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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Can Greenhouse Technology Adoption Unlock Technical Efficiency Gains? Evidence From Melon Farming in East Java, Indonesia

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Abstract

This study aims to examine the factors that influence melon farmers in adopting greenhouse technology and analyze the impact of greenhouse technology on increasing the technical efficiency of melon farming. The sample size was 120 melon farmers in East Java Province, Indonesia. Probit regression was used to analyze the factors influencing farmers' adoption of Greenhouse technology, while the Stochastic Production Frontier function was employed to obtain the estimated technical efficiency value of each planting system in melon farming. The empirical results indicate that socio-economic variables such as age, education, and partnership relationships have a positive and statistically significant influence on the decision of melon farmers in the adoption of Greenhouse technology. In contrast, the variables including the number of family dependents, years of farming experience, and the main type of work as a farmer demonstrate a negative and significant influence. Overall, both the Greenhouse and conventional planting systems are technically efficient, although the levels of efficiency vary between the two methods and the performance outcomes are not identical. Regarding propensity score matching estimation, the greenhouse melon farming system has a higher technical efficiency value than conventional farming, with a difference of 0.041 in the stratification matching estimation and 0.0858 in the sample after the matching process, which strengthens the robustness of the findings. This finding clearly illustrates that farming through the adoption of Greenhouse technology has a positive and substantial impact on increasing technical efficiency, and therefore it is considered an appropriate, relevant, and reliable technology recommendation for increasing melon productivity in a sustainable way.

Keywords: Greenhouse, Efficiency, Productivity, Propensity score matching; Stochastic production frontier

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1. Introduction

The decline in the number of harvest areas of melon farms in Indonesia by -9.92%, especially the melon production centers of 3,354 ha, is inconsistent with the potential form of output produced due to land conversion to other sectors (Directorate General of Horticulture, 2022). The orientation of increasing production is not only through the expansion of planting land. Still, it must be oriented to the value of the results obtained using appropriate and rational production inputs (Islam et al., 2023; Workneh and Kumar, 2023; Khatri-Chhetri et al., 2023; Asmara et al., 2016). The findings of Anang et al (2020) showed that the success of agriculture in developed countries with a capacity of less land area compared to developing countries is due to the effective adoption of technology in the form of renewal of crop varieties, the use of technology in accelerating production, and the use of appropriate land. However, in Indonesia, the adoption of technology at the farm level often occurs due to resistance from farmers due to their inability to apply the technology. Extension intensity is very important as a means of non-formal education for farmers to get technical training-based education to positively affect technology adoption and increase farmer innovation (Wu et al., 2024; Sanogo et al., 2023; Salam and Islam, 2023; Nguyen-Thi-Lan et al., 2023). Low socioeconomic qualities such as low quality of education, age, lack of involvement in farmer groups, and others trigger resistance to adopting technology among farmers (Abdulai et al., 2018).

The findings of Huang et al (2024) regarding the existence of modern planting techniques do not always have a positive correlation to the increase in technical efficiency; in fact, the study illustrates that the level of comparison between organic farming has a lower level of technical efficiency than conventional farming. Therefore, there is a need for alternative methods of using the right technology to provide a high productivity level for using existing inputs. Some previous literature on the efficiency of production inputs for melon farming only focuses on open or traditional land, and the results are still paradoxical. This is evident in the research of Ebukiba et al (2022) and Yekti et al (2017), where there is a disparity regarding the results of technical efficiency analysis, which are both conducted on open land. Research by Ebukiba et al (2022) found that melon farmers in the capital city of Nigeria, who manage melon farming on open land, are technically inefficient on average. In contrast to research by Yekti et al (2017) on farming in the Kulon Progo district, Indonesia is able to produce technically efficient melon farms. Although both studies were conducted in different geographical locations, the effectiveness of using open land without adopting technology is still biased toward increasing production. Research Felices et al (2023); Maraveas et al (2023); Ihoume et al (2023); and Sajid et al (2023) One of the alternative technologies that can be applied to creating effectiveness and increasing the amount of production on minimal land is Greenhouse technology.

Research on the level of technology adoption and technical efficiency in melon farming using the Greenhouse planting method is still minimal and almost undetectable for scientific studies; given the current conditions, there is an escalation of progress in alternative technology that can be applied in farming activities. So, the urgency of this research on the level of technology adoption and technical efficiency of melon farming with the application of a Greenhouse as a planting method is important in examining the effectiveness of the amount of input in the application of the Greenhouse method to increase the amount of melon crop production. Research on the production efficiency of greenhouse planting and open land has been carried out by M. Li et al (2023) and conducted in mountainous areas of China. However, the research of M. Li et al (2023) only examines the main factors of the scale of operations and factors affecting agricultural land in the mountainous areas of China without showing an accurate comparative analysis of the level of production efficiency between Greenhouse and open land, specific to certain commodities and only the value of the production efficiency of each planting method, so that recommendations for appropriate planting methods for future agricultural technology are still biased. The basis of the research conducted in this study looks at the results of research by Irawan et al (2023), explaining that the Greenhouse method applied to melon farming has been widely developed in various regions because it has been shown to have a positive impact on meeting the number of market needs for the rapidly growing demand for melon fruit. The level of efficiency in farming can be proven in research by Susanto et al (2023) that melon farming with the Greenhouse planting method of organic fertilizer as the main fertilizer and planting media using polybags has a positive effect on increasing melon farming production compared to melon farming on open land.

