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Impact of eco-friendly practices on technical efficiency of grafting tomato production: Evidence from tomato growers of Moulvibazar district in Bangladesh

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Abstract

This study examines how eco-friendly farming practices affect the technical efficiency of grafted tomato production in Moulvibazar District, Bangladesh. Primary data was collected from 210 tomato producers using the multistage sampling technique. The collected data was analyzed to estimate technical efficiency and its determinants by employing stochastic frontier analysis (SFA). Results found that tomato farmers were about 71% efficient, which implies that tomato production could be increased by nearly 29% if resources and technology were used optimally. The study discovered that while higher input costs lowered productivity, using more land, labor, and tractors helped enhance tomato output. Education, household size, access to training, access to extension services, and experience with grafting improved efficiency, whereas leasing land and earning income from non-farming activities caused a lowering of efficiency. Eco-friendly practices like mixed cropping, using vermicompost, yellow sticky traps, pheromone traps, and mulching films significantly improved efficiency, making farmers 2% to 98% more efficient than those who didn't adopt these methods. These practices helped better manage inputs, control pests, and maintain healthy soil, boosting both productivity and environmental sustainability. Therefore, promoting eco-friendly tomato production practices through national programs, better extension services, improved credit access, and secure land rights can promote sustainable farming adoption and raise tomato production efficiency.

Keywords: Mixed Cropping; Mulching Films; Pheromone Trap; SFA; Yellow Paper

1. Introduction

The concerns about sustainable agricultural production arise worldwide due to the dual implications of this sector in the economy and environment. On one hand, agriculture is criticized for damaging ecological balance, polluting air, water, and soil, and causing biodiversity and habitat loss. In contrast, it produces renewable energy, preserves landscapes and biodiversity (Röös et al., 2018), and ensures food security and safety. In response to the abovementioned challenges, the sustainability advocates are emphasizing eco-friendly and safe cultivation practices in agricultural production for environmental betterment. Therefore, it is necessary to direct agricultural production towards efficient and sustainable practices that can reduce the adverse effects generated by agriculture.

Being an agriculturally based economy, Bangladesh aims to make its agricultural sector sustainable to provide rural livelihoods, ensure food security, and make a remarkable contribution to its economy. Therefore, to achieve sustainability, the country should prioritize pollution-lessening farming practices in the agriculture sector, especially in the crop and vegetable sector. These two sectors contribute approximately 5.88% to the country's total gross domestic

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product (GDP) (BBS, 2022). Also, vegetables play a crucial role in meeting food and nutrition security in Bangladesh. Among vegetables, tomato (Solanum lycopersicum) is the most widely cultivated high-value vegetable in Bangladesh, serving both domestic consumption and emerging markets. The favorable and diverse agro-ecological conditions, better market availability, and technological improvement permit the cultivation of tomatoes both in winter and summer (Das and Jahan, 2022) in Bangladesh. Bangladeshi vegetable producers gradually shifted from conventional to grafted tomato cultivation (Rahman and Acharjee, 2020), which is much more favorable for the environment. Grafting tomatoes is more suitable for the summer season than non-grafting tomatoes (Das and Jahan, 2022), provides higher yields, and benefits the environment by demanding fewer pesticides, as they are disease resistant (Petluru et al., 2024). Although they require higher costs, labor, and time for production and sometimes lead to plant health and growth issues due to physiological disorders and improper management (Barret et al., 2012; Lee et al., 2010). However, the popularity of grafting tomatoes is increasing day by day among Bangladeshi farmers due to its higher yield and long production season. Additionally, grafting in tomato production benefits farmers by enhancing income generation and contributing to poverty alleviation (Das and Jahan, 2022). Despite these advantages, tomato production in this country still relies heavily on synthetic inputs, excessive water use, and traditional input-intensive practices. Such practices generate higher yields in the short term, but they degrade soil, pollute water bodies, and compromise food safety in the long term (Amirahmadi et al., 2023). Additionally, excessive use of agrochemicals creates health hazards for both producers and consumers (Anjaria and Vaghela, 2024), highlighting the necessity for more sustainable approaches to vegetable production.

Integrated pest management, mixed cropping, and the use of organic inputs are such eco-friendly and sustainable approaches in tomato production that they require fewer fossil inputs and are able to maintain productivity. Use of yellow sticky paper and pheromone traps physically controls insects and reduces the application of insecticides (Gan et al., 2024). Similarly, the use of mulching films lowers the weedicide and herbicide usage by deterring the growth of weeds (Zhang et al., 2024). These eco-friendly practices promote soil health, conserve natural resources, reduce the use of chemical fertilizers and pesticides, and enhance food safety and quality while mitigating pollution (Wang, 2023). However, the adoption of such safe farming practices remains limited, and several factors can contribute to it. For instance, how these practices affect the productivity and net income of farmers remains unclear. Farmers will only adopt these practices if they are beneficial in terms of both productivity and net returns. Efficiency, more specifically technical efficiency, is defined as the ability of a farm to produce the maximum output from a given set of inputs, which is an important indicator of farm performance or productivity. So, understanding how eco-friendly practices influence technical efficiency is essential for identifying strategies that simultaneously improve productivity, sustainability, and farmers' profitability. Specifically, this study will answer the following questions: What is the extent of adoption of eco-friendly and safe vegetable production techniques among tomato farmers? How do these practices affect technical efficiency in tomato production? What are the determinants of technical inefficiency? By addressing these questions, this study provides detailed insights into how eco-friendly practices contribute to both productivity and environmental sustainability in tomato farming.

