

AKBAR AKBAR[1, 2]

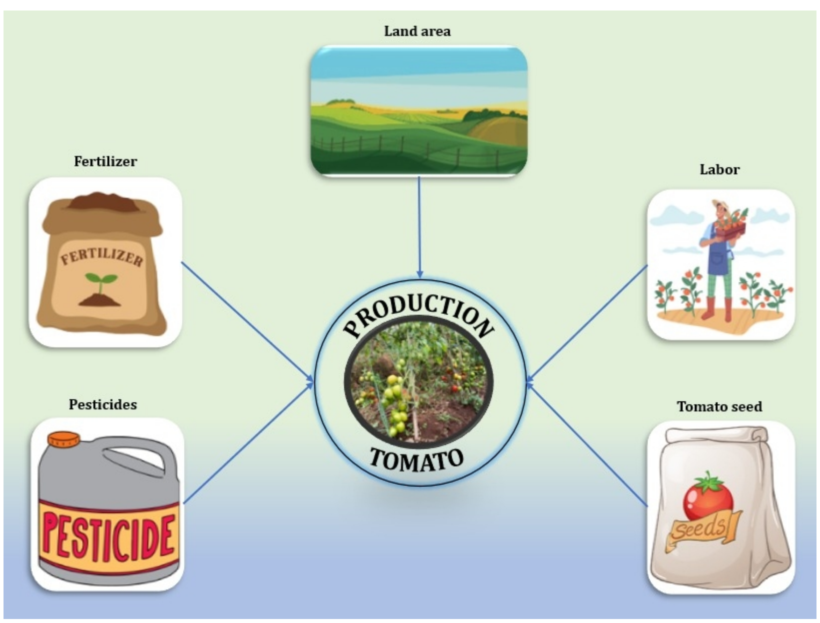
ARDI RUMALLANG[1]

CICI RAHMAWATI[1]

MUH AL ASWAR RUSMAN[1]

[1] Universitas Muhammadiyah Makassar, Agriculture Faculty, Department of Agribusiness, Makassar (Indonesia). ORCID Akbar, A.: https://orcid.org/0000-0002-7860-8871; ORCID Rumallang, A.: https://orcid.org/0000-0002-1025-3277; ORCID Rahmawati, C.: https://orcid.org/0009-0004-1813-8806; ORCID Rusman, M.A.: https://orcid.org/0000-0002-6130-1777

[2] Corresponding author. akbar@unismuh.ac.id



Factors influencing tomato production in the Highlands. Photo: A. Akbar

Last name: AKBAR / RUMALLANG / RAHMAWATI / RUSMAN

Short title: EFFICIENCY ANALYSIS OF FARMING TOMATO IN THE HIGHLANDS

Doi: https://doi.org/10.17584/rcch.2024v18i3.18355

Received: 15-10-2024 Accepted: 24-10-2024 Published: 16-11-2024

ABSTRACT

Tomato farming plays a significant role in Indonesia's agricultural economy, especially in highland areas like Tombolo Pao District. However, the efficiency of production inputs in these regions remains underexplored. This study aims to evaluate the technical and price efficiency of tomato farming, focusing on the use of key production factors such as land, seeds, fertilizer, pesticides, and labor. Using a stochastic frontier analysis, data were collected from 60 tomato farmers selected through simple random sampling. The results indicate that land size and seed quality significantly contribute to tomato yields, while fertilizer use negatively impacts production due to overapplication. Pesticides and labor were found to have no significant effect on output. The average technical efficiency score of 0.759 suggests that there is room for improvement in farming practices. Price efficiency was below optimal, especially for fertilizers and labor. The findings emphasize the need for better resource management in tomato farming, particularly through optimized land use, improved seed selection, and controlled fertilizer application.

Additional key words: fruit vegetables; input output analysis; land; seeds; fertilizer; pesticides; labor.

RESUMEN

El cultivo del tomate desempeña un papel importante en la economía agrícola de Indonesia, especialmente en zonas de tierras altas como el distrito de Tombolo Pao. Sin embargo, la eficiencia de los insumos de producción en estas regiones sigue estando poco estudiada. Este estudio pretende evaluar la eficiencia técnica y de precios del cultivo del tomate, centrándose en el uso de factores de producción clave como la tierra, las semillas, los fertilizantes, los pesticidas y la mano de obra. Utilizando un enfoque de frontera estocástica, se recogieron datos de 60 agricultores de tomate seleccionados mediante muestreo aleatorio simple. Los resultados indican que el tamaño de la tierra y la calidad de las semillas contribuyen significativamente al rendimiento del tomate, mientras que el uso de fertilizantes afecta negativamente a la producción debido a su aplicación excesiva. Se comprobó que los plaguicidas y la mano de obra no tienen efectos significativos sobre la producción. La puntuación media de 0,759 en eficiencia técnica sugiere que hay margen de mejora en las prácticas agrícolas. La eficiencia de los precios fue inferior a la óptima, especialmente en el caso de los fertilizantes y la mano de obra. Los resultados subrayan la necesidad de mejorar la gestión de los recursos en el cultivo del tomate, especialmente mediante la optimización del uso de la tierra, la mejora de la selección de semillas y el control de la aplicación de fertilizantes.

Palabras clave adicionales: hortalizas de fruto; análisis de insumo-producto; tierra; semillas; fertilizantes; pesticidas; mano de obra.