On this basis, the contribution of this research shows the level of novelty in analyzing the factors that influence the level of adoption of Greenhouse technology as a Melon planting system and the level of technical efficiency in melon farming using the Greenhouse technology planting system. In addition, the novelty of this research is that it compares the estimated level of technical efficiency of melon farming in greenhouse and conventional systems. The results of this study can provide an overview of the impact of the adoption of Greenhouse technology and non-adoption of technology on increasing the technical efficiency of melon farming in East Java. This study's findings impact the design of appropriate agricultural technology development, especially in formulating effective policies for increasing national melon productivity. Measurement of production efficiency has an important contribution to the design or scheme of improving the welfare of small farmers and agricultural development in developing countries (Ghimire et al., 2023; Kitole et al., 2024). The novelty is certainly a support for further literature and a supporting reference for policymakers in creating advanced agricultural system regulations through efforts to empower the adoption of appropriate agricultural technology. To demonstrate the research contribution, this paper analyzes the factors influencing melon farmers' adoption of greenhouse technology, examines the level of technical efficiency under greenhouse systems, and compares greenhouse-based and conventional melon farming.

2. Materials and Methods

2.1. Research Location and Sampling

The study was conducted in East Java Province, Indonesia, which was purposively selected as the largest melon-producing region in the country, contributing approximately 53.06% to national melon production (Directorate General of Horticulture, 2022). The research location was determined using a multistage sampling approach, whereby sampling was conducted through several hierarchical stages to ensure representativeness across production systems. In the first stage, East Java was selected based on its dominant contribution to national melon production. In the second stage, districts were identified based on two criteria: (i) districts representing major centers of conventional melon production and (ii) districts with the highest adoption of greenhouse-based melon cultivation. Based on official statistics from the Central Bureau of Statistics (BPS, 2024), Plumpang Subdistrict, Tuban Regency, was selected as the conventional melon production center, while Wates Subdistrict, Blitar Regency, was selected to represent areas with intensive greenhouse melon adoption, consistent with previous empirical evidence reported by Cahyani et al. (2024). The study was conducted between November 2023 and March 2024.

The sampling technique applied in this study was non-probability sampling, focusing on two distinct farmer groups: melon farmers adopting greenhouse technology and farmers using conventional (traditional) cultivation methods. Due to the absence of reliable population data on greenhouse melon farmers, the minimum sample size was determined using Cochran's formula (Sugiyono, 2019):

$$n = \frac{z^2pq}{e^2} \quad \text{(Eq. 1)}$$

$$n = \frac{(1{,}96)^2(0{,}5)(0{,}5)}{0{,}1^2} = 96$$

where z represents the 95% confidence level (1.96), p and q denote the probability of correct and incorrect sampling (0.5), and e indicates a sampling error of 10%. Based on this formulation, the minimum required sample size was 96 observations. However, to further reduce sampling error and improve estimation precision, the sample size was deliberately increased to 120 farmers, in line with methodological recommendations that enlarging sample size enhances statistical reliability when population parameters are uncertain (Firmansyah and Dede, 2022). The final sample consisted of 60 greenhouse-adopting farmers and 60 non-adopting (conventional) farmers, enabling balanced comparative analysis across production systems.

2.2. Data Variable and Analysis

This section describes the data, variable construction, and empirical strategies employed to examine greenhouse technology adoption and its implications for technical efficiency in melon farming in East Java. To address these objectives in a coherent and complementary manner, the analysis employs a combination of Probit regression, Stochastic Production Frontier (SPF) analysis, and Propensity Score Matching (PSM). Each method serves a distinct analytical purpose and together they provide a comprehensive understanding of farmers' adoption behavior, production performance, and efficiency outcomes. Probit regression is used to identify the socioeconomic and institutional factors associated with greenhouse adoption, SPF analysis is applied to estimate technical efficiency and characterize production technology, and PSM is employed to compare efficiency outcomes between adopters and non-adopters under more comparable conditions. To ensure clarity and consistency across the econometric models, all variables used in the analysis are defined and categorized according to their respective roles in the adoption and production models. Table 1. presents the definitions, measurements, and rationales of the socioeconomic variables used in the adoption model and the production input variables employed in the technical efficiency model.

Table 1. Description of Variables

Variable	Symbol	Description and Rationale	Measurement
Socionomics Variables (Adoption Model)			
Adoption	Y	Dependent variable indicating farmers' decision to adopt greenhouse technology	Dummy (1 = greenhouse adoption, 0 = otherwise)
Age	X1	Captures farmers' demographic characteristics and decision-making maturity	Years
Number of Dependents	X2	Reflects household responsibilities that may affect risk attitudes and adoption decisions	Persons
Experience	X3	Measures accumulated farming knowledge and production experience	Years
Education	X4	Proxy for human capital and ability to understand and adopt new technology	Years of Formal Schooling
Extension Intensity	X5	Captures exposure to agricultural information and advisory services	Number of extension activities per season
Internet Access	D1	Represents access to digital information and innovation channels	Dummy (1 = access, 0 = no access)
Farmer Group Participation	D2	Reflects social capital and collective learning mechanisms	Dummy (1 = member, 0 = non-member)
Partnership Relationship	D3	Captures linkages with external actors (input suppliers, traders, or agribusiness firms) that may facilitate technology adoption	Dummy (1 = partnered, 0 = not partnered)
Main Occupation	D4	Indicates reliance on farming as the primary livelihood	Dummy (1 = farming, 0 = non-farming)
Production Input Variable (Technical Efficiency Model)			
Production	Y	Total melon production per planting season	Kilograms per season
Labor	X1	Total labor input used in melon production	Man-days (HOK) per season
Land Area	X2	Cultivated land area used for melon farming	Square meters (m^2)
Seed	X3	Quantity of seed input used	Packs per season
Organic Fertilizer	X4	Amount of organic fertilizer applied	Kilograms per season
Inorganic Fertilizer	X5	Amount of chemical fertilizer applied	Kilograms per season
Perticide	X6	Total pesticide usage per season	Liters per season
Adoption	Mi	Captures production frontier shifts associated with greenhouse technology	Dummy (1 = greenhouse, 0 = conventional)