Empirical evidence suggests that ecofriendly practices may affect technical efficiency in both positive and negative ways. For instance, organic farming retards the use of synthetic inputs and lowers the cost of production but reduces productivity (OECD, 2018). Koiry and Huang (2023) showed that mixed cropping enhances productivity while organic farming reduces it. Application of pesticides protects production by lowering pest damage but adversely affects the organisms required for future production (Skevas and Lansink, 2014). Investment also plays a crucial role in the success of ecological practices (Jaeck and Lifran, 2014). Practices that demand higher investment but generate lower productivity may discourage further adoption. In the context of tomato cultivation, partial substitution of chemical fertilizers with organic fertilizers resulted in higher yield and net returns in Bangladesh (Haque et al., 2023), highlighting both economic and environmental benefits. Studies showed that conservation farming practices may bring efficiency gains (Chaudhary et al., 2022) but may result in substantial inefficiencies among tomato farmers (Kabir et al., 2020). Therefore, the evidence on the association between eco-friendly practices and technical efficiency is inconclusive, practice-, region-, and context-specific. So, there remains a notable gap in understanding the joint impact of multiple eco-friendly and safe vegetable production techniques on technical efficiency, particularly for tomato farming. The present study attempts to address this gap by examining the adoption status of eco-friendly and safe vegetable farming practices among tomato farmers in the Moulvibazar district of Bangladesh and their impact on technical efficiency. Additionally, it also examines the farm-specific, socioeconomic, and institutional determinants of inefficiency.

Moreover, this study has significant contributions to the literature. Firstly, it will deliver evidence on the effect of eco-friendly practices on technical efficiency by focusing on an under-researched crop and region of Bangladesh. Secondly, it bridges the gap between identifying the practices that should be adopted and understanding how they affect farm performance. Thirdly, what factors should the policymakers consider for the design of targeted interventions in the future? Overall, this study extends research that has largely focused on staple crops and broad national trends, thereby filling a critical knowledge gap.

2. Literature review

The horticultural sector in Bangladesh has grown considerably in recent years, with tomatoes emerging as a major cash crop for rural households. Despite this growth, tomato production efficiency remains constrained by various factors. Therefore, understanding the determinants of technical efficiency is crucial from both empirical and policy-oriented viewpoints. An extensive body of literature discussed the several aspects of tomato production as well as presented that efficiency is affected not only by farm and household characteristics but also institutional factors, technological improvement, and production practices. Therefore, the relationship between eco-friendly production practices and technical efficiency is important to understand. This review summarizes the key contributions from the past literature by focusing on grafted tomato systems and eco-friendly practices and highlights the gaps that motivate the present study.

A number of research studies examined the technical efficiency of tomato production, especially in smallholder settings. For instance, Mwangi et al. (2020) found that education and access to extension services are significant contributors to input inefficiencies in tomato production. Age and education were also found to be the main determinants of technical inefficiency in Pakistan (Khan and Shoukat, 2013). Mitra and Yunus (2018) used input-oriented data envelopment analysis (DEA) and estimated the existence of 17% inefficiency among Bangladeshi tomato farmers and identified the favorable effect of education, training, and improved variety on efficiency, whereas age had an adverse effect. By employing meta frontier analysis, Aloysius et al. (2021) found technological gaps such as choice of varieties and management practices among various farmer groups in terms of technical efficiency. The location of farms, extension services, irrigation rate, and cropping pattern are principal determinants of economic and technical efficiency in Nigeria (Tsoho et al., 2012).

However, tomato yield can be affected in various ways. Precise application of pesticides and fertilizers can lower input wastages and improve crop health, thereby enhancing yield (Beyuo et al., 2024). Because depending too much on chemical-intensive methods results in pesticide resistance, ecological pollution, and pesticide poisoning to farmers (Schreinemachers et al., 2017b). Some production techniques, like the incorporation of organic inputs, improved irrigation plans, and balanced nutrition, increase the yield potential of plants whose root systems respond to soil conditions (Ray et al., 2025). Integrated pest management increases production efficacy along with attenuating crop losses and enhancing effective output. Timeliness of operations and worker safety measures affect labor productivity, which in turn influences crop yield. Therefore, safe farming practices have the potential to enhance technical efficiency, but that depends on several factors.

Eco-friendly approaches have also been evaluated in terms of other contexts. Ahmed and Shams (1998) study the feasibility of ecological inputs using partial budget analysis. Smits et al. (2008) examined the role of good governance in the adoption of eco-friendly ways of production. The role of eco-friendly farming in poverty reduction, political stabilization, and environmental regeneration is studied by Shukla and Rajan (1996). Owusu-Sekyere et al. (2020) investigated the heterogeneous customer demand for ecologically produced food items, while the interaction between ecological farming and productivity is examined by Coomes et al. (2019). Based on this literature, it may be argued that ecologically friendly agriculture can play a role in various dimensions and contexts of society, the economy, and the environment.

To conclude, there remains limited understanding of how specific eco-friendly practices affect technical efficiency in grafted tomato systems in Bangladesh, highlighting a clear gap for empirical investigation.

3. Methodology

3.1. Study area, sampling technique and data

This study used a cross-sectional research design by following a quantitative approach to investigate the association between eco-friendly practices and technical efficiency in tomato production. Since there is uncertainty whether farmers will continue tomato production with eco-friendly practices in the medium or long term, the cross-sectional design was adopted. A multistage sampling procedure was followed to collect primary data from tomato farmers. At the first stage, Kamalganj upazila in Moulvibazar district was purposively chosen in accordance with the funders' and projects' demand, as interventions were conducted there. Kamalganj upazilla comprises 9 unions. In the second stage, 5 unions were randomly selected from 9 unions using the lottery method. In the third stage, 2 villages were randomly selected from each of the 5 selected unions. Finally, at the fourth stage, 210 grafted tomato producers from 10 villages were selected using a simple random sampling technique. The simple random sampling method was chosen for its ease of use, suitability for large populations, ability to minimize selection bias, and potential to generalize findings.

