FARMERS’ TECHNICAL EFFICIENCY AND THEIR ADOPTION TO NEW VARIETY OF SORGHUM: EVIDENCE FROM EAST JAVA OF INDONESIA

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ABSTRACT

Objective: The study delves into the technical efficiency of sorghum cultivation and evaluates the effects of the adoption of the new superior variety on the efficiency of farmers.

Methods: The research employs a methodology that involves the use of stochastic frontier analysis and propensity score matching to examine cross-sectional data obtained from a sample of 150 farmers located in Lamongan Regency, East Java, Indonesia.

Results: The findings indicate that sorghum farmers exhibit suboptimal levels of technical efficiency. The adoption of the bioguma variety has a positive impact on the technical efficiency of farmers. Farmers who choose to implement bioguma demonstrate superior levels of efficiency in comparison to their counterparts who utilize alternative varieties.

Suggestions: The study suggests that policymakers should take steps to enhance access to high-quality seeds and encourage farmers to adopt improved varieties. This can be accomplished through measures such as targeted subsidies, favorable credit schemes, or collaborations with seed companies to ensure the availability and affordability of the bioguma variety.

Keywords: sorghum, variety, technical efficiency, new variety adoption.

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EFICIÊNCIA TÉCNICA DOS AGRICULTORES E SUA ADOÇÃO À NOVA
VARIEDADE DE SORGO: EVIDÊNCIAS DE JAVA ORIENTAL DA
INDONÉSIA

RESUMO

Objetivo: O estudo aprofunda a eficiência técnica do cultivo do sorgo e avalia os efeitos da adoção da nova variedade superior na eficiência dos agricultores.

Métodos: A pesquisa emprega uma metodologia que envolve o uso de análise de fronteira estocástica e correspondência de pontuação de propensão para examinar dados transversais obtidos de uma amostra de 150 agricultores localizados na Regência de Lamongan, Java Oriental, Indonésia.

Resultados: Os achados indicam que os produtores de sorgo apresentam níveis abaixo do ideal de eficiência técnica. A adoção da variedade de bioguma tem um impacto positivo na eficiência técnica dos agricultores. Os agricultores que optam por implementar bioguma demonstram níveis superiores de eficiência em comparação com seus homólogos que utilizam variedades alternativas.

Sugestões: O estudo sugere que os formuladores de políticas devem tomar medidas para melhorar o acesso a sementes de alta qualidade e incentivar os agricultores a adotar variedades melhoradas. Isso pode ser conseguido através de medidas como subsídios direcionados, regimes de crédito favoráveis ou colaborações com empresas de sementes para garantir a disponibilidade e acessibilidade de preços da variedade de bioguma.

Palavras-chave: sorgo, variedade, eficiência técnica, adoção de nova variedade.

1 INTRODUCTION

Sorghum has emerged as a prominent agricultural commodity in diverse global regions (Shah et al., 2021). Sorghum is a versatile crop that can grow in a variety of agroecological zones, including arid, semiarid, and high-rainfall regions. The crop's adaptability renders it a crucial agricultural commodity for small-scale farmers in emerging economies (Muhammad et al., 2020). The capacity of sorghum to withstand environmental stressors such as drought, high temperatures, and poor soil fertility underscores its importance in regions with limited resources. Sorghum has a significant nutritional value due to its high levels of protein, fiber, minerals, and vitamins (Mironesa et al., 2021). Sorghum can be considered a suitable dietary option for individuals with gluten sensitivities due to its lack of gluten content. Furthermore, its favorable bioenergy properties render it a promising candidate for the production of biofuel, biogas, and biochar (Bazaluk et al., 2021). The multifaceted characteristics of sorghum render it a valuable crop for promoting sustainable agriculture and ensuring food security, thereby
warranting additional research and development endeavors. Sorghum grains are globally recognized as the fifth most significant cereal crop following wheat, corn, rice, and barley.