The factors influencing the adoption of greenhouse technology in East Java are examined using a Probit regression model. This approach is appropriate given the binary nature of the adoption decision, where farmers either adopt greenhouse technology or continue with conventional cultivation methods. The probit regression function, according to Gujarati (2011), is generally as follows:

$$Y = A + \beta i X i + \varepsilon \qquad \text{(Eq. 2)}$$

The formulation is then transformed into the function equation of this study as follows:

$$Y = A + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 D_1 + \beta_7 D_2 + \beta_8 D_3 + \beta_9 D_4 + e \qquad \text{(Eq. 3)}$$

The probit regression testing approach uses Maximum Likelihood Estimate (MLE) parameters. To test these parameters and how much influence the independent variables have on the adoption of greenhouse planting technology, the *Wald* (Z) test is conducted in statistical modeling. The Probit regression analysis results with the Chi-Square table value at the free degree (df)=1 with the significance level used in this study is (α) = 1%, 5%, 10%. The estimated propensity scores derived from this model are later used as inputs in the Propensity Score Matching analysis.

Estimating the level of technical efficiency of melon farming with several planting techniques using the Stochastic Production Frontier approach will then obtain the Maximum Likelihood estimate (MLE). The general function modeling form in the analysis using the Stochastic Production Frontier analysis technique, according to Coelli et al. (2005), is as follows:

$$Y = \exp\,(\beta 0 + \beta 1\ LnXi + (Vi - Ui) \qquad \text{(Eq. 4).}$$

In this study, the SPF model is specified in a Cobb-Douglas functional form and focuses on estimating the production frontier while allowing for random production shocks captured by the symmetric error term Vi. The model does not estimate or decompose technical inefficiency. Accordingly, the empirical production frontier equations are formulated in natural logarithmic form as follows:

$$LnY_{pooled} = (LnA + \beta 1.LnX1 + \beta 2.LnX2 + \beta 3.LnX3 + \beta 4.LnX4 + \beta 5.LnX5 + \beta 6.LnX6 + \beta 8.D_1 M_i) + (Vi - Ui) \qquad \text{(Eq. 5)}$$

$$LnY_{GH} = (LnA + \beta 1.LnX1 + \beta 2.LnX2 + \beta 3.LnX3 + \beta 4.LnX4 + \beta 5.LnX + \beta 6.LnX6 + (Vi - Ui) \qquad \text{(Eq. 6)}$$

$$LnY_{NGH} = (LnA + \beta 1.LnX1 + \beta 2.LnX2 + \beta 3.LnX3 + \beta 4.LnX4 + \beta 5.LnX5 + \beta 6.LnX6) + (Vi - Ui) \qquad \text{(Eq. 7)}$$

Description: Y denotes total melon output obtained by both greenhouse and conventional farmers. X1-X6 represent conventional production inputs. Mi is included as a technology dummy variable indicating greenhouse adoption (1 = greenhouse, 0 = conventional). This variable is not treated as a conventional production input but is incorporated to capture systematic shifts in the production frontier associated with greenhouse technology adoption. The inclusion of M_i allows the stochastic frontier model to account for technological heterogeneity between greenhouse and conventional production systems, by identifying differences in production structure.

The results of the analysis will describe the condition of the technical efficiency of melon farming, which, in general, the formulation of technical efficiency according to Coelli et al. (2005) can be formulated as follows:

$$ETi = \frac{y}{y*} = E[\exp\,(-Ui)] \qquad \text{(Eq. 8).}$$

Y is the total production of Melon Greenhouse farmers and/or traditional melon farmers observed, while Y* is the total potential production of Melon Greenhouse farmers and/or conventional melon farmers. Research Harianto and Keraru (2022) in making decisions regarding parameters or categorization can be technically efficient if it obtains an efficiency value ≥ 70% or 0.7. These parameters are adopted from the expression Coelli et al (2005), which is used in this study as an indicator seeing the level of technical efficiency of melon farming based on these indicators can show the greater potential value that Greenhouse melon farmers and traditional melon farmers can achieve.

The impact of adopting the Greenhouse method on melon cultivation and comparing it with traditional cultivation was examined using the Propensity Score Matching (PSM) analysis approach. PSM is employed to reduce observable selection bias by comparing greenhouse adopters with non-adopters who share similar socioeconomic characteristics. Probit regression is determined by calculating the estimated Propensity Score value. Rosenbaum and Rubin (1984); Mideksa et al (2023); and Rhezandy et al (2023) The propensity Score value estimation is as follows:

$$e(xi) = P(Zi = 1|Xi = xi) = \frac{exp(\beta 0+\beta 1X1+\cdots\ldots+\beta nXn)}{1+exp(\beta 0+\beta 1X1+\cdots\ldots+\beta nXn)} \quad \text{(Eq. 9)}$$

Zi = 1 is a group of melon farmers who adopt Greenhouse technology, while Zi = 0 is a group of melon farmers who do not adopt technology (conventional). The value of β0 is the coefficient value of each variable, and the value of X is a covariate variable. After obtaining the estimated value of the Propensity Score value, it will then be tested by conducting a Matching process through the Stratification Matching approach by matching the Propensity Score value between the group of melon farmers who adopt Greenhouse technology and melon farmers who do not adopt technology (traditional). So, the function in this Matching process is as follows:

$$A(Pi) = \underbrace{min}_{0}\|P1 - P0\|, 0 \,\epsilon\, I0 \quad \text{(Eq. 10)}$$

P1 is the Propensity Score of melon farmer groups who adopt Greenhouse technology, and P0 is the Propensity Score of melon farmers who do not adopt the technology (conventional). The value of I1 is the set of melon farmer groups that adopt Greenhouse technology, and I1 is the set of melon farmers who do not adopt technology (conventional).