The total sample size for this research was determined by employing Cochran's (1977) formula.

$$n = \frac{Z^2 p(1-p)}{d^2} \quad \dots\dots\dots. \quad (1)$$

Where, n depicts the sample size, p is the population proportion (0.5), q = 1-p (0.5), d is the margin of error (i.e., 0.05) and Z is the standard deviation for 95% confidence interval. Therefore, the total sample size will be as follows,

$$n = \frac{(1.96)^2 \times 0.5 \times 0.5}{(0.05)^2} = 384$$

Due to time and funding constraints, and for the purpose of better representation, this study selected 210 tomato growers as sample respondents. Data were collected from sample respondents through face-to-face interviews using a structured questionnaire in the month of September, 2025.

3.2. Variables description

This study incorporated many variables that represent the socio-economic characteristics of tomato producers, input-output relationships in tomato production, and several eco-friendly tomato production practices. Five input variables were used in this study through detailed calculations. Among them, land is the most crucial input in tomato cultivation. Land implies the total amount of area on which one household produced tomatoes in a season. Land was initially measured in decimal and then transformed into hectares (Ha) by dividing 247 decimals for standard representation. The variable Labor constituted both the family (i.e., family labor involved in tomato production activities directly) and hired labor. At first, the number of hours spent on each activity by both the family members and hired workers was accounted for and then converted to man-days by dividing the total hours of working by 8 hours. Materials implies the cost of physical inputs used in tomato production. It includes all types of physical inputs used in tomato production. For example, chemical fertilizers (i.e., ammonium sulfate, triple super phosphate, muriate of potash, borax, gypsum, zinc sulfate, diammonium phosphate), organic fertilizers (i.e., cow dung, vermicompost), plant protection materials (i.e., insecticides, pesticides, weedicides, herbicides), tomato saplings, staking materials, pheromone lures, yellow sticky papers, sticky materials, mulching films, and other materials such as rope, bamboo poles, and tying materials. To maintain the uniformity in units, the cost of all these physical inputs was summed up under the variable Materials. The irrigation cost is another important variable in tomato cultivation, which depicts the total amount of money a farmer spent for irrigating the tomato plants. The tractor cost implies the amount of money spent by the farmer to prepare land by ploughing, harrowing, and leveling. Output is measured in kilograms (kg) and used as the dependent variable in technical efficiency analysis in this paper. It represents the total amount of tomatoes produced from the total cultivated land area during a season. The variable Total return was calculated by adding all the money the farmer received from selling tomatoes at different times throughout the season and the opportunity cost of family consumption.

Among the socio-economic variables Age was represented in years and calculated by subtracting the household head's year of birth from the current year of production. Education was also measured in years by recording the number of years the farmer spent in a formal institution. Household size was measured by adding all individuals living in the household, including old-aged people, adults, and children, who share meals and contribute to or depend on household resources. Gender was recorded as that of the household head, coded as 0 for female and 1 for male. Marital status was also recorded as the legal or personal condition of a farmer in relation to marriage and coded as 0 for unmarried, 1 for married, and 2 for others (divorced or separated). The variable number of earning members implies the total number of active people in a household who earn and contribute to family resources. The variable Occupation was coded as 0 for the farmers whose primary livelihood depended on vegetable production and 1 for those who earned a livelihood by doing other activities such as day laboring, business, or formal or informal jobs. Experience indicates the number of years farmers have been actively engaged in vegetable or tomato production. The variable "years to adoption of grafted" depicts the number of years a farmer has been using grafted saplings in their tomato cultivation. The source of the grafted sapling was coded as 0 if the farmer produced the tomato sapling using the grafting technique by themselves and 1 if the farmer purchased grafted saplings from the market or local nursery. Land tenure is a categorical variable in this study that describes the type of land ownership or access arrangement a farmer had for cultivating tomatoes. It was coded as 0 if the farmer cultivated tomatoes only on his own land, 1 if the farmer produced tomatoes on leased land, and 2 if the farmer cultivated tomatoes on both his own and leased land (i.e., mixed tenure).

Access to extension services reflects whether the farmer received advice or support from government extension officers or non-government organizations. Access to credit denotes whether the farmer had access to formal or informal credit facilities for financing rice production. Access to training indicates whether the farmer has participated in any training programs related to crop production or farm management. All three of these variables are binary and coded as 0 for no access and 1 for access. The five variables related to eco-friendly practices—vermicompost use, mixed cropping adoption, yellow sticky paper use, pheromone trap use, and mulching film use—are binary in this study and were coded as 0 for farmers who did not adopt the practices and 1 for those who did.

3.3. Technical efficiency and stochastic frontier approach

The production theory of economics postulates two measures of efficiency: allocative and technical efficiency. If a farm can attain both, that is regarded as economically efficient. This research mainly focused on technical efficiency, which indicates a farm's ability to produce maximum output from a given number of inputs (Farrell, 1957). Because technical inefficiency can be reduced by managing the managerial practices in the farm. The measurement of efficiency is widely discussed in the literature, and researchers' attempts to measure technical efficiency can be categorized into two approaches: parametric and non-parametric. Non-parametric approaches are those deterministic ways that use mathematical programming to measure efficiency. Data envelopment analysis (DEA) is such a non-parametric technique that estimates the technical efficiency of a decision-making unit (DMU) (Arabmaldar et al., 2023), although this approach is more useful for the industrial sector rather than agriculture (Srinivasulu et al., 2015). Although the DEA model can handle multiple outputs and inputs, it is unable to separate efficiency scores from unknown variations. Also, it is unable to estimate model parameters (Kavoi et al., 2016) and sensitive to outliers. In contrast, the parametric approach, such as stochastic frontier analysis (SFA), is advantageous as output variability arises from uncertain events. SFA allows for estimation of the production frontier by decomposing the error term into inefficiency and random error components.