INTRODUCTION

Horticultural crops play a critical role in human life due to their nutritional value and contribute to food security (Rajani and Shourabh, 2017; Amane, 2023). Horticulture is one of the sub-sectors of agriculture that significantly contributes to poverty alleviation, public welfare and Indonesia's economy (Choudhary, 2013; Pitaloka, 2017). It includes a wide range of crops such as vegetables, fruits, ornamental plants, and bio-pharmaceuticals. Among the prominent horticultural commodities in agribusiness is the tomato (*Solanum lycopersicum* L.) in providing the required source of nutrients. Tomato is a vital source of vitamins C and A, minerals, and carotene, all essential to human health (Ullah *et al*., 2016; Akotowanou *et al*., 2022; Sinaga, 2023). The demand for fresh and processed tomatoes has been rising consistently due to the increasing need for balanced nutrition. Tomatoes are not only valuable as vegetables but also as a fresh food source that can address vitamin deficiencies. In addition, tomato farming demonstrates high productivity potential (Wowiling *et al*., 2023).

Tomato productivity is closely linked to the success of agricultural practices, which can be measured through yield outcomes, income generation, and operational efficiency (Dyanto *et al*., 2022). Tomato farming has proven to be highly productive, with an average yield of 16.6 t ha^{-1}, and is considered very profitable, with an efficiency ratio of 2.5 (Akbarrizki, 2017; Mahyudi and Husinsyah, 2019; Dyanto *et al*., 2022). Tomato production in Indonesia has experienced continuous growth over the years. Data from the Indonesian Central Bureau of Statistics (CBS) reveal that tomato production reached 1.11 million tons in 2021, a 2.72% increase from the previous year's 1.08 million tons. Since 2017, national tomato production has trended upward, achieving its highest level in the last decade in 2021. In 2018, production was recorded at 976,772 t, increasing to 1,020,331 t in 2019 and 1,084,993 t in 2020, before further rising to 1,107,575 t in 2021 (Badan Pusat Statistik, 2022).

Tombolo Pao District in Gowa Regency is a region with high potential for horticultural development, particularly in tomato farming. Tomatoes are cultivated throughout the district, which benefits from favorable climatic conditions (Safir *et al*., 2023). However, farmers in this area typically engage in cultivation without considering the associated costs, leading them to face several challenges related to production factors that could influence farm outcomes. This situation underlines the importance of understanding how production factors impact farming efficiency. Farmers must be aware of the critical production inputs that affect their agricultural practices and the costs associated with these inputs. Optimizing the use of production factors is one of the key strategies to increase tomato yields and ensure that farming activities are as efficient as possible.

Tomato production efficiency depends heavily on the effective use of inputs such as land, seeds, fertilizer, pesticides, and labor. Inefficient use of these inputs can lead to reduced productivity and profitability. The literature highlights various factors influencing tomato production, including land size, seed quality, and input costs (Degefa *et al*., 2023; Kartika and Kurniasih, 2021). Inefficient farming practices have been attributed to the misallocation or overuse of key inputs such as fertilizers, resulting in diminished returns and environmental sustainability (Ren *et al*., 2021). For instance, improper timing or excessive use of fertilizers can harm soil fertility, reducing crop yields rather than enhancing them (Setyorini *et al*., 2006). Similarly, the improper application of pesticides can reduce crop protection efficacy, leading to lower overall production levels (Hadi and Sita, 2016).

The research problem at the core of this study centers on inefficiencies in the use of production inputs in tomato farming in Tombolo Pao District. The general solution to this problem, based on the literature, is to optimize input use to ensure that each production factor contributes maximally to farm output. In particular, previous studies suggest that balancing the use of land, seeds, fertilizers, and labor is key to achieving higher productivity and efficiency in tomato farming (Chiarella *et al*., 2023). As demonstrated in earlier research, farm efficiency can be improved through the adoption of improved agricultural practices, better seed varieties, and more effective input management (Sri, 2016; Hadi and Sita, 2016; Ren *et al*., 2019).

Specific solutions from the literature focus on several key areas. First, increasing the efficiency of land use is crucial, as larger, better-managed plots tend to yield higher outputs (Aragón *et al*., 2022; Ma *et al*., 2023). Efficient land use involves not only maximizing the area under cultivation but also ensuring that the soil is adequately prepared and maintained for optimal productivity. Another key area is seed selection. Research shows that using high-quality seeds significantly impacts tomato production (Özer, 2018; Gallegos-Cedillo *et al*., 2024). Seed varieties that are more resilient to pests and diseases, combined with proper planting techniques, can lead to substantial improvements in yield. Additionally, managing fertilizer application is critical, as excessive or poorly timed fertilization can lead to nutrient imbalances and phosphorus loss that adversely affect crop growth and maintain crop yields (Liu *et al*., 2021; Noulas *et al*., 2023). Labor efficiency also plays an important role; highly skilled workers who apply best practices in crop management can significantly boost tomato productivity (Chiarella *et al*., 2023).

Despite these insights, several gaps remain in the understanding of how best to optimize production inputs in the specific context of highland tomato farming in Indonesia. While previous studies have identified general input efficiency issues, few have focused specifically on the stochastic nature of agricultural production in highland areas. Additionally, the unique climatic and geographical factors present in the highlands require a tailored approach to input management in developing tomato farming businesses (Mario *et al*., 2005).

This study aims to fill these gaps by analyzing the efficiency of tomato farming in the Highlands Gowa Regency using a stochastic frontier analysis. The research focus on identifying the production factors that have the greatest impact on output and assessing the degree of efficiency with which these inputs are used by farmers. The novelty of this study lies in its application of a stochastic frontier model to measure both technical, price and economic efficiency in highland tomato farming, an approach that has not been widely employed in previous studies. By evaluating how well land, seeds, fertilizers, pesticides, and labor are being utilized, this research seeks to provide a more comprehensive understanding of farming efficiency in the highlands.