After the analysis of the Matching process has been carried out, the impact of melon farmers adopting Greenhouse technology on technical efficiency will be analyzed through Average Treatment of Treated (ATT) analysis. The ATT function in this study adopts the function developed by Sinaga et al (2019); Mideksa et al (2023); Adediran et al (2024); Wonde et al (2022); Mtenga et al (2024); and Salam and Islam (2023) as follows:

$$ATT = E(Y1|\mathrm{P(X)}, D = 1) - E(Y0|\mathrm{P(X)}, D = 0) \quad \text{(Eq. 11)}$$

Where D = 1 is a group of melon farmers adopting Greenhouse technology, D = 0 is melon farmers not adopting Greenhouse technology. The ATT captures the average difference in technical efficiency attributable to greenhouse adoption among farmers who have actually adopted the technology, under the assumption of selection on observables.

3. Results and Discussion

3.1. Mean differences in variables for each melon planting method

Table 2 shows the differences in socio-economic characteristics between Greenhouse and Non-Greenhouse melon farmers. These comparisons are reported as descriptive statistics to illustrate the general profiles of the two groups and to assess their similarity before and after the matching process. For continuous variables, the mean values reflect average levels measured in their respective units (such as years or number of persons), while for dummy variables, the means indicate the proportion of farmers with a given characteristic. Before matching (the unmatched sample), several variables, including age, number of dependents, farming experience, education level, partnership relationships, and main occupation, show noticeable differences between Greenhouse and Non-Greenhouse farmers. After applying propensity score matching, the matched sample consists of farmers who are more comparable in terms of observed characteristics. In this matched sample, some variables, such as the number of dependents, education, partnership relationships, and main occupation, still display differences, indicating that the two groups are not perfectly identical. These differences are reported to describe sample conditions after matching rather than to serve as the main findings of the study.

In the unmatched sample, Greenhouse farmers tend to be slightly older than Non-Greenhouse farmers. After matching, this age difference becomes smaller, suggesting improved comparability between the two groups. On average, Greenhouse farmers have fewer household dependents, while their farming experience is generally lower than that of Non-Greenhouse farmers, indicating that many Greenhouse adopters are relatively newer to melon cultivation. Greenhouse farmers also exhibit higher levels of formal education, a pattern that remains visible after matching. In addition, a higher proportion of Greenhouse farmers are involved in partnership arrangements with private actors, such as input suppliers or marketing agents. This pattern reflects differences in farmer characteristics and institutional access, rather than suggesting that Greenhouse adoption directly leads to such partnerships. Differences are also observed in main occupation, where Greenhouse farming is more commonly undertaken as an additional source of income, while conventional melon farming more often represents the primary livelihood of Non-Greenhouse farmers.

Table 2. Mean Differences among Socioeconomic Farmers

Variable	Unmatched				Matched			
	Greenhouse (60)	Non-Greenhouse (60)	Diff	P-Value	Greenhouse (60)	Non-Greenhouse (53)	Diff	P-Value
Age	46.767	42.967	3.80	0.06*	46.767	43.453	3.314	0.1204
Number of dependent	2.183	2.600	-0.4	0.017**	2.183	2.491	-0.3	0.086*
Experience	14.167	18.900	-4.3	0.03**	14.167	17.887	-3.7	0.1163
Education	10.950	9.150	1.80	0.0005***	10.950	9.340	1.610	0.0029***
Extension intensity	1.700	1.250	0.45	0.23	1.700	1.245	0.455	0.2584
Internet access	0.967	0.950	0.017	0.65	0.967	0.962	0.004	0.9005
Farmer group	0.750	0.750	0.00	1.00	0.750	0.736	0.014	0.865
Partnership relationship	0.400	0.117	0.28	0.0003***	0.400	0.132	0.268	0.0013***
Main occupation	0.583	0.850	-0.2	0.001***	0.583	0.830	-0.2	0.004***

Notes: ***) Significant at 1% level, **) Significant at 5% level, *) Significant at 10% level

The use of production inputs and output levels between Greenhouse and conventional melon farmers is presented in *Table 3*. This table is intended to provide a descriptive overview of input-use patterns and production characteristics before and after the matching process, and is used for descriptive purposes only. Both the unmatched and matched samples are reported to illustrate how production inputs are used across the two farming systems. The production variable, measured in kilograms per season, does not show notable differences between Greenhouse and Non-Greenhouse farmers. Although the mean difference in production appears numerically large, it is statistically insignificant because production levels exhibit substantial variability across farmers in both groups, such that the observed difference is relatively small compared to the dispersion of output. In contrast, several input variables, measured in physical units such as labor (man-days per season), land area (square meters), fertilizers (kilograms per season), and pesticides (liters per season), display clear differences between the two groups.