This study employs the SFA model, which was proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977) and further developed by Battese and Coelli (1995), to estimate the technical efficiency of tomato production. According to Aigner et al. (1977) and Meeusen and van den Broeck (1977), SFA estimates the deviation of actual output from the potential frontier and distinguishes between inefficiency and stochastic shocks caused by random external factors. The model is useful mainly for two reasons: 1) Tomato production usually depends on uncertain conditions like pest and disease attacks or climatic variability. 2) It allows for testing of hypotheses to specify a functional form. A tremendous advantage of this model is that it includes an inefficiency component, which is utilized to test for the degree of technical inefficiency of farming households (Okoye et al., 2016). Though its main weakness lies in its assumption, which requires an explicit form for technology and distribution of the inefficiency terms (Haji and Andersson, 2006). The stochastic production function can be represented as follows;

$$Y_l = f(X_l, \beta)\exp(\in_k) \quad \dots\dots\dots\dots\dots\dots (2)$$

Where, Y_l is the output produced by the l^{th} farm, X_l is the vector of inputs used by the l^{th} farm, l indicates number of farms (1,...,N), i $f(.)$ indicates the production frontier, β represents the vector of parameters, and $\in_l = V_l - U_l$. V_l depicts the noise term which follows normal distribution with mean 0 and variance σ^2. U_l is the non-negative technical inefficiency of the l^{th} farm. From equation (2) the technical inefficiency of the farmer can be expressed as;

$$TE_l = \frac{Y_l}{Y_{l*}} = \frac{(X_l, \beta)\exp\,(V_l - U_{l)}}{(X_l, \beta)\exp\,(V_l)} \quad \dots\dots\dots\dots\dots. (3)$$

Where the numerator represents the frontier output and the denominator implies the observed output of the l^{th} farmer. Therefore,

$$TE_l = \exp(-U_l) \quad \dots\dots\dots\dots\dots\dots\dots\dots. (4)$$

The equation can be also expressed as follows;

$$-U_l = \delta_o + \sum_{r=1}^{r} \delta_r K_r + \varphi_r \quad \dots\dots\dots\dots.. (5)$$

Where, K_r indicates variables that affects technical inefficiency and δ_r is the estimated parameter of K_r. The value of technical inefficiency $-U_l$ varies from 0 to 1, where 1 indicates full efficiency and 0 otherwise.

3.4. Empirical model specification for stochastic frontier analysis (SFA)

Examination of technical efficiency by using the stochastic frontier model demands specifying a production function. The Cobb-Douglas production function was chosen over the translog production function in this paper due to its flexibility. Also, both the Cobb-Douglas and trans-log production functions were tested using the likelihood ratio (LR) test, and based on the results (Table 2), the Cobb-Douglas production function was chosen. It is specified as;

$$Y_j = \beta_0 + \sum_{k=1}^{5} \beta_k \ln X_{jk} + v_j - u_j \dots\dots\dots\dots\dots (6)$$

4. Results and Discussion

4.1. Descriptive statistics

The descriptive statistics of socio-economic characteristics of tomato farmers in Kamalganj upazila, the status of eco-friendly practices, and the input used by sampled tomato farmers are presented in Table 1. The average age of tomato farmers was 42 years in the study area, which indicates that most of the tomato farmers were in their middle and active age. Middle-aged farmers are more involved in vegetable production due to their risk-bearing capacity and considerable experience (Hasan et al., 2025). The household heads had an average of five years of schooling, indicating that most tomato producers had completed primary education. Education is a crucial factor to increase awareness and adoption of good agricultural practices (Hasan et al., 2024). Our findings indicate the limited adoption of eco-friendly practices. The average household size of tomato-growing households was 5 members, indicating that a medium-sized family may provide adequate labor for grafted tomato production, which is labor-intensive in Bangladesh. The national rural average family size is also around five members (BBS, 2023). In the study area, the average number of earning members per household was one, suggesting a low dependency ratio. The agricultural sector is male-dominated (Peralta, 2022), which aligns with the findings of this study stating that 91% of households were headed by males in the study area. The majority, 93%, of farmers (i.e., household heads) were married, indicating family stability, which may favorably affect labor allocation and management.

Vegetables, specifically tomatoes, were the main source of income for 95% of respondents, indicating a high level of specialization in vegetable farming. Such specialization may reduce inefficiency in vegetable production by enhancing technical knowledge and skills (Hasan et al., 2020). The tomato growers had a mean experience of 22 years in vegetable cultivation, which is likely to positively influence the productivity of grafted tomato production. Access to extension services from government and non-government institutions was relatively high in the study area, estimated at 83%, which is encouraging, as extension services, training, and credit play a crucial role in promoting eco-friendly practices and advanced production techniques. Access to training and extension services has a positive impact on productivity (Antwi-Agyei and Stringer, 2021; Hossain and Rahman, 2021; Boothby et al., 2010). Also, limited credit availability may constrain the adoption of eco-friendly practices, which may often require a handsome amount of investment (Zhang et al., 2025). In the study area, 53% of farmers received training, but only 23% of farmers had access to credit for tomato production. The descriptive statistics on the land tenure system show that 57% of farmers grew tomatoes on their own land, 33% on leased land, and 10% under mixed tenure arrangements. This distribution indicates a considerable share of tenant farming.