Furthermore, this study will contribute to the literature by offering empirical insights that could inform agricultural policies aimed at improving farming practices in highland areas. The findings are expected to provide actionable recommendations for farmers and policymakers, helping to enhance productivity, profitability, and sustainability in tomato farming. The scope of this research extends to evaluating the technical efficiency of tomato production, as well as exploring the potential for optimizing the use of key inputs to achieve higher levels of efficiency.

MATERIALS AND METHODS

This research was conducted in Balassuka Village, Tombolo Pao District, Gowa Regency, from August 23 to October 8, 2023. This location was chosen because it is an area with an altitude of 600 m above sea level and an average rainfall of 100 mm-160 mm per year which is suitable for planting tomatoes. The study aimed to assess the efficiency of tomato farming by examining the use of production factors including land area, seeds, fertilizer, pesticides and labor. The methodological approach adopted in this research was a structured and systematic process involving several key steps, ensuring that the findings were robust and reliable. The study employed a simple random sampling method to select the sample population of tomato farmers in Balassuka Village, Tombolo Pao. The population of tomato farmers in the village consisted of 233 individuals, and the sample size was determined using the Slovin formula (Tejada and Punzalan, 2012; Adam, 2020). The formula (1) is presented as follows

$$n=\frac{N}{1+\left(Nx\,e^{2}\right)} \tag{1}$$

where, *N* was total population and *e* margin of error (15%)

substituting the values: $n=\frac{233}{1+\left(233\,x\,0{,}15^{2}\right)}=\frac{233}{1+2.9}=\frac{233}{3.9}=60$

Thus, a total of 60 tomato farmers were selected as the sample for the study. This sample size was considered representative of the population and sufficient for the statistical analyses to be performed. The study relied on both primary and secondary data sources. Primary data were collected through direct observation and structured interviews using a pre-prepared questionnaire. The questionnaire aimed to capture relevant data on the farmers' use of inputs such as land, seeds, fertilizer, pesticides, and labor. Interviews were conducted face-to-face with the selected farmers to ensure the accuracy and comprehensiveness of the data collected. In addition to primary data, secondary data were also utilized. These secondary sources included previous studies, government reports, and agricultural statistics from the Central Bureau of Statistics (CBS), which provided background information on tomato production trends in Indonesia and the region.

The primary objective of the data analysis was to identify the key production factors influencing tomato farming and to assess the technical and allocative efficiency of these factors. The Cobb-Douglas production function was used to model the relationship between tomato production (output) and the various inputs (factors of production). The general form of the Cobb-Douglas production function is (2):

$$Y = aX1^{b1} X2^{b2} X3^{b3} X4^{b4} X5^{b5} X6^{b6} e^{u} \quad (2)$$

where, Y was tomato production (kg), $X1$ land area (ha), $X2$ = seed quantity (g), $X3$ fertilizer use (kg), $X4$ pesticide use (L), $X5$ = labor (h), a constant, u error term, and $b_1, b_2, b_3, b_4, b_5, b_6$=¿ coefficients representing the elasticity of each input with respect to output.

To simplify the model, the Cobb-Douglas function was transformed into a natural logarithmic form, which allowed for linear regression analysis (3)

$$\ln Y = \ln b_0 + b_1 \text{In}_{X1} + b_2 \ln_{X2} + b_3 \ln_{X3} + b_4 \ln_{X4} + b_5 \ln_{X5} + u \quad (3)$$

This model enabled the estimation of the marginal contributions of each input to tomato production. The significance of each input in the model was tested using the t-test, calculated as follows (Soekartawi, 1993) (4)

$$t_{calculated} = \frac{bi}{S_{bi}} \quad (4)$$

where, b_i was coefficient of the independent variable and S_{bi} standard error of the estimated coefficient.

The null hypothesis (H0) posits that the independent variable has no significant effect on the dependent variable (tomato production), while the alternative hypothesis (H1) suggests that the independent variable does have a significant effect. The decision rule is:

- If $t_{calculated} > t_{table}$, reject H0 and accept H1, indicating that the variable has a significant effect on tomato production
- If $t_{calculated} < t_{table}$, accept H0, indicating that the variable has no significant effect.

To assess the efficiency of input use in tomato farming, the study applied technical and allocative efficiency analysis. Technical efficiency was evaluated using a stochastic frontier production function, which accounts for random shocks and inefficiencies that may affect production output. For allocative efficiency, the study examined the marginal product value (NPMx) in relation to the input price (Px). Allocative efficiency is achieved when the marginal

Akbar, A., A. Rumallang, C. Rahmawati, and M.A. Rusman. 2024. Efficiency analysis of farming tomato (*Solanum lycopersicum* L.) in the highlands using a frontier stochastic analysis: evidence from Gowa, Indonesia. Revista Colombiana de Ciencias Hortícolas 18(3), e18355. Doi: https://doi.org/10.17584/rcch.2024v18i3.18355

product value equals the input price, i.e., $NPMx/Px=¿1$. formulas used in this analysis are as follows (5, 6 and 7)

$$NPMx=PM\,x_i \times Py \quad (5)$$

$$PM\,x_i=\frac{bi \times Y}{x_i} \quad (6)$$

$$x_i=\frac{bi \times Y \times Py}{P_x} \quad (7)$$

where, $NPMx$ was marginal product value of the input, $PM\,x_i$ marginal product of the input, bi elasticity of the production factor, x_i average use of the input, P_x price of the input, and Py price of output (tomato).

The criteria for evaluating allocative efficiency were $NPMx/Px<1$ input is used inefficiently and should be reduced, $NPMx/Px>1$ input is underutilized and should be increased, and $NPMx/Px=1$ input is used efficiently, and profit is maximized.