Sorghum cultivation has been established in Indonesia since 1970. Sorghum has emerged as a dependable commodity during the arid season, particularly in regions that rely on precipitation for agricultural production. Currently, sorghum cultivation is underway in multiple regions, with a total planted area of 3,440 hectares in Indonesia (Gupito, Irham, and Waluyati 2014). Despite sorghum being recognized as one of the significant cereals globally and Indonesia having a longstanding history of cultivation, this commodity has yet to be incorporated into the nation's strategic development plan. The advancement of food technology and agricultural systems has brought about a growing interest in sorghum among various governmental bodies across multiple provinces. One of them is in East Java Province, where the local government has set up a sorghum commodity development area in the hopes of increasing the potential of local food in order to foster food sovereignty. The process of sorghum development encompasses the advancement of cultivars, techniques for cultivation, and methods for post-harvest processing.

The primary interest of key actors in the sorghum farming industry is the promotion of welfare. The most straightforward observation to make is an augmentation in the revenue of agriculturalists. If the crop gives farmers a profit, they'll keep growing sorghum. From an economic standpoint, the assessment of farm efficiency can be conducted via the examination of technical efficiency. Technical efficiency refers to the ability to achieve maximum output by utilizing minimal input, thereby resulting in optimal income (Miriti et al. 2021). In the production unit, technical efficiency measures the performance of farming production. On the other hand, technical efficiency may be subject to the influence of social-economic variables and demographic factors pertaining to farmers. The input factor, particularly the plant varieties, holds the greatest influence. The production of growth, maintenance, and yields is significantly impacted by varieties (Mishra et al. 2018).

The technical efficiency of sorghum plants has been extensively studied. The majority of earlier studies continue to identify managerial, social economic, and institutional elements as external causes of technical inefficiency (Chepng’etich et al. 2015; Chepng’Etich et al. 2015; Dredawa 2019). A comparative analysis of sorghum varieties’ efficiencies is scarce in the current body of knowledge, regardless of the fact...
that sorghum cultivars have distinct cultivation techniques and potential yields (Dayakar Rao 2018). The present research aims to make a scholarly contribution by presenting findings on the technical efficiency of evaluating sorghum farming across different varieties cultivated in Indonesia.

This research examine the technical efficacy of sorghum farming in order to determine how the cultivation of different varieties of sorghum compares and contrasts with one another. Stochastic Frontier analysis is employed to attain the objective of discerning the dissimilarity between the varieties utilized, via a propensity score matching analysis. The findings of this investigation offer significant policy implications concerning the advancement of sorghum in Indonesia, particularly from an upstream perspective.

The analysis of technical efficiency has a theoretical foundation in production economics, as supported by empirical evidence. Efficiency is predicated upon the comprehensive utilization of production factors to achieve optimal output without any wastage. According to academic discourse, a production process is deemed inefficient when a substantial quantity of inputs is utilized to generate a meager output. The conventional method for assessing technical efficiency involves computing the quotient of the output and the inputs utilized. The traditional way of looking at productivity and efficiency has been replaced by the frontier approach, which is based on econometrics and linear programming. As per the frontier efficiency measure, firms that operate at the maximum level of production are deemed to be efficient. The significant spatial separation among production lines can be regarded as a manifestation of suboptimal performance.

2 THEORETICAL FRAMEWORK

Sorghum plays a vital role in agriculture and serves multiple purposes such as animal feed, biofuels, and human consumption. Due to its higher drought tolerance compared to corn, sorghum is favored as a cereal crop in regions with low rainfall or frequent drought (Widodo et al. 2023). Furthermore, sorghum exhibits resilience to certain soil toxicities and adapts well to various temperature ranges and high altitudes (Ratnavathi 2018). It can be used as dry fodder, green fodder, hay, or silage. Sorghum serves as a dietary staple for millions of people in approximately 30 countries across Africa and Asia, particularly in subtropical and semi-arid regions. It holds significance as
a food and fodder source, predominantly in traditional, smallholder farming (Hariprasanna and Rakshit 2016). Additionally, it is increasingly utilized as a feed crop in high-input commercial farming and is emerging as a biofuel crop. Sorghum's importance as a food commodity is amplified amidst climate change conditions and the global food crisis threat (Widodo et al. 2023). In the era of modern agriculture, technical efficiency needs to be considered, even though sorghum has resistance to climate change and drought.