The adoption of eco-friendly practices among tomato farmers was varied and specifically focused on pesticide reduction. About 59% of farmers produced grafted saplings in their own homestead area or nursery, while 41% purchased grafted saplings from a local market or nursery. The average time to adoption of grafting techniques was 5 years among tomato producers. Regarding organic soil management, 44% of farmers applied vermicompost to produce tomatoes, while cow dung remained the main organic input in the study area. About 94% of farmers applied cow dung as organic fertilizer for tomato production. The high use of cow dung reflects traditional organic practices, whereas vermicomposting, being a relatively modern method, remains less adopted. The use of pest management practices such as yellow sticky papers (45%), pheromone traps (42%), and mulching films (74%) shows growing awareness of non-chemical pest control. These practices are essential for reducing pesticide dependency, thus lowering production costs and environmental damage.

Table 1 Descriptive Statistics

Variables	**Unit**	**Mean/Percentage**	**Standard deviation**
Socio-economic related variables			
Age	years	42.0	12.0
Education	years	5.0	3.32
Household size	number	5.0	1.64
Number of earning members	number	1.0	0.69
Gender			
Female (0)	%	9.0	28.09
Male (1)	%	91.0	28.09
Marital Status			
Unmarried (0)	%	6.0	23.58
Married (1)	%	93.0	25.97
Others (2)	%	1.0	0.09
Occupation			
Vegetable production (0)	%	95.0	0.19
Others (1)	%	5.0	0.17
Experience	years	22.0	11.49
Access to extension service			
No (0)	%	17.0	37.81
Yes (1)	%	83.0	37.81
Access to training			
No (0)	%	47.0	50.00
Yes (1)	%	53.0	50.00
Access to credit			
No (0)	%	77.0	42.22
Yes (1)	%	23.0	42.22
Land tenure			
Own (0)	%	57.0	49.61
Lease (1)	%	33.0	47.13
Mixed (2)	%	10.0	30.00
Eco-friendly farming related variables			
Sources of grafted saplings			
Own (0)	%	41.0	49.32
Purchased (1)	%	59.0	49.32
Years to adoption of grafting	years	5	2.1
Use of vermicomposting			

No (0)	%	56.0	49.79
Yes (1)	%	44.0	49.79
Cow dung			
No (0)	%	6.0	24.41
Yes (1)	%	94.0	24.41
Yellow paper use			
No (0)	%	55.0	49.84
Yes (1)	%	45.0	49.84
Pheromone trap use			
No (0)	%	58.0	49.40
Yes (1)	%	42.0	49.40
Mulching film use			
No (0)	%	26.0	44.33
Yes (1)	%	74.0	44.33
Input-Output related variables			
Output	Kg	15807.0	15518.45
Land	Ha	0.26	0.20
Labor	Man-days	79.0	63.77
Material cost	Taka	155862.0	141050.0
Irrigation cost	Taka	7144.0	5683.19
Tractor cost	Taka	6871.0	7804.42

Source: Authors' estimation, 2025.

Table 1 also shows that the average yield of grafted tomatoes was 15,807 kg per farm, with a standard deviation of 15,518 kg, indicating a considerable variability in yield among farmers. This may be the result of differences in management practices, technologies, and input application. The mean landholding among tomato farmers was 0.26 ha in the study area, suggesting smallholder tomato producers in Bangladesh. The average cost of materials, irrigation, and tractor cost of tomato production in the study area were calculated to be 155862, 7144, and 6871 Tk. Respectively. These findings are consistent with other studies, for instance (Das and Jahan, 2022). The mean amount of labor was calculated to be 79 man-days per farm, indicating the labor-intensive nature of tomato production in the study area.

4.2. Profitability of grafted tomato production

Table 2 represents the profitability analysis of grafted tomato production in Kamalganj upazila. The findings demonstrated the impact of various costs and returns on tomato growers' profitability and its economic viability. The findings show that the per hectare average cost of production was calculated to be 1057161 Tk. The total variable cost of tomato production in the study area amounted to 872,494 Tk., involving seedling, staking, vermicomposting, chemical fertilizer, and plant protection material costs. The total fixed costs, including family labor and land use, accounted for 184,667 Tk. The cost of labor, land use, and physical input materials were the major contributors to the cost of tomato production. Tomato farmers received a total return of 1,507,220 Tk., resulting in a gross margin of 634,726 Tk. and a net profit of 450,059 Tk. The benefit-cost ratio of tomato production was calculated to be 1.43, suggesting grafting-based tomato production was profitable. Farmers gained 1.43 Tk. for every 1 Tk. invested, which highlights the economic viability of tomato production.

Table 2 Per hectare profitability of tomato production

Variables	Unit	Quantity	Price	Cost / Returns
Seedling cost	Number	21203	10.23	216907
Stalking cost	Number	21457	3.05	65444
Vermicompost cost	Kg	5036.1	13.80	69498
Cost of cow dung	Kg	11808	2.00	23616
Cost of chemical fertilizer	Tk.	-	-	109159
Cost of vitamin use	Tk.	-	-	5833
Cost of yellow paper	Number	83	45	3735
Cost of Pheromone trap	Number	56	60	3360
Cost of Mulching	Tk.	-	-	99739
Cost of plant protection materials	Tk.	-	-	108512
Cost of irrigation	Tk.	-	-	31257
Cost of tractor	Tk.	-	-	30234
Cost of Hired labor	Man-days	263	400	105200
A. Total Variable cost	Tk.			872494
Cost of Family labor (a)	Tk.	60	400	24000
Cost of land use (b)	Tk.	-	-	164667
B. Total Fixed cost (a + b)	Tk.			184667
C. Total cost of production (A+B)	Tk.			1057161
D. Total Return	Tk.	68510	22	1507220
E. Gross Margin (D – A)	Tk.			634726
F. Net margin (E – B)	Tk.	-	-	450059
G. Benefit-Cost ratio (BCR) (D/C)	1.43			

Source: Authors' estimation, 2025.