Finally, the study assessed economic efficiency, which combines technical and allocative efficiency. Economic efficiency (*EE*) was calculated using the following formula (8)

$$EE = ET \times EH \quad (8)$$

where, *ET* was technical efficiency and *EH* allocative efficiency.

The evaluation criteria for economic efficiency were $EE<1$ the farm is economically inefficient, $EE=1$ the farm is economically efficient, and $EE>1$ the farm is not yet economically efficient.

RESULTS AND DISCUSSION

Socio-economic characteristics of tomato farmers

The profile of respondents involved in this study provides a comprehensive understanding of the status of tomato farmers in the highlands Tombolo Pao District, Gowa Regency. This section discusses the demographic characteristics of the respondents, including age, education level, farming experience, and land size. Additionally. The socio-economic characteristics of tomato farmers in the study area are presented in table 1.

Table 1. Socio-economic characteristics of tomato farmers.

Variable	Association	Frequency	Percentage (%)
Age in years	25 – 31	7	13.33
	32 – 38	4	6.67
	39 – 45	15	25.00
	46 – 52	13	21.67
	53 – 59	10	15.00
	60 – 66	11	18.33
	Totals	60	100
Education level	Primary school	17	28.33
	Secondary school	9	15.00
	High school	21	35.00
	Bachelor’s degree	13	21.67
	Totals	60	100
Farming experience	5 – 9	6	10.00
	10 – 14	16	26.67
	15 – 19	14	23.33
	20 – 24	9	15.00
	25 – 29	10	16.67
	30 – 34	5	8.33
	Totals	60	100
Land size	0.3 – 0.58	14	23.33
	0.59 – 0.87	10	16.67
	0.88 – 1.16	2	3.33
	1.17 – 1.45	15	25.00

	1.46 – 1.74	13	21.67
	1.75 – 2.03	6	10.00
	Totals	60	100

Age of tomato farmers

Age is an essential factor influencing farming activities, as it directly impacts the farmer's physical ability, decision-making skills, and openness to adopting new farming technologies (Arita *et al*., 2022). Table 1 presents the age distribution of tomato farmers in Tombolo Pao District. Table 1 reveals that most tomato farmers are between 39 and 45 years old, accounting for 25% of the respondents, while the youngest group, aged 25 to 31 years, constitutes 13.33%. This indicates that the majority of farmers are still within the productive age range, allowing them to be physically capable and more likely to adopt new innovations in farming (Alam *et al*., 2016; Managanta, 2020). Consequently, these farmers are expected to enhance tomato production through improved skills and knowledge.

Education level of the tomato farmers

Education plays a crucial role in agricultural practices, as it influences farmers' ability to comprehend and apply modern farming technologies, ultimately improving productivity. Table 1 shows the education levels of the tomato farmers. Table 1 indicates that most respondents have attained a high school education (35%), followed by those with an elementary school background (28.33%). Education is an essential indicator of the farmers’ capacity to manage technology and innovations, and it is expected that those with higher education levels, such as high school and bachelor’s degree holders, will achieve better productivity compared to those with lower education levels.

Farming experience

Experience in farming is a key factor in determining a farmer’s ability to manage agricultural practices and deal with challenges. Figure 4 outlines the respondents' farming experience. The majority of farmers have 10–14 years of experience (26.67%), while only 8.33% of respondents have 30–34 years of experience. Farmers with more experience tend to have developed the skills necessary to enhance productivity and manage agricultural risks.

Land size

Land size is a critical production factor in agriculture, as larger land areas generally lead to higher yields. Table 1 provides an overview of the land size owned by the respondents. Table 1 shows that most farmers (25%) own land between 1.17 and 1.45 hectares, while only 3.33% own between 0.88 and 1.16 ha. The larger the land area, the greater the potential tomato yield, underscoring the importance of land size in agricultural productivity.

Factors influencing tomato farming

This section presents the results of the stochastic frontier analysis applied to estimate the impact of various production factors on tomato farming in Tombolo Pao District, Gowa Regency. The analysis is based on the Cobb-Douglas production function, and table 2 summarizes the findings for each production variable. Studies have shown that farms that optimize their input usage can significantly improve production efficiency, which is essential for agricultural growth (Frangu *et al*., 2018).

Table 2. Estimation results of tomato farming production factors.

Variable	Coefficient	Standard error	*t*-ratio
Production	0.20927823	0.33438997	0.24201629
Ln X1 (land)	0.39187047	0.17841825	2.1963586
Ln X2 (seeds)	0.36392189	0.18391427	1.9787583
Ln X3 (fertilizer)	-0.91620249	0.41882314	-2.1875642
Ln X4 (pesticide)	0.28843663	0.29828452	0.96698491
Ln X5 (labor)	0.50747247	0.42540827	0.11929069

The coefficients and *t*-ratios help determine the significance and influence of each production factor on tomato yields in the region. The findings for each variable are discussed below:

The influence of land area on tomato production

The coefficient for land is positive and statistically significant with a *t*-ratio of 2.19, which exceeds the critical value of 1.67. This indicates that land size significantly influences tomato production in Tombolo Pao. These results align with prior research (Wadu, 2023; Weldegiorgis *et al*., 2018), which suggests that land is a critical agricultural production factor that plays a substantial role in determining output. Larger land areas typically lead to higher production. Large cropping area and fertile soil further enhance the productivity of the land for tomato farming.