Technical efficiency refers to the extent to which a firm or organization optimally utilizes its resources to produce output (de la Fuente-Mella, Rojas Fuentes, and Leiva 2020). This fundamental concept in production economics serves as a crucial metric for evaluating the performance of firms and organizations. The theoretical underpinnings of technical efficiency are rooted in the notion that firms and organizations should endeavor to utilize their resources in the most effective manner, aiming to maximize output while minimizing costs (Ding and Kinnucan 2011). Employing mathematical models, these methods enable a comparative evaluation of firms or organizations by considering their inputs (e.g., labor, capital, and materials) and outputs (e.g., goods or services produced). Analyzing the results derived from these methodologies can unveil opportunities for enhancing efficiency within firms or organizations and can aid in devising strategies to enhance overall performance (Dessale 2019).

One method to measure technical efficiency is Stochastic Frontier Analysis (SFA), it is an econometric technique used for efficiency measurement. SFA involves incorporating two error components: a random error term and an inefficiency term. Both components are assumed to follow specific distributions, enabling maximum likelihood estimation (Behr 2015). SFA is a method employed to estimate production frontiers and assess production efficiency levels. In this analysis, a parametric approach is utilized, and econometric methods are employed to calculate efficiency (Machmud, Nandiyanto, and Dirgantari 2018). SFA can be employed to directly compute technical efficiency and its determinants, which are subsequently estimated using Maximum Likelihood Estimation (MLE).

Technical efficiency can be associated with the adoption of new technology among farmers, and improved varieties can be considered as novel agricultural technologies. Farmer adoption of new varieties can have a positive impact on technical efficiency by improving production processes and increasing yields (Jones-Garcia and
However, there can be barriers to adoption that need to be addressed in order to realize the full potential of these technologies. Policymakers have the capacity to promote farmers' adoption of new technologies through diverse measures (Azam and Shaheen 2019; Noor et al. 2022). An effective strategy involves offering incentives for the adoption of sustainable agricultural practices, which may include both market and non-market incentives, regulatory measures, and cross-compliance initiatives that link direct payments to farmers’ adherence to fundamental environmental standards and the maintenance of land in sound agricultural and environmental condition (Lemeilleur et al. 2020; My et al. 2018).

3 METHOD

The present study utilized a stochastic frontier approach to assess the technical efficiency level of sorghum farmers. The stochastic frontier analysis is a theoretical and empirical approach that integrates production function analysis and econometric methodologies. It enables the distinction between inefficiency and random error and offers a gauge of how effectively farmers are working in relation to the production frontier. By comparing the actual output of sorghum farmers with the maximum output possible given the inputs and the production technology, this study was able to evaluate the technical efficiency of sorghum farmers. This approach takes into account both random variations in output and systematic differences in production efficiency among farmers. Furthermore, Propensity score matching (PSM) technique was applied to estimate the impact of bioguma variety adoption on farmers technical efficiency.

We can estimate the causal impact of the adoption on farmers’ technical efficiency by comparing the average difference of technical efficiency level between the adopters and the non-adopters. One of the benefits of PSM is that it does not need a panel or a baseline data survey. The PSM method was introduced by Rosenbaum and Rubin (Rubin, 1997) to evaluate the impact of a treatment or a program. Since introduced, this method has been widely applied especially in agricultural studies e.g., Sinyolo (Sinyolo, 2020), Wordofa et al. (Wordofa et al., 2021), and S. Zhang et al. (Zhang et al., 2020). Furthermore, this approach has also been used to measure the impact of an bioguma variety adoption in Indonesia, such as by Muhammin et al. (Muhammin et al., 2020), Rahman et al. (Rahman et al., 2019), and Suwandari et al., (Suwandari et al., 2020). The rationale for applying the PSM method is because the adoption of an improved bioguma
variety is self-selected with both observable and unobservable variables. If the study only compares the technical efficiency level between the adopters and the non-adopters, the result of the comparison could be biased. PSM can solve the problem of selection bias by establishing comparable respondents and matching the propensity score of each respondent. After the groups with similar scores were established, the technical efficiency levels of the adopters and the non-adopter could be compared more justly.