The profitability findings from this study are consistent with the previous studies that indicate significant economic benefits of tomato production. The BCR of 1.43 that indicates a positive return on investment is somewhat moderate compared to BCR values reported for other regions. For example, past studies reported the BCR of 1.77 in rooftop tomato farming in northern Bangladesh (Yunus et al., 2023) and 4.19 in hybrid tomato cultivation in Jessore (Lyndem, 2021). Variations in BCR are attributable to differences in farming systems, input costs, and local agro-ecological conditions. The considerable input costs observed in this study, particularly for vermicomposting and mulching, reflect the emphasis on sustainable organic amendments and soil cover techniques. These practices are known to enhance soil health and reduce chemical dependency (Manzoor et al., 2024). The profitability scenario of the study area supports the sustainability of tomato production. Because the application of organic fertilizer and eco-friendly techniques enhanced both yield and production quality, thereby improving profitability (Laily et al., 2021). Labor remains a significant cost component of grafting-based tomato cultivation, constituting a considerable amount of total expenses when including hired and family labor, highlighting labor-intensive activities such as staking, mulching, and pest management.

4.3. Model specification test results

Table 3 compares the Cobb-Douglas and Translog production functions for estimating technical efficiency by following the stochastic frontier approach. The Cobb-Douglas production function, with 26 parameters, yielded a log-likelihood of -140.67, an AIC of 167.89, and a BIC of 201.78. In contrast, the Translog production function, with 40 parameters, estimated a log-likelihood of -186.45, an AIC of 193.33, and a BIC of 280.36. Since the Cobb-Douglas production function has both lower AIC and BIC than the Translog function, the findings indicate that the Cobb-Douglas production function should be preferred over the Translog production function. Consequently, the Cobb-Douglas production function was chosen for estimating technical efficiency in the sampled tomato farms.

Table 3 Specification of model for efficiency estimation

Null Hypothesis	DF	Log-likelihood value	AIC[P]	BIC[Q]
Cobb-Douglas production function	26	-140.67	167.89	201.78
Trans-log production function	40	-186.45	193.33	280.36

DF-degrees of freedom. AIC-Akaike information criterion. BIC-Bayesian information criterion.
Source: Authors' estimation, 2025

4.4. Estimates of stochastic production frontier

The estimated parameters of the stochastic production function, using maximum likelihood estimation (MLE), are reported in Table 3. The data analysis was conducted in STATA 18 software. Table 4 represents a significant Wald Chi-square statistic (i.e., -140.67), suggesting that the joint effect of all independent variables on tomato output is statistically significant. This indicates that the model is well fitted. For ease of interpretation, all input and output variables were normalized by dividing them by their respective sample means. This normalization permits the estimated first-order parameters of the Cobb-Douglas production function to be interpreted as partial output elasticities with respect to a unit change in each input variable, while holding all other inputs at their sample mean values (Huang et al., 2016).

Table 4 also shows that the estimated coefficients of land (significant at the 1% level), labor (significant at the 1% level), and tractor (significant at the 5% level) had expected positive signs and were statistically significant. The elasticities of land, labor, and tractors were estimated to be 0.273, 0.069, and 0.057, respectively. These elasticities suggest that land was the most essential input of tomato production, followed by amount of labor and tractor cost. These findings emphasize the favorable impact of land and labor on tomato production and align with the theory of production economics, which states that output is a function of both fixed and variable input. However, the estimated coefficient of material cost was -0.037, which had a negative sign and was statistically significant at the 5% level. This implies that the reduction of 1% cost in physical input could increase 3.7% of tomato production in the study area. The negative impact of material costs on production underscores the importance of cost-effective input management in tomato cultivation.

Table 4 Estimates of stochastic production frontier and technical inefficiency determinant model

Variables	Symbol	Coefficients	Standard Error	z	P > |z|
Dependent variable: Tomato production					
Ln land	β_1	0.273***	0.103	2.65	0.008
Ln labor	β_2	0.069***	0.018	3.83	0.000
Ln materials	β_3	-0.037**	0.018	-2.05	0.040
Ln irrigation cost	β_4	0.156	0.105	1.49	0.135
Ln tractor cost	β_5	0.057**	0.023	2.51	0.012
Constant	β_0	0.576***	0.159	3.62	0.000
Dependent variable: technical inefficiency					
Age	Z_1	0.017	0.012	1.31	0.190
Education	Z_2	-0.007**	0.003	2.33	0.020
Household size	Z_3	-0.095**	0.048	-1.97	0.049
Experience	Z_4	-0.017	0.013	-1.33	0.184
Number of Earning members	Z_5	0.017*	0.009	1.88	0.060
Dummy gender (1)	Z_6	0.343	0.391	0.88	0.381

Dummy access to extension (1)	Z_7	-0.300***	0.102	-2.94	0.003
Dummy access to training (1)	Z_8	-0.458**	0.232	-1.97	0.049
Dummy access to credit (1)	Z_9	-0.366	0.311	-1.18	0.239
Dummy adoption of mixed cropping (1)	Z_{10}	-0.982***	0.246	-4.07	0.000
Dummy land tenure leasing (1)	Z_{11}	0.790***	0.208	3.78	0.000
Dummy land tenure mixed (2)	Z_{12}	0.318	0.471	0.68	0.500
Dummy sources of grafted saplings (1)	Z_{13}	0.027	0.251	0.11	0.916
Years to adoption of grafting	Z_{14}	-0.158***	0.058	-2.59	0.010
Dummy vermicompost use	Z_{15}	-0.023**	0.011	-2.09	0.037
Dummy yellow paper use	Z_{16}	-0.134**	0.056	-2.35	0.019
Dummy pheromone trap use	Z_{17}	-0.480**	0.235	-2.04	0.041
Dummy mulching film use	Z_{18}	-0.539**	0.270	-1.99	0.047
Constant	Z_0	-2.243**	0.879	-2.55	0.011
Mean technical efficiency	70.82				
Log Likelihood	-140.67				
Wald Chi^2	35.45***				
Prob > Chi^2	0.000				
Number of observations	210				