Table 3. Mean Differences of farmers in terms of inputs and outputs

Variable	Unmatched				Matched			
	Greenhouse (60)	Non-Greenhouse (60)	Diff	P-Value	Greenhouse (60)	Non-Greenhouse (53)	Diff	P-Value
Production	7514.333	6038.867	1475.46	0.2253	7514.333	6269.472	1244.862	0.330
Labor	42.867	118.883	-76.01	0.000***	42.867	120.283	-77.41	0.000***
Land area	850.033	2062.667	-1212.6	0.009***	850.033	2140.566	-1290.5	0.007***
Seeds	10.167	10.683	-0.517	0.7256	10.167	10.906	-0.739	0.632
Organic fertiliser	1677.422	281.058	1396.3	0.000***	1677.422	310.538	1366.9	0.000***
Inorganic fertiliser	46.335	598.750	-552.4	0.000***	46.335	596.698	-550.3	0.000***
Pesticide	1.143	3.536	-2.393	0.000***	1.143	3.644	-2.501	0.000***

Notes: ***) Significant at 1% level, **) Significant at 5% level, *) Significant at 10% level

Descriptively, Greenhouse farmers tend to use less labor and cultivate smaller land areas compared to conventional farmers. Labor use differs significantly between greenhouse and non-greenhouse farmers, indicating a consistent gap in labor requirements across the two systems. This reflects the more mechanized nature of greenhouse farming, while conventional farming remains more labor-intensive. Greenhouse farmers also apply higher amounts of organic fertilizer, while conventional farmers rely more on inorganic fertilizers. This pattern reflects differences in cultivation practices and input management strategies across farming systems, and is consistent with the findings of Susanto et al. (2023), which revealed that Greenhouse farming prioritizes organic materials to support plant growth. These differences mainly reflect variations in farming practices and production methods, rather than differences in output performance. In addition, pesticide use among Greenhouse farmers is relatively lower. This can be explained by the more controlled production environment in Greenhouse systems, which reduces exposure to pests. A similar explanation is provided by Felices et al. (2023), who note that Greenhouse cultivation, as a closed planting system, helps limit pest intensity that may disrupt crop growth.

3.2. Factors Influencing Greenhouse Technology Adoption Decision

The factors influencing melon farmers to adopt Greenhouse technology as a cropping system were estimated using probit regression, tabulated in *Table 4*. The estimation results show that age, number of dependents, experience, education, partnership relationship, and main occupation are factors that have a significant influence on the decision to adopt Greenhouse technology in melon crops. In contrast, the intensity of counseling, internet access, and participation in farmer groups do not significantly influence. The R^2 value explains that the decision to adopt greenhouse technology in melon plants is 29.29% influenced by independent variables in the research model, while 70.71% is explained by independent variables outside the model.

Table 4. Probit Regression Estimation in Determining Factors Affecting the Adoption of Greenhouse Technology in Melon Farming

Variable	Coefficient	std. error	*Z*	*P-value*
Constanta	-2.5169	1.2307	-2.05	0.041**
Age	0.0581	0.1725	3.37	0.001***
Number of dependent	-0.3144	0.1630	-1.93	0.054*
Experience	-0.0332	0.0150	-2.22	0.027**
Education	0.1433	0.0641	2.24	0.025**
Extension intensity	0.0540	0.0629	0.86	0.391
Internet access	-0.1293	0.6615	-0.2	0.845
Farmer group	0.1722	0.3206	0.54	0.591
Partnership relationship	0.8701	0.3279	2.65	0.008***
Main occupation	-0.6443	0.3148	-2.05	0.041***
Log likelihood		-58.8110		
LR chi^2 (9)		48.73		
Prob > chi^2		0.0000		
Pseudo R^2		0.2929		

Notes: ***) Significant at 1% level, **) Significant at 5% level, *) Significant at 10% level

The estimation results generated in probit modeling explain that the age factor positively influences the intensity of farmers adopting greenhouse technology by 0.058%. The increasing age of farmers, precisely in the results of this study, will trigger farmers to adopt Greenhouse technology. This is inversely proportional to the findings of Hassan (2021), which explain that an increase in the age of farmers can have an impact on the decline in farm managerial skills. The age factor is often connoted to young farmers, who actually older farmers also have the same ability to accept new innovations (Hariyati et al., 2024). Mothe and Nguyen-thi (2021) explain that the main focus of older age prioritizes the element of fulfilling needs, in contrast to younger age with a focus on fulfilling careers; in this case, it can be attributed that farmers with more mature age will maximize the intensity of fulfilling higher and more conservative productivity through the adoption of Greenhouse technology. This statement, if linked to other variables in this study, is very relevant to the negative and significant effect of the main occupation variable on the adoption of Greenhouse technology with a coefficient of 0.6443. Objectively, the results of the field findings show that farmers who do melon farming using the greenhouse planting system, the main occupation of 41.6%, are not farmers but in other sectors. This is done as an additional income with the intensity of the main work that remains maximum. In line with the findings, Syafrial et al (2021) explain that work outside the agricultural sector can be a supporting factor in meeting the need for superior production inputs.

The number of family dependents exhibits a negative and marginally significant association at the 10% level with the decision to adopt Greenhouse technology. This suggests that farmers with larger household responsibilities may be less inclined to adopt Greenhouse technology, possibly due to the higher investment costs required. DeLay et al (2022); Kaleel and Ali (2024); Wu et al (2024) A similar thing is revealed the technology adoption process is often hampered due to the high additional costs in farming activities, even though the technology adoption activities will possibly obtain greater production yields.

The experience factor has a negative and significant influence on technology adoption, with a coefficient value of 0.0332%. This finding reflects that the high farming experience will tend to apply the old methods produced from generation to generation in melon farming management. These results contradict the findings of (Sanogo et al., 2023). Suprapti et al (2016) explained that superior varieties are often rejected by most farmers and prioritise local varieties produced for generations. The subjective experience factor will have a positive impact on the adoption of Greenhouse technology if it can be accompanied by the collectivity of increasing farmer knowledge (Salam and Islam, 2023). This is relevant to the estimation results of the Education variable in this study, which has a positive and significant effect on the decision to adopt Greenhouse technology with a coefficient of 0.1433%. This means that farmers' higher education will have an impact on the adoption of greenhouse technology through their knowledge of melon farming. Education is often associated with farmers' knowledge and analytical skills in solving technical farming problems (Nugroho et al., 2022; Dissanayake et al., 2022; Amankwah and Gwatidzo, 2024). The average education of Greenhouse melon farmers in the research location ranged from 12-16 years in formal education, inversely proportional to conventional farmers with an average education of 6 years.