The PSM technique starts by separating the farmers into two groups (the adopter and the non-adopter group). If $\pi_{0i}^m$ is the technical efficiency level of farmers who adopted i, the technical efficiency level for the farmer who adopted is written as $\pi_{1i}^m$, and the technical for farmers did not adopt is written as $\pi_{0i}^m$. The ratio of technical efficiency level between the adopters and the non-adopters can be formulated as follows:

$$\Delta_i = \pi_{1i}^m - \pi_{0i}^m$$  \hspace{1cm} (1)

If the heterogenic impact between the adopters and the non-adopters, and the average impact is not identified, then:

$$AE = E(\pi_{1i}^m - \pi_{0i}^m)$$  \hspace{1cm} (2)

A problem in the assessment of equation 3 is the technical efficiency of the adopters in case the non-adopters are unable to be observed. The accomplishment is replaced with the non-adopter farmers. So, the equation 3 is as follows:

$$AE = E(\pi_{1i}^m - \pi_{0nm}^m)$$  \hspace{1cm} (3)

Where,

$\pi_{0nm}^m$ is technical efficiency level for the adopters.

If the adopter group was randomly drawn from the populations, then:

$$E(\pi_{1i}^m) = E(\pi_{0nm}^m)$$  \hspace{1cm} (4)

However, if the decision-making process of adopting an improved bioguma variety depends on the farmers’ characteristics, then we can write as follows:
The selection bias can be solved by the PSM technique. This requires a conditional independent assumption (CIA). In this case, the CIA is the characteristic of the adopters and non-adopters that are random so the adaptation decision is not related to the technical efficiency. PSM was defined as the conditional likelihood of the adoption by taking into account the characteristics of farmers (Rosenbaum & Rubin 1985), as follows:

\[ p(X) = \Pr(m = 1|X) \]  

Where,

\[ m = 1 \text{ if the farmers adopt the improved bioguma variety and 0 if farmers do not adopt, and } X \text{ is the farmers characteristic variables.} \]

The balancing property was needed by the propensity score and can rewritten as follows:

\[ m \perp X | p(X) \]  

Meanwhile, if combined with the CIA assumption, it can be written as follows:

\[ \pi^m_0, \pi^m_1 \perp m | p(X) \]  

Equation 8 implies that if the adopters and non-adopters have a similar propensity score, the average difference in the technical efficiency was an unbiased estimator of the average effect.

4 RESULT AND DISCUSSION
4.1 DESCRIPTIVE STATISTICS

Descriptive statistics for selected study variables are in Table 1. The aforementioned table presents data pertaining to the average and the degree of variability, as measured by the standard deviation, for every variable. Initially, it was observed that the variable pertaining to the adoption of the Bioguma variety indicated that roughly 25.3% of the farmers included in the sample had adopted said variety. The level of technical efficiency among farmers is measured through the application of a stochastic
frontier approach. The sample's average technical efficiency is 0.501, implying that the farmers are operating at approximately 50.1% of their maximum potential efficiency. The calculated value of the standard deviation being 0.257 indicates the presence of variability in the efficiency levels across the farmers. The calculated mean age of the farmers in the sample is 55.167, suggesting that the average age of the participants is approximately 55 years. The average value of education level is 6.360, indicating that, on average, the farmers in the sample have completed approximately 6.36 years of education. The "Off-farm" variable is a binary variable that takes a value of 1 if the farmer has an off-farm job and 0 otherwise. The mean value for this variable is 0.407, indicating that approximately 40.7% of the farmers in the sample have an off-farm job. The mean value for land status is 1.107, indicating that, on average, the farmers in the sample have more than one parcel of land. The "sorghum experience" variable represents the farmers' experience in planting sorghum, measured in years. The mean experience is 21.780, indicating that, on average, the farmers in the sample have around 21.78 years of experience in planting sorghum. The standard deviation of 14.972 suggests some variability in the sorghum planting experience among farmers. The "Farm experience" variable represents the farmers' overall experience in agricultural activities, measured in years. The mean experience is 29.987, indicating that, on average, the farmers in the sample have around 29.987 years of experience in agricultural activities. The standard deviation of 12.107 suggests some variation in the overall farming experience among farmers. The "Internet access" variable is a binary variable that takes a value of 1 if the farmer has internet access and 0 otherwise. The mean value for this variable is 0.280, indicating that approximately 28% of the farmers in the sample have internet access. The standard deviation of 0.451 suggests some variability in the farmers' internet access status.