Source: Authors' estimation, 2025

Tomato production in Bangladesh is labor intensive, and for this reason, land and labor are the dominant contributors to it (Mitra and Yunus, 2018), which is consistent with this study's findings. Previous studies (e.g., Younas et al., 2024; Hasan et al., 2020; Sibiko et al., 2013; Dipelou and Akinbode, 2008) also reported that the larger farm sizes and increased labor inputs could enhance productivity. The insignificance of irrigation costs in this study contrasts with expectations, possibly due to the study area's reliance on natural rainfall, reducing the need for irrigation. However, this finding is also consistent with the prior research, indicating that water availability and irrigation practices can significantly affect crop yields (Hassan et al., 2020).

4.5. Determinants of technical inefficiency in tomato production

The technical inefficiency model was utilized to find out the determinants of technical inefficiency, as represented in Table 4. Since the dependent variable in this model is technical inefficiency, a negative coefficient implies a positive contribution to technical efficiency and vice versa. Table 4 further indicates how various socioeconomic, institutional, and eco-friendly practices affect tomato farmers' technical inefficiency.

The estimated coefficient of education (-0.007, significant at 5% level), household size (-0.009, significant at 5% level), access to extension service (-0.300, significant at 1% level), access to training (-0.458, significant at 5% level), and years to adoption of grafting (-0.158, significant at 1% level) had the expected negative sign, implying their positive effect on technical efficiency in tomato production. Educated farmers are more capable of accessing and understanding farming information, leading to better input utilization. Therefore, higher education increases farmers' management skills, decision-making ability, and adoption of improved technologies. Similar results were documented by Ali and Flinn (1989) in Pakistan and Mekonnen et al. (2021) in Ethiopia, who reported that education positively contributes to farmers' technical efficiency through improved knowledge and technology adoption. Furthermore, larger households may have better access to family labor, lowering the dependence on hired labor and ensuring timely completion of critical farming operations. Previous studies (e.g., Rahman and Salim, 2013; Ogundari and Ojo, 2007) found similar findings, which stated that household size contributes to enhanced efficiency in smallholder farms by easing labor constraints during peak periods. Farmers who received extension services from government or non-government institutions were 30% more technically efficient than those who did not. The reason is extension services provide farmers critical information regarding pest management, grafting methods, and management of eco-friendly production practices to reduce the cost of production. Similar findings were reported in the study of Tabe-Ojong and Molua (2017), who stated that extension facilities enhance efficiency and facilitate adoption of sustainable production practices. Also, training activities enhance farmers' technical knowledge, skills, and problem-solving capacity, especially in grafting technology and input use. In the study area, tomato farmers who had received training were 45.8% more technically efficient than their counterparts. This finding is consistent with the outcomes of other studies, for instance, Asfaw (2021) and Haji (2008), which reported the positive impact of training on technical efficiency. The variable representing the number of years farmers have been adopting grafting technology was negative and statistically significant, implying that farmers with longer grafting experience operated efficiently. This reflects a learning-by-doing effect, where experience contributes to better operational understanding and input optimization. Comparable findings were reported by Rahman and Kazal (2015) and Sarkar et al. (2021), who found that prolonged exposure to new agricultural technologies increases efficiency through accumulated learning and adaptation.

However, the coefficient of the number of earning members was estimated to be 0.017, which is statistically significant at the 10% level, indicating greater off-farm engagement might divert labor from on-farm activities, thereby increasing inefficiency. A comparable finding was reported by Asfaw (2021) and Degineh and Endrias (2019), who observed that households with more off-farm income opportunities allocated less labor and time to tomato cultivation, resulting in higher inefficiency. Land tenure arrangements were also found to have a considerable impact on technical inefficiency. Farmers operating under leasehold tenure showed significantly 79% higher inefficiency compared to owner-operators. This result indicates that insecure land tenure discourages long-term investment in land quality and eco-friendly inputs.

The mean technical efficiency of grafting tomatoes was estimated to be around 71%, indicating that, on average, farmers could potentially increase their output by about 29% using the existing technology and input levels if they operated efficiently. This level of efficiency suggests a moderate scope for improvement in grafted tomato production in Bangladesh. Previous studies documented that the average technical efficiency of tomato production was found to be 68% in Cameroon (Tabe-Ojong and Molua, 2017) and Ethiopia (Hidgot and Zeweled, 2024). The 75% mean efficiency of tomato production was found in Pakistan (Younas et al., 2024), while 81% technical efficiency was found in the study of Asfaw (2021). These findings ensure the reliability of the estimated technical efficiency in this paper.

4.6. Impact of eco-friendly practice on technical efficiency

The use of mulching films is related to physical control of weeds (Jabran, 2019); installation of yellow sticky papers and pheromone traps is related to integrated pest management (Mohapatra et al., 2024); and application of vermicompost and adoption of mixed cropping is related to reduction of synthetic inputs and promotion of biodiversity (Moreira et al., 2024). All these practices are eco-friendly, which protects biodiversity, ecosystems, and the environment through reducing pollution. The main focus of this paper was to examine the impact of these practices on efficiency, and the findings are presented in Table 4. The results show that the estimated coefficients of variables related to these eco-friendly practices had expected negative signs, indicating adoption of these practices reduces the technical inefficiency in tomato production. The coefficients of adoption of mixed cropping, vermicompost application, yellow paper use, pheromone trap use, and mulching film use were estimated to be -0.982 (significant at the 1% level), -0.023 (statistically significant at the 1% level), -0.134 (significant at the 5% level), -0.480 (significant at the 5% level), and -0.539 (significant at the 5% level), respectively. These coefficients imply that mixed-cropping-adopting farmers were about 98% technically more efficient than their counterparts. Similarly, vermicompost, yellow paper, pheromone lure, and mulching film users were 2.3%, 13.4%, 48%, and 53.9% technically more efficient than non-users in the study area, respectively.