Variable partnership relationships positively and significantly influence the decision to adopt greenhouse technology in melon farming, with a coefficient value of 0.8701%. This means that the higher the partnership relationship between farmers and private institutions, the easier it is for farmers to adopt greenhouse technology in melon farming. According to the findings in the field, farmers take advantage of the partnership relationship in terms of financing and the fulfillment of production inputs. This finding, when linked to the study of Nechar et al (2021), indicates that local partnerships play a vital role in facilitating agricultural economic activities by attracting farmers through higher profit prospects. Field findings found that almost most Greenhouse farmers, 46.7%, do farming in partnership with the private sector, while conventional farmers are only 11.6% of the total who do farming in partnership. This is very relevant to the previous discussion that most farmers in the technology adoption process are often constrained by providing production inputs that require relatively very large investment costs (Wu et al., 2024; DeLay et al., 2022).

3.3. Estimation of Stochastic Production Frontier Function

The estimation of the results of the Stochastic Production Frontier calculation in this study was carried out through three stages of analysis and two approaches, namely estimating through the Pooled model (120 samples), Greenhouse (60 samples), and conventional melon farming (60 samples). The calculation results are divided into two approaches, namely the sample before the Matching process (Unmatched) and the sample after the Matching process (Matched). The estimation results are tabulated in the *Table 5* (Unmatched), and *Table 6* (Matched).

In Pooled modeling on Unmatched and Matched samples, almost all input variables have a significant effect, except for the pesticide variable, which has no significant effect on the whole model. The adoption variable in the pooled model shows a negative coefficient for greenhouse technology, indicating that greenhouse farmers produce a lower total quantity of melons than conventional farmers. This outcome reflects the relatively smaller production scale and more restrained use of production inputs in greenhouse cultivation compared to conventional farming systems. Hence, the negative sign primarily captures differences in production structure and scale rather than weaker farming performance. Greenhouse technology is generally designed to optimize output under controlled conditions and limited input use, rather than to maximize total production volume (Susanto et al., 2023; Felices et al., 2023).

Table 5. Stochastic Production Frontier Estimation: Unmatched Sample

Variable	Pooled (120)			Greenhouse (60)			Non-Greenhouse (60)		
	Coeff	std. Error	P-Value	Coeff	std. Error	P-Value	Coeffi	std. error	P-Value
Constanta	3.939	0.273	0.000***	3.938	0.335	0.000***	4.103	0.549	0.000***
Labor	0.144	0.061	0.019**	0.302	0.077	0.000***	-0.022	0.087	0.795
Land area	0.471	0.049	0.000***	0.424	0.063	0.000***	0.587	0.075	0.000***
Seeds	0.311	0.063	0.000***	0.263	0.067	0.000***	0.225	0.136	0.097*
Organic fertiliser	0.117	0.019	0.000***	0.092	0.051	0.073*	0.006	0.032	0.851
Inorganic fertiliser	-0.046	0.024	0.062*	-0.042	0.028	0.134	-0.012	0.051	0.811
Pesticide	-0.020	0.014	0.159	-0.011	0.014	0.440	0.064	0.046	0.160
Adoption	-1.974	0.462	0.000***						
lnsing V	-1.553	0.249	0.000***	-3.499	0.408	0.000***	-2.074	0.763	0.007***
lnsig U	-2.609	0.660	0.000***	-2.986	0.710	0.000***	-2.591	3.500	0.459

Notes: ***) Significant at 1% level, **) Significant at 5% level, *) Significant at 10% level

The estimated effect of labor variables has a significant effect on melon production in the Pooled model and a separate model in Greenhouse farming. In contrast, conventional farming modeling has no significant effect on melon production. This can be explained by the fact that Greenhouse melon farm labor has a higher level of knowledge and competence in increasing the quantity of melon production than conventional melon farmers. Technical skills and agility in adopting new labor technology in farm management are important factors in increasing production (Ali and Lafta, 2020). In addition, the land area variable has a significant effect on melon production in the entire model. This can be explained by the fact that the level of sensitivity of melon production is determined based on the amount of land area used. Huang et al (2023); Workneh and Kumar (2023); and Bouteska et al (2024) argue the importance of expanding the planted area in the agricultural sector through controlled mechanization policies to support increased agricultural production capacity so that agricultural self-sufficiency can be easily achieved.