Moreover, the aforementioned table encompasses variables that are associated with agricultural production through the utilization of the Stochastic Frontier Analysis (SFA) methodology. The "Production" variable represents the total sorghum production in kilograms per hectare. The mean production is 4041.260 kg/ha, indicating that, on average, the farmers in the sample produced approximately 4041.260 kilograms of sorghum per hectare. The standard deviation of 2299.452 suggests significant variability in sorghum production among farmers. The "Organic fertilizer" variable represents the amount of organic fertilizer used in kilograms per hectare. The mean amount of organic fertilizer used is 3.194 kg/ha, indicating that, on average, farmers in the sample apply
approximately 3.194 kilograms of organic fertilizer per hectare. The standard deviation of 2.157 suggests some variability in the use of organic fertilizer among farmers. The "Seed" variable represents the amount of seed used in kilograms per hectare. The mean amount of seed used is 192.067 kg/ha, indicating that, on average, farmers in the sample plant approximately 192.067 kilograms of seed per hectare. The standard deviation of 161.402 suggests some variation in the amount of seed used among farmers. The "Chemical fertilizer" variable represents the amount of chemical fertilizer used in kilograms per hectare. The mean amount of chemical fertilizer used is 631.127 kg/ha, indicating that, on average, farmers in the sample apply approximately 631.127 kilograms of chemical fertilizer per hectare. The standard deviation of 255.440 suggests some variability in the use of chemical fertilizer among farmers. The "Pesticide" variable represents the amount of pesticide used in kilograms per hectare. The mean amount of pesticide used is 1.275 kg/ha, indicating that, on average, farmers in the sample apply approximately 1.275 kilograms of pesticide per hectare. The standard deviation of 1.210 suggests some variation in the use of pesticides among farmers. Overall, the descriptive statistics provided in Table 1 offer an overview of the selected variables in the study. They provide information on the adoption of the Bioguma variety, farmers' technical efficiency, demographic characteristics such as age and education, off-farm employment status, land ownership, farming experience, internet access, and various inputs and outputs related to sorghum production. These statistics allow for an initial understanding of the sample characteristics and can serve as a basis for further analysis and interpretation of the data.

Table 1. Descriptive statistics of selected variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety adoption</td>
<td>Dummy 1 if the farmers adopt Bioguma variety; 0 otherwise</td>
<td>0.253</td>
<td>0.436</td>
</tr>
<tr>
<td>Technical efficiency</td>
<td>Farmers' technical efficiency level using a stochastic frontier</td>
<td>0.501</td>
<td>0.257</td>
</tr>
<tr>
<td>Age</td>
<td>Age of farmer in year</td>
<td>55.167</td>
<td>9.356</td>
</tr>
<tr>
<td>Education</td>
<td>Farmers' education level in year</td>
<td>6.360</td>
<td>4.504</td>
</tr>
<tr>
<td>Off-farm</td>
<td>Dummy 1 if farmer has an off-farm job; 0 otherwise</td>
<td>0.407</td>
<td>0.493</td>
</tr>
<tr>
<td>Land status</td>
<td>Dummy 1 if the farmers has their own land; 0 otherwise</td>
<td>1.107</td>
<td>3.464</td>
</tr>
<tr>
<td>Sorghum experience</td>
<td>farmer's experience planting sorghum in year</td>
<td>21.780</td>
<td>14.972</td>
</tr>
<tr>
<td>Farm experience</td>
<td>farmers experience for agricultural activity in year</td>
<td>29.987</td>
<td>12.107</td>
</tr>
<tr>
<td>Internet access</td>
<td>Dummy 1 if farmer has internet access; 0 otherwise</td>
<td>0.280</td>
<td>0.451</td>
</tr>
<tr>
<td>SFA</td>
<td>otherwise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>Total sorghum production Kg/ha</td>
<td>4041.260</td>
<td>2299.452</td>
</tr>
</tbody>
</table>
Table 2 shows the results of a stochastic frontier estimation analysis, which tries to figure out how different input variables affect agricultural productivity and how efficient the technology is. In general, this study showed that chemical and organic fertilizers had a positive and significant impact on sorghum production.