Table 5 in this paper also presented a comparison of technical efficiency between eco-friendly practice-following farms and non-following farms. The findings suggest that the mean technical efficiency of vermicompost using farms (73%) was higher than their counterparts (67%). Similarly, the average technical efficiency of tomato farms that applied yellow paper, pheromone traps, and mulching films was higher than the non-using farms. The average technical efficiency of mixed cropping farms was 72%, which was also higher than the non-mixed cropping farms (67%).

Table 5 Summary of technical efficiency

Eco-friendly practices	Number of farms	Technical efficiency	Standard deviation
Vermicompost using farms	95	0.73	0.20
Vermicompost non-using farms	115	0.67	0.17
Use of yellow paper	98	0.71	0.21
Non-use of yellow paper	112	0.69	0.17

Use of pheromone trap	91	0.74	0.19
Non-use of pheromone trap	119	0.66	0.18
Use of mulching films	151	0.71	0.19
Non-use of mulching films	59	0.68	0.18
Adoption of mixed cropping	97	0.72	0.21
Non-adoption of mixed cropping	113	0.67	0.17
Mean	210	70.82	0.19

Source: Authors' estimation, 2025.

The findings of this study are also consistent with the prior research. Mkhabela (2010) found that vegetable-based mixed cropping positively affects the technical efficiency. Amos et al. (2004) also showed that mixed cropping systems enhance technical efficiency and productivity in Nigeria. Moreira et al. (2024) documented the favorable impact of intercropping, which is also a type of mixed cropping, on productivity and raising farmers' income. The positive impact of vermicompost application on soil health promotion and productivity enhancement was found in the studies of Gazi et al. (2024) and Manzoor et al. (2024). The techniques of chemical control in the form of yellow paper use and the pheromone trap technique significantly enhanced the productivity of vegetables, especially tomato production (Kifelew et al., 2024; Mohapatra et al., 2024). Evidence of the positive impact of plastic mulching films, whether biodegradable or not, on yield, productivity, and efficiency through weed control and input use efficiency in vegetable production, especially tomatoes, is found in the past literature (Burato et al., 2025; Hu et al., 2023; Xiao et al., 2023; Amare and Desta, 2021).

The results of this study could be explained by the agronomic and economic benefits associated with the adoption of eco-friendly practices in tomato production. Mixed cropping probably enhanced resource use efficiency by promoting complementary interactions among crops, which resulted in better soil fertility management, pest suppression, and lowered dependency on chemical inputs. The application of vermicompost might enhance soil structure, increase microbial activity, and improve nutrient availability, which collectively contributes to better plant growth and yield performance. Unlike chemical fertilizers, vermicompost releases nutrients gradually, leading to more efficient nutrient absorption and reduced wastage, which is also another reason for efficiency improvement. The use of yellow sticky papers and pheromone traps, both components of integrated pest management (IPM), reduced pest infestations through physical and behavioral control mechanisms. This minimized crop losses and decreased reliance on synthetic pesticides. Similarly, the use of mulching films conserved soil moisture, suppressed weeds, and maintained favorable soil temperatures. These effects created better plant growth conditions and reduced competition for nutrients and water, resulting in higher productivity and efficiency. Overall, the findings suggested that eco-friendly practices improved input utilization and yield outcomes by enhancing soil health, pest control, and resource management. Consequently, farmers who adopted these practices achieved higher technical efficiency compared to non-adopters.

5. Conclusion

This study examined the impact of eco-friendly practices on the technical efficiency of grafted tomato production in Moulvibazar District, Bangladesh, using a stochastic frontier approach. The findings revealed that the mean technical efficiency of grafted tomato growers was approximately 71%, implying a potential 29% increase in output if farmers operated efficiently with the existing technology and input levels. Land, labor, and tractor use significantly contributed to tomato production, whereas excessive expenditure on physical inputs reduced output. Among the determinants of technical inefficiency, education, household size, access to extension and training, and years of experience with grafting positively influenced efficiency, while land leasing and off-farm engagement increased inefficiency.

The adoption of eco-friendly practices mixed cropping, vermicompost application, yellow sticky paper, pheromone traps, and mulching films significantly reduced technical inefficiency. These practices improved soil health, pest control, and input use efficiency, leading to higher productivity and profitability. The study provides empirical evidence that eco-friendly farming enhances both environmental sustainability and technical efficiency in tomato production.

Policy implications arise from these findings. First, strengthening agricultural extension and farmer training programs is essential to promote knowledge and skills related to eco-friendly practices. Second, improving access to credit and secure land tenure can encourage long-term investment in sustainable technologies. Third, the integration of eco-friendly practices into national horticultural development programs can enhance input efficiency and environmental outcomes. Finally, targeted subsidies or incentives for inputs such as biodegradable mulching films and vermicompost could accelerate the transition toward sustainable and efficient tomato production systems.

Compliance with ethical standards

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Disclosure of conflict of interest

The author declares that there are no competing financial or personal interests that could have influenced the work reported in this paper.

Statement of ethical approval

Informed consent was obtained from all individual participants included in the study

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