Table 6. Stochastic Production Frontier Estimation : Matched Sample

Variable	Pooled (113)			Greenhouse (60)			Non-Greenhouse (53)		
	Coeff	std.error	P-Value	Coeff	std.error	P-Value	Coeff	std.error	P-Value
Constanta	3.942	0.281	0.000***	3.938	0.336	0.000***	4.099	0.494	0.000***
Labor	0.149	0.063	0.017**	0.303	0.077	0.000***	-0.029	0.087	0.741
Land area	0.466	0.051	0.000***	0.425	0.064	0.000***	0.600	0.081	0.000***
Seeds	0.314	0.064	0.000***	0.263	0.067	0.000***	0.218	0.144	0.129
Organic fertiliser	0.118	0.021	0.000***	0.093	0.052	0.073*	0.001	0.037	0.975
Inorganic fertiliser	-0.044	0.025	0.086*	-0.043	0.028	0.134	-0.007	0.059	0.911
Pesticide	-0.020	0.015	0.170	-0.012	0.015	0.440	0.058	0.046	0.209
Adoption	-2.052	0.469	0.000***						
lnsig V	-1.475	0.256	0.000***	-3.499	0.408	0.000***	-2.192	0.709	0.002***
lnsig U	-2.635	0.653	0.000***	-2.986	0.710	0.000***	-2.216	2.018	0.272

Notes: ***) Significant at 1% level, **) Significant at 5% level, *) Significant at 10% level

The importance of planting areas in increasing the production capacity of melons is also adjusted to the amount of use of melon seeds. This is evident in the positive and significant effect of the seed variable in the pooled model and the separate modeling in the greenhouse system. While the conventional melon farming model has a positive and significant effect on the sample before Matching, the seed variable has no significant effect after the sample matching process. This change suggests that the initial significance observed before matching may be driven by differences in farm characteristics rather than a robust production effect of seed input. The findings of Rahman et al (2023) also revealed that increasing the amount of seed use can be interpreted as an increase in the number of plant populations to be planted so that it will be in line with the increasing amount of production. However, the results suggest that the effect of seed use on output is not consistent, as the relationship becomes weaker after differences in farmer characteristics are taken into account.

Organic fertilizer has a positive and significant effect on melon production in pooled modeling and shows a weaker but still positive association in the greenhouse system, while no statistically significant effect is observed in the conventional farming model. Organic fertilizer is one of the main fertilizers for Greenhouse melon plants. Organic fertilizers are very important in supporting plant growth and increasing plant productivity (Shaker and Rasool, 2022; Sukendah et al., 2023). The findings in the field show that the average Greenhouse system melon plants use 1700 Kg ha^{-1} of organic fertilizer, while in the conventional system, only 250 Kg ha^{-1}. This substantial difference reflects contrasting fertilizer management practices across the two production systems. A contrasting pattern is observed for inorganic fertilizer, which shows a negative association with melon production only in the pooled model, while the separate greenhouse and non-greenhouse models do not exhibit a clear relationship. This pattern suggests that the effect of inorganic fertilizer on melon production is weak and varies across farming systems, rather than representing a stable production effect. Rather than implying a direct need to reduce inorganic fertilizer use, these results highlight differences in fertilizer management practices across production systems. Sáenz et al (2024) highlight the role of organic farming as a pivotal pathway to improving soil fertility and ensuring environmental sustainability. Complementarily, Özpinar (2023) demonstrates that chemical fertilizers, particularly nitrogen, constitute one of the largest sources of energy consumption and greenhouse gas emissions in rainfed canola production. Together, these findings underscore the importance of reducing reliance on chemical inputs and prioritizing organic alternatives as a strategy that sustains productivity while enhancing energy efficiency and ecological resilience.

3.4. Impact of Greenhouse Technology Adoption on The Technical Efficiency Level of Melon Farming

The distribution of the estimated technical efficiency level of melon farming for each planting system is shown in Table 7. Table 6 shows the estimated results of the Propensity Score Matching analysis with the Matching technique using the Stratification Method. The estimation results of the average technical efficiency of melon farming in East Java, Indonesia, show its existence as a whole technically efficient with an average score > 0.7. The representation results on the average technical efficiency in the Pooled and Separated models in the sample before the Matching process amounted to 0.784 and 0.8019. Likewise, after the Matching process, the sample is 0.7871 for the Pooled model and 0.7871 for the separated model.

The propensity score determined through the probit regression estimation results ranges from 0.229 to 0.998 (*Figure 1*). The distribution of propensity score values that overlap due to the effect of bias is excluded from the model. The results of this study revealed that 7 samples had bias effects, so in the matching process, there were 60 samples of greenhouse melon farmers (Treatment) and 53 conventional melon farmers (Control).

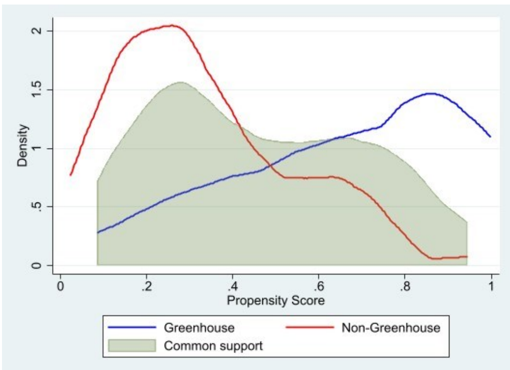

Figure 1. Propensity Score Distribution

The matching process uses the stratification method in *Table 7* in the comparative test of the two melon planting techniques using 113 samples (Matched). The Matching sample results were also used from the beginning of the analysis of this study. Average treatment effect on the treated (ATT) based on the Propensity

Score Matching estimation results of 0.041 in the pooled model and 0.063 in the Separated model, which means that melon farmers who adopt Greenhouse technology are more technically efficient than conventional melon farmers with a higher difference of 0.041 in the Pooled model and 0.063 in the Separated model. The modeling results are acceptable because they are statistically significant. Pooled technical efficiency results do not represent an accurate comparison level; there is a need for a matching process based on the technical efficiency value of each planting technique (Ma et al., 2018).