Pesticide variable indicates that the coefficient is statistically insignificant at conventional significance levels (α=0.05). Therefore, there is insufficient evidence to conclude that Pesticide has a significant effect on agricultural productivity in this study. Moving on to the Chemical fertilizer variable, the coefficient is estimated to be 0.382 with a standard error of 0.098. The z-score is 3.920, and the p-value is reported as 0.000. This suggests that Chemical fertilizer has a significant positive impact on sorghum production. These findings indicate that Chemical fertilizer plays a crucial role in enhancing sorghum production. Farmers who increase their usage of Chemical fertilizer are likely to experience higher yields of sorghum compared to those who use lower amounts. For the Seed variable, the coefficient is also statistically insignificant at the conventional significance level. Thus, there is insufficient evidence to conclude that Seed has a significant effect on sorghum production in this analysis. Regarding the Organic fertilizer variable, the coefficient is estimated to be 0.146, and the p-value is reported as 0.044. These results suggest that Organic fertilizer has a significant positive impact on farm output. These findings highlight the importance of organic fertilizer in promoting sorghum production. Farmers who incorporate organic fertilizers into their agricultural practices are likely to observe higher yields of sorghum compared to those who do not utilize organic fertilizers.

| Variables         | Coef.  | Std. Err | z      | P>|z| |
|-------------------|--------|----------|--------|------|
| Pesticide         | 0.012  | 0.052    | 0.230  | 0.817|
| Chemical fertilizer| 0.382 | 0.098    | 3.920  | 0.000***|
| Seed              | -0.092 | 0.068    | -1.360 | 0.175|
| Organic fertilizer | 0.146 | 0.073    | 2.010  | 0.044**|
| _cons             | 6.816  | 0.569    | 11.990 | 0.000**|
| /lnsig2v          | -3.185 | 0.503    | -6.340 | 0.000|
| /lnsig2u          | 0.470  | 0.146    | 3.220  | 0.001|
| sigma_v           | 0.203  | 0.051    | 0.124  | 0.333|
Furthermore, figure 1 presents the technical efficiency levels of sorghum farmers and their corresponding percentages. Technical efficiency refers to the effectiveness with which resources are utilized to produce output. The table divides technical efficiency into four ranges: 0-0.29, 0.3-0.59, 0.6-0.89, and 0.9-1. For each range, the table provides the respective percentage value. According to the data, the range of 0-0.29 exhibits a technical efficiency of 22.67%. This suggests that a significant proportion of resources allocated within this range are not effectively utilized in generating output. In the range of 0.3-0.59, the technical efficiency increases to 32.67%, indicating a moderate improvement in resource utilization. Moving to the range of 0.6-0.89, the technical efficiency further improves to 42.67%. This range demonstrates a relatively higher level of resource utilization efficiency compared to the previous two ranges. Finally, in the range of 0.9-1, the technical efficiency drops significantly to 2%. This suggests that only a small portion of resources within this range are effectively utilized to produce output.

These findings highlight the variations in technical efficiency levels across different ranges. It is evident that there is room for improvement in resource utilization, particularly in the lower ranges of technical efficiency. The higher ranges indicate a relatively better utilization of resources, albeit with a decline in efficiency towards the upper end. Further research and analysis are necessary to understand the factors contributing to these variations and develop strategies to enhance overall technical efficiency.
4.3. DETERMINANTS OF FARMERS’ VARIETY ADOPTION: A PROBIT MODEL

Table 3 presents the results of a probit model examining the determinants of variety adoption in the context of *bioguma* variety. The first predictor variable, Age shows a negative coefficient and it is not statistically significant indicating that age does not have a significant impact on *bioguma* variety adoption. The second predictor variable, Education has a positive coefficient and it is statistically significant suggesting that higher levels of education positively influence *bioguma* adoption. Education plays a pivotal role in the adoption of new varieties, and its impact is not only significant but also positive. When individuals are equipped with a higher level of education, they tend to exhibit a greater willingness to embrace and incorporate innovative practices and technologies. This positive coefficient suggests that as education levels increase, the likelihood of adopting new varieties also rises. This finding is in line with the previous study by Oyewole et al., (2020), Kudama et al. (2020) and Rahman et al.,  (2022) . In the context of Indonesia similar finding also pointed out by Syafrial et al., (2021) who highlight the important role of farmers’ education level on variety adoption. The third predictor, Off-farm, has a positive coefficient but it is not statistically significant, indicating that off-farm activities do not have a significant effect on *bioguma* adoption.