The influence of seeds on tomato production

The seeds variable also exhibits a significant positive effect on tomato production, with a *t*-ratio of 1.97, indicating a substantial contribution to yield. This finding emphasizes the importance of using high-quality seeds, as confirmed by the results of research conducted by Misra *et al*. (2023), which explains that quality seeds are selected from high-yielding varieties that have characteristics of disease resistance, and fast growth that help farmers get better yields. However, the result contrasts with Majid *et al*. (2022), who found that seed use had no significant effect on production, likely due to overuse or poor-quality seeds in other regions. The findings in Tombolopao suggest that the use of improved seed varieties can substantially increase yields (Taiy *et al*., 2017; Pattiasina *et al*., 2023), provided they are applied in optimal quantities. The average cost of tomato seeds in the village is 25,000 IDR, which aligns with market conditions. The price of seeds is determined by the quality of seeds used by tomato farmers.

The influenc of fertilizer on tomato production

The results show that fertilizer has a significant negative impact on tomato production, with a t-ratio of -2.18. This suggests that excessive or improper use of fertilizers may reduce productivity, a finding consistent with the work of Setyorini *et al*. (2006). Fertilizer application in tomato farming must be precise, both in terms of timing and quantity, to ensure the soil retains adequate nutrients. In Gowa Regency, over-fertilization may have led to soil nutrient imbalances, ultimately reducing the effectiveness of this input. The most commonly used fertilizers in the region include organic manure, urea, and phonska. Types and dosage of fertilizers used in tomato farming in Tombolopao Subdistrict, Gowa Regency presented table 3.

Table 3. **Types and dosage of fertilizers used in tomato farming.**

Type of fertilizer	Dosage of fertilizer use (g/plant)	Recommended dosage (g/plant)
Urea	390.98	500
Phonska	15.04	5
Organic fertilizer (manure)	12.03	5

The influence of pesticides on tomato production

The pesticide variable does not show a significant effect on production, with a *t*-ratio of 0.96, which is below the critical threshold of 1.67. This result aligns with the findings of (Asfaw, 2021), which suggest that pesticides, while having a positive effect, are often not applied in optimal quantities or are of inadequate quality to significantly impact production. Farmers commonly use chemical pesticides such as bemolik, and victory, which are readily available and affordable. However, the lack of proper guidance on pesticide use may be limiting its effectiveness.

The influence of labor on tomato production

Labor is another variable that does not significantly affect tomato production, with a *t*-ratio of 0.11. This result is consistent with Kurniawan *et al*. (2018), who found that labor, while essential, does not always translate into higher production when not managed effectively. Facts in the field show that the labor force working on tomato farms is dominated by unskilled workers. This is due to the lack of capital to obtain adequate labor. Additionally, the lower education levels among farmers leads to inefficient labor use, further hindering productivity. Labor remains a crucial factor in various stages of tomato farming (Testa *et al*., 2014), including land preparation, planting, maintenance, and harvesting, but requires better management to contribute effectively to increased yields.

Tomato farming efficiency

The efficiency of tomato farming was analyzed to determine whether the combination of production factors was optimized for maximum output. The application of SFA in tomato farming efficiency analysis allows for a comprehensive understanding of both technical and allocative efficiency. Aparicio *et al*. (2023) and Thomas *et al*. (2024) classified efficiency into technical, allocative, and economic categories, providing a framework for assessing the overall performance of tomato farmers. This classification is essential for identifying specific areas where improvements can be made, such as optimizing input usage or enhancing management practices. This section presents the findings on technical, price, and economic efficiency, based on the data collected from farmers in the region.

Technical efficiency

Technical efficiency refers to how effectively production factors are utilized in the farming process. The technical efficiency of tomato farming was calculated using a stochastic frontier analysis model. The results are summarized in table 4.

Table 4. Results of estimation of technical efficiency of production function in tomato farming using the stochastic frontier approach.

Variable	Coefficient	Standard Error	*t*-ratio
Production	0.20927823	0.33438997	0.24201629
Ln X1 (land)	0.39187047	0.17841825	0.21963586
Ln X2 (seeds)	0.36392189	0.18391427	0.19787583
Ln X3 (fertilizer)	-0.91620249	0.41882314	-0.21875642
Ln X4 (pesticide)	0.28843663	0.29828452	0.96698491
Ln X5 (labor)	0.50747247	0.42540827	0.11929069

The mean technical efficiency for tomato farming was calculated as 0.759, indicating that farmers in the region are relatively efficient in their use of production factors. However, there is room for improvement. Table 4 reveals that land and seeds have a positive effect on production, while fertilizers and pesticides have a negative effect This indicates that fertilizer use is not in accordance with the recommended use. This suggests that fertilizer use may not be optimized, either due to over-application or mismanagement. The closer the technical efficiency value is to 1, the more efficient the farming process. In this case, with a mean technical efficiency of 0.759, tomato farming can be considered technically efficient, though improvements in the management of certain inputs, especially fertilizer, could enhance productivity.

Price efficiency

Price efficiency measures how well the cost of inputs is aligned with their contribution to output. Table 5 presents the results of the price efficiency analysis for tomato farming in Tombolo Pao District.

Table 5. Results of price efficiency estimation in tomato farming using the stochastic frontier analysis.

Input	NPMx	Px	NPMx/Px
Land	83,416,667	5,005,000	1.666667
Seeds	69,458,333	416,750,000	0.166667
Fertilizer	20,126,667	120,760,000	0.166667
Pesticides	67,616,667	40,570,000	1.666667
Labor	12,666,667	76,000,000	0.166667
Total	506,570,002	659,085,000	3.833335
Average	253,570,001	131,817,000	0.766667

The overall price efficiency score of 3.83 indicates that tomato farming is not price-efficient. If the ratio of marginal product value (NPMx) to input price (Px) exceeds 1, the input is being used efficiently. In this case, land and pesticides are price-efficient, with ratios of 1.66 each, suggesting they are used effectively. Conversely, seeds, fertilizer, and labor show ratios of 0.16, indicating that these inputs are not being used optimally. To improve price efficiency, farmers should reduce the use of seeds, fertilizer, and labor or reassess their application methods to ensure a better return on investment.