Table 7. Estimation of Propensity Score Matching in Measuring the Impact of Greenhouse Technology Adoption on Technical Efficiency

Technical Efficiency Sample	Matching Method	Treatment	Control	ATT	std.error	t-value
Pooled	*Stratification*	60	53	0.041	0.019	2.196**
Separated	*Matching Method*	60	53	0.063	0.030	2.103**

Notes: ***) Significant at 1% level, **) Significant at 5% level, *) Significant at 10% level

Estimates of the comparative analysis across planting systems are presented in *Table 8*. The results show that the average technical efficiency of greenhouse-based melon farming reaches 0.8223, while conventional farming records lower efficiency levels of 0.7816 in the unmatched sample and 0.7365 after matching. The estimated efficiency gap between greenhouse and non-greenhouse farming is 0.0407 before matching and increases to 0.0858 after the matching procedure in the separated models, both of which are statistically significant at the 1% level. In the pooled models, the estimated differences in technical efficiency remain positive but are only marginally significant at the 10% level. In contrast, the separated models consistently yield strong and statistically significant results before and after matching, indicating that the efficiency advantage of greenhouse farming is more clearly captured when the two production systems are modeled separately. Overall, the findings suggest that greenhouse adoption is associated with higher technical efficiency in melon farming, with estimated gains ranging from approximately 3% to 9%, depending on the model specification and matching procedure. The consistency of results in the separated models provides strong empirical support for the hypothesis that greenhouse farming enhances technical efficiency relative to conventional practices

Table 8. Estimated Value of Technical Efficiency Comparison

Sample	Mean Technical Efficiency	Combined	Greenhouse	Non-Greenhouse	Diff	P-value
Unmatched Sample	Pooled	0.7844	0.7998	0.7691	0.0307	0.0619*
	Separated	0.8019	0.8223	0.7816	0.0407	0.0072***
Matched Sample	Pooled	0.7871	0.8014	0.7709	0.3046	0.0716*
	Separated	0.7820	0.8223	0.7365	0.0858	0.0000***

Notes: ***) Significant at 1% level, **) Significant at 5% level, *) Significant at 10% level

The results of this study also confirmed the study of Maraveas et al (2023) and Sajid et al (2023) regarding Greenhouse farming as an alternative technology through the most appropriate planting system in anticipating various weather uncertainties in order to demonstrate its existence in increasing crop productivity. Greenhouse technology in melon plants can be developed in various weather conditions so that the intensity of production activities can be carried out throughout the season. The use of production inputs in the Greenhouse melon system is more minimal, as described in the previous chapter, and the use of fertilizers that rely on organic fertilizers as the main fertilizer, which in this case is very easy to obtain through the use of manure from livestock owned by each farmer. Another benefit of Greenhouse technology is minimizing the risk of crop failure due to pests. This can be seen from the behavior of Greenhouse melon farmers who almost do not use pesticides in the implementation of farming in contrast to melon farming activities on open land, which has a level of risk of crop failure due to seasonal uncertainty, dependence on chemical fertilizers as the main stimulus for melon plant growth, and the use of pesticides which tend to be more. Research studies on the positive impact of the adoption of Greenhouse technology as an experiment in this study have confirmed the argument of DeLay et al (2022); L. Li et al (2023); Ebukiba et al (2022); Hanani et al (2023); Tamirat and Tadele (2023); Mulugeta and Heshmati (2023); Puppala et al (2023); and Ewunetu et al (2023) that through the mechanization of agricultural technology will have a positive impact on input use efficiency and farm productivity.

4. Conclusions

This study shows that greenhouse technology offers a more efficient production alternative for melon farming in East Java. Farmers who are older, better educated, and engaged in partnership arrangements are more likely to adopt greenhouse systems, highlighting the role of human capital and institutional support in shaping technology adoption decisions. In contrast, farmers with greater household responsibilities, longer farming experience, and stronger dependence on farming as a primary occupation tend to remain in conventional production systems. Overall, melon farming in East Java can be considered technically efficient, reflecting generally rational input use across both production systems. However, greenhouse-based farming consistently demonstrates higher technical efficiency than conventional farming. The results indicate that greenhouse adoption is associated with an efficiency improvement of approximately 3% to 9%, depending on the empirical specification. This improvement suggests that greenhouse technology enhances efficiency not by expanding production scale, but by enabling farmers to manage limited inputs more effectively under controlled production conditions. From a policy perspective, greenhouse technology represents a viable option for improving technical efficiency in melon farming. For farmers who do not adopt greenhouse technology due to initial investment constraints, conventional melon farming is recommended to be carried out collectively through farmer consolidation, aiming to minimize total input expenditures and to achieve more optimal allocation of labor intensity among farmers. In addition, more rational input management is required, particularly by reducing dependence on inorganic fertilizers and prioritizing the use of organic fertilizers derived from locally available manure. Despite these contributions, several limitations should be acknowledged. This study focuses primarily on technical efficiency and does not explicitly evaluate economic efficiency or environmental sustainability across different cropping systems. Moreover, the analysis is constrained by limited availability of farm-level economic and investment data, as most farmers do not maintain systematic production records. Future research is therefore encouraged to incorporate detailed land, investment, and sustainability indicators to provide a more comprehensive assessment of greenhouse technology adoption and its implications for farmers' welfare.

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Ethical Statement

Formal ethics approval was not available as there was no Institutional Review Board directly involved in this project at the time of data collection. However, the research protocol adhered to the ethical principles, and official permission for field data collection was granted by the Faculty of Agriculture, Universitas Brawijaya (Assignment Letter No. 12276/UN10.F04/TU/2023, dated 27 October 2023).

Conflicts of Interest

The authors declare no conflict of interest.

Authorship Contribution Statement

Concept: Firmanda, S. A; Design: Hanani, N.; Data Collection or Processing: Hanani, N.; Statistical Analyses: Firmanda, S.A.; Literature Search: Firmanda, S. A., Hanani, N.; Writing, Review and Editing: Firmanda, S. A.

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