The fourth predictor, Land status has a negative and statistically significant coefficient suggesting that land status plays a role in variety adoption, with those rent their cultivated land being less likely to adopt *bioguma* varieties. Land ownership status has been found to have a negative and significant impact on the adoption of new varieties.
When land ownership is concentrated in the hands of a few individuals or entities, it often leads to limited access to resources and technology for small-scale farmers. This lack of access hampers their ability to adopt and benefit from new agricultural varieties that could enhance productivity and increase yields. Additionally, concentrated land ownership can create barriers to entry for smallholders, limiting their capacity to invest in improved seeds, machinery, and other inputs necessary for adopting new varieties. As a result, the potential benefits of innovative agricultural practices are often not fully realized, leading to slower progress in the agricultural sector and potential disparities in productivity between large and small-scale farmers. Several studies also highlight similar findings that land status has an essential role for farmers technology adoption such as new variety (Roessali et al., 2019; Rawung et al., 2021). The fifth predictor, sorghum experience and farm experience, has a negative and positive coefficient respectively, but it is not statistically significant, indicating that prior experience with sorghum does not significantly influence bioguma variety adoption. The seventh predictor, "Internet access," shows a positive coefficient and it is highly statistically significant at 1% level, indicating that having internet access greatly increases the likelihood of variety adoption. Internet access has had a profound and positive impact on the adoption of new varieties. With the advent of the internet, people now have unparalleled access to information, resources, and global networks. This has revolutionized the way individuals and communities interact with and embrace new ideas, including the adoption of innovative products and technologies. As the source of information, in this particular study agricultural related information, internet access have been widely proven to improve farmers adoption (Zhou et al., 2023; Khan et al., 2022; Cai et al., 2022).

Table 3: Determinant of variety adoption: A probit model

| Variety                  | Coef. | Std. Err. | z     | P>|z| |
|--------------------------|-------|-----------|-------|-----|
| Age                      | -0.043| 0.034     | -1.260| 0.208|
| Education                | 0.152 | 0.063     | 2.410 | 0.016**|
| Off-farm                 | 0.357 | 0.428     | 0.830 | 0.404|
| Land status              | -0.986| 0.519     | -1.900| 0.057*|
| sorghum experience       | -0.012| 0.021     | -0.560| 0.573|
| Farm experience          | 0.049 | 0.032     | 1.550 | 0.120|
| Internet access          | 2.161 | 0.408     | 5.300 | 0.000***|
| Constat                  | -1.105| 1.482     | -0.750| 0.456|
| Log likelihood           | -31.418|
| LR chi2(7)               | 106.950|
| Prob > chi2              | 0.000 |
| Pseudo R2                | 0.6299 |

Note: *** p < 0.01.; ** p < 0.05.; * p < 0.1.
Source: Authors’ Analysis, 2023.
4.4 THE IMPACT OF BIOGUMA ADOPTION ON FARMERS TECHNICAL EFFICIENCY