Economic efficiency

Economic efficiency combines both technical and price efficiency to evaluate the overall efficiency of input use in the production process. The results of the economic efficiency analysis are presented in table 6.

Table 6. Results of economic efficiency estimation in tomato farming using the stochastic frontier analysis.

Input	TE	PE	EE
Land	0.75938806	1.66	1.26

Input	**TE**	**PE**	**EE**
Seeds	0.75938806	0.16	0.12
Fertilizer	0.75938806	0.16	0.12
Pesticides	0.75938806	1.67	1.27
Labor	0.75938806	0.16	0.12
Total	3.76969403	3.81	2.89
Average	0.75938806	0.76	0.57

An economic efficiency (EE) score greater than 1 indicates inefficiency, and in this case, the mean EE of 0.57 shows that tomato farming is not yet economically efficient. This inefficiency suggests that adjustments in input use are necessary to optimize production (Nakana *et al*., 2021). Land and pesticides demonstrate relatively higher economic efficiency (1.26 and 1.27, respectively), indicating their effective use. However, seeds, fertilizer, and labor show low economic efficiency (0.12 each), signaling significant inefficiencies in these areas.

CONCLUSION

The conclusions of this study yield indicate finding that land size and seed quality significantly influence tomato production, while fertilizer use showed a negative impact, possibly due to overuse or improper application. Pesticides and labor did not significantly affect production, highlighting the need for improved resource management in these areas. The technical efficiency of tomato farming was relatively high at 0.759, suggesting that farmers are reasonably efficient, but there is still potential for optimization.

The study contributes to the existing literature by providing empirical evidence on the efficiency of production factors in highland tomato farming, particularly in Indonesia. It underscores the importance of land and seed optimization while cautioning against excessive fertilizer use. This research offers practical implications for policymakers and farmers, encouraging the adoption of better seed varieties and more effective fertilization practices. Future research could explore the role of technology adoption and its impact on farming efficiency, as well as investigate other highland areas to generalize the findings. This study highlights the need for ongoing efforts to enhance resource management and input use in tomato farming.

Acknowledgements

The author would like to express his deepest appreciation to all parties who have contributed to this effort, with special thanks to Muhammadiyah University of Makassar for providing research and publication funding support in the 2024/2025 budget year.

Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

Author's Contributions: A. Akbar: conceptualized the idea, compiling articles, A. Rumallang: Developing research methods, and compiling discussions and conclusions, C. Rahmawati: collecting and processing data, M.A. Aswar Rusman: validating articles, discussing results and conclusions. All authors have read and agreed to the published version of the manuscript.

BIBLIOGRAPHIC REFERENCES

Adam, A.M. 2020. Sample size determination in survey research. J. Sci. Res. Rep. 26(5), 90-97. Doi: https://doi.org/10.9734/jsrr/2020/v26i530263

Akbarrizki, M. 2017. Penentuan harga pokok produk (HPP) dan analisis keuntungan usahatani tomat di kelurahan Teluk Lingga kabupaten Kutai Timur. J. Pertanian Terpadu 5(2), 34-45. Doi: https://doi.org/10.36084/jpt..v5i2.125

Akotowanou, O.C.A., E.S. Adjou, A.B. Olubi, S.D. Kougblenou, E.D. Ahoussi, and D.C. Sohounhloué. 2022. The tomato (*Solanum lycopersicum* L.) in community development: an overview focused on nutritional properties, agronomic constraints, recent achievements and future prospective. Int. J. Front. Biol. Pharm. Res. 3(2), 8-16. Doi: https://doi.org/10.53294/ijfbpr.2022.3.2.0061

Alam, M.N., M.T. Uddin, M. Moniruzzaman, N. Tabassum, and M.M. Haque. 2016. Socio-economic characteristics of the tomato farmers in selected areas of Chapainawabganj district. Fundam. Appl. Agric. 1(2), 101-105.

Amane, G.S. 2023. Analisis efisiensi teknis, harga dan ekonomis terhadap penggunaan input pada usahatani tomat di desa Bukit Asri. Media Agribisnis 7(1), 156-160. Doi: https://doi.org/10.35326/agribisnis.v7i1.3251

Aparicio, J., J.L. Zofío, and J.T. Pastor. 2023. Decomposing economic efficiency into technical and allocative components: an essential property. J. Optim. Theory Appl. 197(1), 98-129. Doi: https://doi.org/10.1007/s10957-023-02188-2

Aragón, F.M., D. Restuccia, and J.P. Rud. 2022. Are small farms really more productive than large farms? Food Policy 106, 102168. Doi: https://doi.org/10.1016/j.foodpol.2021.102168

Arita, B., A.A. Managanta, and I. Mowidu. 2022. Hubungan karakteristik petani terhadap keberhasilan usahatani jagung. J. Sos. Ekon. Pertan. Agribisnis 19(1), 105. Doi: https://doi.org/10.20961/sepa.v19i1.55116

Asfaw, D.M. 2021. Analysis of technical efficiency of smallholder tomato producers in Asaita district, Afar National Regional State, Ethiopia. PLoS ONE 16(9), e0257366. Doi: https://doi.org/10.1371/journal.pone.0257366

Badan Pusat Statistik Indonesia. 2022. Statistical yearbook of Indonesia. Vol. 1101001. In: BPS-Statistics Indonesia, https://www.bps.go.id/publication/2020/04/29/e9011b3155d45d70823c141f/statistik-indonesia-2020.html; consulted: April, 2024.

Chiarella, C., P. Meyfroidt, D. Abeygunawardane, and P. Conforti. 2023. Balancing the trade-offs between land productivity, labor productivity and labor intensity. Ambio 52(10), 1618-1634. Doi: https://doi.org/10.1007/s13280-023-01887-4

Choudhary, S.K. 2013. Contribution of national horticulture mission in agricultural development. Int. J. Adv. Res. Manag. Soc. Sci. 2(6), 52-64.

Degefa, K., G. Abebe, and G. Biru. 2023. Factors affecting sorghum production in Western Ethiopia: evidence from smallholder farmers. Int. J. Food Agric. Nat. Resour. 4(2), 33-39. Doi: https://doi.org/10.46676/ij-fanres.v4i2.109

Dyanto, R., D. Sukmawati, Nataliningsih, and N. Apandi. 2022. Pengaruh faktor sosial ekonomi dan Partisipasi Petani Anggota Kelompok Tani Terhadap Keberhasilan Usahatani tomat (*Solanum lycopersicum* L). J. Ilmu-Ilmu Pertanian Peternak. 10(1), 25-32. Doi: https://doi.org/10.31949/agrivet.v10i1.2680

Frangu, B., J.S. Popp, M. Thomsen, and A. Musliu. 2018. Evaluating greenhouse tomato and pepper input efficiency use in Kosovo. Sustainability 10(8), 2768. Doi: https://doi.org/10.3390/su10082768

Gallegos-Cedillo, V.M., C. Nájera, A. Signore, J. Ochoa, J. Gallegos, C. Egea-Gilabert, N.S. Gruda, and J.A. Fernández. 2024. Analysis of global research on vegetable seedlings and transplants and their impacts on product quality. J. Sci. Food Agric. 104(9), 4950-4965. Doi: https://doi.org/10.1002/jsfa.13309

Hadi, S. and B.R. Sita. 2016. Produktivitas Dan faktor-faktor yang berpengaruh terhadap produksi usahatani tomat (*Solanum lycopersicum* Mill.) di Kabupaten Jember. J. Sos. Ekon. Pertanian 9(3), 67-78. Doi: https://doi.org/10.19184/jsep.v9i3.6495

Kartika, M.N. and B. Kurniasih. 2021. Pengaruh irigasi tetes dan mulsa terhadap pertumbuhan Tajuk tanaman tomat (*Solanum lycopersicum* L.) di lahan kering Gunungkidul. Vegetalika 10(1), 31-43. Doi: https://doi.org/10.22146/veg.55590

Kurniawan, I., A. Suyatno, E. Dolorosa, J. Sosial, and E. Pertanian. 2018. Analisis faktor-faktor yang mempengaruhi produksi tomat (*Solanum lycopersicium* Mill) di Desa Rasau Jaya i Kecamatan Rasau Jaya Kabupaten Kubu Raya. J. Sains Pertanian Equator 8(1).

Liu, L., X. Zheng, X. Wei, Z. Kai, and Y. Xu. 2021. Excessive application of chemical fertilizer and organophosphorus pesticides induced total phosphorus loss from planting causing surface water eutrophication. Sci. Rep. 11(1), 23015. Doi: https://doi.org/10.1038/s41598-021-02521-7

Ma, Y., M. Zheng, X. Zheng, Y. Huang, F. Xu, X. Wang, J. Liu, Y. Lv, and W. Liu. 2023. Land use efficiency assessment under sustainable development goals: a systematic review. Land 12(4), 894. Doi: https://doi.org/10.3390/land12040894

Mahyudi, F. and H. Husinsyah. 2019. Analisis kelayakan Ushatani tomat (*Solanum lycopersicum*) di Kelurahan Landasan Ulin Utara Kecamatan Liang Anggang Kota Banjarbaru Provinsi Kalimantan Selatan. Ziraa'Ah Majalah Ilm. Pertanian 44(3), 267-276. Doi: https://doi.org/10.31602/zmip.v44i3.2225

Majid, N.K., T.I. Noor, and R. Kurnia. 2022. Faktor faktor yang mempengaruhi produksi usahatani tomat. Suatu kasus di Desa Cibeureum Kecamatan Sukamantri Kabupaten Ciamis. J. Ilm. Mahasiswa Agroinfo Galuh 9(3), 1357-1363. Doi: https://doi.org/10.25157/jimag.v9i3.8442

Managanta, A.A. 2020. The role of agricultural extension in increasing competence and income rice farmers. Indones. J. Agric. Res. 3(2), 77-88. Doi: https://doi.org/10.32734/injar.v3i2.3963

Mario, M.D., L. Hutahaean, and J.B. Alfaons. 2005. Kesesuaian lahan untuk pengembangan hortikultura di Dataran Tinggi Napu Sulawesi Tengah. pp. 285-291. In: Seminar Nasional Inovasi Teknologi Pertanian Berwawasan Agribisnis Mendukung Pembangunan Pertanian Wilayah Kepulauan, Ambon, Indonesia.