This study investigates the influence of variety adoption on technical efficiency using a propensity score matching (PSM) estimation. The analysis employs different matching algorithms, including Nearest Neighbours Matching, Radius Matching, Kernel Matching, and Stratification Matching, to assess the average treatment effect on the treated (ATT). The results are reported in Table 4, which presents the estimated ATT. According to the results, the Nearest Neighbours Matching algorithm employed 38 treated units and 12 control units, resulting in an ATT of 0.195. Similarly, the Radius Matching algorithm utilized 38 treated units and 30 control units, yielding an ATT of 0.133. The Kernel Matching algorithm involved 38 treated units and 31 control units, leading to an ATT of 0.183. Lastly, the Stratification Matching algorithm employed 38 treated units and 31 control units, resulting in an ATT of 0.207. Furthermore all the matching are statistically significant. This finding indicated that the adoption of bioguma variety has a positive and significant effect on farmers technical efficiency. Farmers who adopt bioguma tend to have higher technical efficiency level than farmers who use other variety. The bioguma variety of sorghum indeed exhibits several advantages compared to conventional sorghum varieties. The following provides a detailed explanation of these advantages; first, the bioguma variety has larger stems compared to regular sorghum varieties. This feature is advantageous in terms of plant strength and stability. The larger stem provides better support for upright growth, making the plants more resistant to strong winds and extreme weather conditions. Second, higher sugar content (Brix): Brix is a measure used to describe the sweetness level in plants. The bioguma variety has a higher sugar content (Brix) compared to regular sorghum varieties. The higher sugar content indicates that bioguma plants have a sweeter taste. This can be advantageous when using sorghum as a raw material for bioethanol production, animal feed, or natural sweeteners. Third, higher volume of sap: Sap is the liquid obtained from the extraction of sorghum stems. The bioguma variety has a higher volume of sap compared to regular sorghum varieties. The presence of a larger sap volume can enhance the production of sugar or bioethanol derived from bioguma sorghum. Sap can also be directly utilized as a raw material for the production of brown sugar. Fourth, higher seed production: One of the primary advantages of the bioguma variety is its higher seed production rate. Sorghum seeds are used in various food and animal feed industries. With higher seed production,

Table 4. The impact of variety adoption on technical efficiency: PSM Estimation

<table>
<thead>
<tr>
<th>Matching algorithm</th>
<th>n. treat.</th>
<th>n. contr.</th>
<th>ATT</th>
<th>Std. Err.</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearest Neighbours Matching</td>
<td>38</td>
<td>12</td>
<td>0.195</td>
<td>0.122</td>
<td>1.597**</td>
</tr>
<tr>
<td>Radius Matching</td>
<td>38</td>
<td>30</td>
<td>0.133</td>
<td>0.083</td>
<td>1.595**</td>
</tr>
<tr>
<td>Kernel Matching</td>
<td>38</td>
<td>31</td>
<td>0.183</td>
<td>0.119</td>
<td>1.545**</td>
</tr>
<tr>
<td>Stratification Matching</td>
<td>38</td>
<td>31</td>
<td>0.207</td>
<td>0.061</td>
<td>3.387***</td>
</tr>
</tbody>
</table>

Note: *** p < 0.01.; ** p < 0.05.; * p < 0.1.
Source: Authors’ Analysis, 2023.

5 CONCLUSION

This study investigates the technical efficiency of sorghum farmers and the impact of adopting the bioguma variety on their technical efficiency. The study utilizes cross-sectional data from 150 farmers in Lamongan Regency, East Java, Indonesia. Furthermore, the data is analyzed using a stochastic frontier and propensity score matching approach. The findings indicate that farmers' technical efficiency is quite low. On the other hand, according to the PSM approach, the adoption of the bioguma variety has a positive effect on farmers' technical efficiency. This suggests that farmers who adopt the bioguma variety tend to have a higher level of technical efficiency.

The findings of this study have important policy implications for promoting technical efficiency among sorghum farmers. Given the relatively low levels of technical efficiency observed, interventions and support should be directed towards improving farmers' knowledge and skills in sorghum production techniques. Training programs and extension services can play a crucial role in disseminating best practices and modern agricultural technologies to enhance farmers' technical capabilities. Additionally, the positive impact of adopting the bioguma variety on technical efficiency suggests the need to encourage its widespread adoption among sorghum farmers. Policymakers should consider implementing measures to increase access to high-quality seeds and provide incentives for farmers to adopt improved varieties. This can be achieved through targeted subsidy programs, favourable credit schemes, or collaborations with seed companies to ensure the availability and affordability of the bioguma variety. Furthermore, policymakers should prioritize investments in agricultural research and development to develop and promote more efficient and resilient sorghum production systems. This can

the bioguma variety can yield larger and more profitable results for farmers or producers relying on sorghum as their main commodity. These advantages make the bioguma variety more promising in terms of plant production, sugar content, and final yields. As the result it can improve farmers technical efficiency level
involve breeding programs to develop new varieties that are not only high-yielding but also adapted to local conditions, pest and disease resistant, and environmentally sustainable.
REFERENCES