Misra, M.K., A. Harries, and M. Dadlani. 2023. Role of seed certification in quality assurance. pp. 267-297. In: Dadlani, M. and D.K. Yadava (eds.). Seed science and technology: biology, production, quality. Doi: https://doi.org/10.1007/978-981-19-5888-5

Nakana, T.M., J.J. Hlongwane, and A. Belete. 2021. Economic efficiency analysis of small-scale tomato farmers in Greater Letaba Municipality, Limpopo Province, South Africa. J. Agribus. Rural Dev. 4(62), 429-434. Doi: https://doi.org/10.17306/j.jard.2021.01416

Noulas, C., S. Torabian, and R. Qin. 2023. Crop nutrient requirements and advanced fertilizer management strategies. Agronomy 13(8), 2017. Doi: https://doi.org/10.3390/agronomy13082017

Özer, H. 2018. The effects of different seedling production systems on quality of tomato plantlets. Acta Sci. Pol. Hortorum Cultus 17(5), 15-21. Doi: https://doi.org/10.24326/asphc.2018.5.2

Pattiasina, T.A., R. Nurmalina, H. Harianto, and A. Fariyanti. 2023. The input allocation and potato production on small-scale farming in Pegunungan Arfak Regency. J. Manaj. Agribisnis 20(1), 79-89. Doi: https://doi.org/10.17358/jma.20.1.79

Pitaloka, D. 2017. Hortikultura: potensi, pengembangan dan tantangan. G-Tech J. Teknol. Terap. 1(1), 1-4. Doi: https://doi.org/10.33379/gtech.v1i1.260

Rajani, R. and J. Shourabh. 2017. The role of horticultural crops in enhancing nutrient security. Int. J. Curr. Microbiol. App. Sci. 6(9), 311-316. Doi: https://doi.org/10.20546/ijcmas.2017.609.039

Ren, C., S. Jin, Y. Wu, B. Zhang, D. Kanter, B. Wu, X. Xi, X. Zhang, D. Chen, J. Xu, and B. Gu. 2021. Fertilizer overuse in Chinese smallholders due to lack of fixed inputs. J. Environ. Manag. 293, 112913. Doi: https://doi.org/10.1016/j.jenvman.2021.112913

Ren, C., S. Liu, H. van Grinsven, S. Reis, S. Jin, H. Liu, and B. Gu. 2019. The impact of farm size on agricultural sustainability. J. Clean. Prod. 220(12), 357-367. Doi: https://doi.org/10.1016/j.jclepro.2019.02.151

Safir, M., M. Jayadi, and R. Neswati. 2023. Pemetaan kesesuaian lahan Desa Tonasa Kecamatan Tombolo Pao untuk tanaman hortikultura. J. Ecosolum 12(2), 223-242. Doi: https://doi.org/10.20956/ecosolum.v12i2.23573

Setyorini, D., R.Saraswati, D. Ea, and K. Anwar. 2006. Kompus. pp. 11-40. In: Simanungkalit, R.D.M., D.A. Suriadikarta, R. Saraswati, D. Setyorini, and W. Hartatik (eds.). Pupuk organik dan pupuk hayati. Balai Besar Litbang-Sumberdaya Lahan Pertanian, Bogor, Indonesia.

Sinaga, A.H. 2023. Analisis efisiensi agribisnis tomat (*Lycopersicum esculentum*). J. Darma Agung 27(1), 911-919. Doi: https://doi.org/10.46930/ojsuda.v29i2.2787

Sri, A.A. 2016. Faktor-faktor yang mempengaruhi produksi cabai merah. Mimbar Agribisnis 1(3), 261-268. Doi: https://doi.org/https://doi.org/10.25157/ma.v1i3.46

Taiy, R.J., C. Onyango, A. Nkurumwa, and K. Ngetich. 2017. Socio-economic characteristics of smallholder potato farmers in Mauche Ward of Nakuru County, Kenya. Univ. J. Agric. Res. 5(5), 257-266. Doi: https://doi.org/10.13189/ujar.2017.050502

Tejada, J.J., J.R.B. Punzalan. 2012. On the Misuse of Slovin's formula. Philipp. Stat. 61(1), 129-136.

Testa, R., A.M. di Trapani, F. Sgroi, and S. Tudisca. 2014. Economic sustainability of Italian greenhouse cherry tomato. Sustainability 6(11), 7967-7981. Doi: https://doi.org/10.3390/su6117967

Thomas, K., K.B. Ramappa, and P.L. Govindarajan. 2024. Strategies to scale up the technical, allocative and economic efficiency of major millet growing farmers in India – A primal system approach. Environ. Sustain. Indicators 24, 100493. Doi: https://doi.org/10.1016/j.indic.2024.100493

Ullah, U., M. Ashraf, S.M. Shahzad, A.R. Siddiqui, M.A. Piracha, and M. Suleman. 2016. Growth behavior of tomato (*Solanum lycopersicum* L.) under drought stress in the presence of silicon and plant growth promoting rhizobacteria. Soil Environ. 35(1), 65-75.

Wadu, J. 2023. Faktor-faktor yang mempengaruhi produksi tomat di Kelurahan Kawangu Kecamatan Pandawai Kabupaten Sumba Timur. J. Rekayasa Manaj. Agroindustri 11(1), 126-132. Doi: https://doi.org/10.24843/JRMA.2023.v11.i01.p12

Weldegiorgis, L.G., G.K. Mezgebo, H.G. Gebremariam, and Z.A. Kahsay. 2018. Resources use efficiency of irrigated tomato production of small-scale farmers. Int. J. Veg. Sci. 24(5), 456-465. Doi: https://doi.org/10.1080/19315260.2018.1438552

Wowiling, Y., J.N.K. Dumais, and S.G. Jocom. 2023. Efisiensi pemasaran tomat di Desa Tondegesan Kecamatan Kawangkoan Kabupaten Minahasa. Agri-Sosioekon. 19(2), 783-792. Doi: https://doi.org/10.35791/agrsosek.v19i2.48306