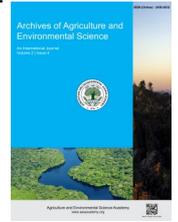This content is available online at AESA

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ORIGINAL RESEARCH ARTICLE

Technical efficiency of tomato production under plastic tunnel technology and their determinants in Kathmandu, Nepal: A stochastic frontier approach

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ABSTRACT

This study aimed to assess the technical efficiency of tomato production under plastic tunnels, and factors influencing it in Kathmandu district. From Chandragiri, Tarakeshwar and Kirtipur Municipalities, 150 randomly selected tomato farmers using plastic tunnel were surveyed using a pre-tested semi-structured questionnaire. Data were analyzed using Excel, IBM SPSS, and STATA. Technical efficiency was estimated using a stochastic frontier model, and its determinants were identified using a Tobit regression model. The average technical efficiency was 79.7%, ranging from 59.0% to 92.2%, indicating a 20.3% potential for improvement. Tomato cultivated area, labor, and seed quantity were found to significantly increase productivity under plastic tunnels, with a 1% increase in each leading to a production rise of 0.431%, 0.394%, and 0.121%, respectively (p<0.01). In contrast, a 1% increase in chemical fertilizer use slightly reduced output by 0.011% (p<0.01), highlighting the importance of balanced input use. The Tobit regression model showed that education, group membership, training, credit access, use of recommended varieties, and mulching practices positively influenced technical efficiency and a unit increase in any of these factors favored tomato yield by 0.001%, 0.046%, 0.025%, 0.035%, 0.018%, and 0.023%, respectively. The study suggests that improving access to resources, technology adoption, and institutional support can enhance efficiency in plastic tunnel tomato farming. These findings provide insights for policymakers and stakeholders aiming to strengthen off-season tomato production in Nepal.

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INTRODUCTION

Tomatoes are among the most widely produced and consumed vegetables, valued at around USD 96 billion annually (FAOSTAT, 2024). Globally, tomatoes are cultivated on 60.6 million hectares, yielding 230.9 million metric tons at an average yield of 37.84 Mt/ha (FAOSTAT, 2024). Asia accounted for 63.9% of total production, with China leading globally (62.02 million Mt) (FAOSTAT, 2024). Greenhouse cultivation has enabled countries like Belgium (423.66 Mt/ha), Sweden, and the Netherlands to achieve the highest yields. Tomato (*Solanum lycopersicum* L.) is Nepal's third most cultivated vegetable by

area and production, following cauliflower and cabbage (MOALD, 2022) and the second most important crop after potatoes (Prajapati *et al.*, 2014). Tomatoes are grown year-round across diverse agro-climatic zones, from the Terai to mid-hills and mountains, supported by plastic greenhouses that enable off-season cultivation according to Thapa Magar *et al.* (2016), and Gotame *et al.* (2021). Nepal cultivates 22,911 hectares of tomatoes, producing 422,703 metric tons, with an average yield of 18.45 Mt/ha, well below the global average of 37.84 Mt/ha and India's 24.55 Mt/ha (FAOSTAT, 2024). This yield gap has led Nepal to import 42,110 metric tons of fresh or chilled tomatoes worth NRs. 610.863 million in FY 2022/23 according to DoC

(2023), despite a 42% increase in domestic production over the last decade. Tomatoes, sensitive to frost, are typically grown as winter crops in the plains and spring crops in the hills (Pal, 2022). However, open-field cultivation faces growing challenges during heavy rainfall, pushing farmers toward plastic tunnels and greenhouse systems (Kafle & Shrestha, 2017). Tunnel farming, introduced by the Lumle Agricultural Research Station in 1996, enables off-season production, now increasingly popular due to high demand and premium pricing (KC *et al.*, 2021). Greenhouse tomato farming can yield up to 500 Mt/ha and deliver net profits of around Rs. 85,400 (~700 USD) per ropani; 2 to 3 times higher than traditional methods when managed well as found Ghimire *et al.* (2017). As urban expansion and population growth continue to drive food demand (Ishtiaque *et al.*, 2017), tunnel farming offers a climate-resilient solution. Also, with land becoming scarce, efficient farming is crucial for Nepal's agriculture (World Bank, 2007) and maximizing output with existing inputs and technology, or through minor modifications, emerges as the most viable alternative (Offiah *et al.*, 2024). However, many small and marginalized farmers, especially in hilly areas, lack technical knowledge, leading to inefficient resource use and low productivity (Sapkota & Bajracharya, 2018).

The Government of Nepal initiated the Prime Minister Agriculture Modernization Project (PMAMP) in 2015 to support the commercialization of various agricultural products (Adhikari & Thapa, 2023). As part of this initiative, specific regions within the Kathmandu district were designated as a vegetable zone to enhance production, productivity, and area used for vegetable farming, including crops like tomatoes. Enhancing the productivity of smallholder farmers within these zones requires a better understanding of farm economics and the efficient use of agricultural inputs (Okello *et al.*, 2019). Technical efficiency is the ability to produce the maximum possible output from available inputs and existing technology, or to achieve a given output with minimal input use (Effiong & Onyenweaku, 2006). Musaba & Bwacha (2014) on a study of technical efficiency of small scale maize production in Masaiti District, Zambia found an average farm-level technical efficiency of 79.6%, indicating substantial room for yield improvement for smallholder farmers using existing inputs and technologies. Moreover, tomato farmers in Ethiopia averaged 80.9% efficiency, with factors like education, training, and credit access positively influencing efficiency (Asfaw, 2021). Similar patterns in studies of Ghimire *et al.* (2023) and Subedi *et al.* (2020) were observed in maize, lentil, and rice production, where better resource management and farmer support could significantly enhance outputs. Inefficiency is often linked to limited extension services, lower involvement in group memberships, low education, limited access to credit, and poor input use according to Ali *et al.* (2017) and Ghimire *et al.* (2023). Pokharel (2021) analyzed the economics of off-season tomato production in Kathmandu, ignoring the efficiency aspects, which are also lacking in studies by Gautam (2019); Kafle & Shrestha (2017). This study aims to assess the technical efficiency of tunnel tomato farming, its influencing factors, and exploring the necessary adjustments to optimize resource use, and implications for better decision-making and policy, aiming to address knowledge gaps.

MATERIALS AND METHODS

Conceptual Framework

The conceptual framework outlines how key factors influence the technical efficiency of plastic tunnel tomato farming (Figure 1). Socio-economic conditions, institutional support, resource use, and agronomic practices all shape agricultural productivity and economic viability. Empirical evidence from studies such as Badimo (2020), Ghimire *et al.* (2023), and Paudel (2022) underscores the critical role these elements play in shaping agricultural outcomes and rural livelihoods. Their interplay directly or indirectly impacts efficiency, improving adoption of plastic tunnels and enhancing farmer livelihoods.

Study area

The research was conducted in three purposively selected municipalities; Chandragiri, Tarakeshwar, and Kirtipur, in Kathmandu district, known for plastic tunnel-based vegetable cultivation, especially tomatoes (Figure 2). These areas fall under the jurisdiction of the Vegetable Zone Project Implementation Unit of the PMAMP. Kathmandu, the capital of Nepal, lies in the Kathmandu Valley of Bagmati Province. This district is the most densely populated district in Nepal with a population of 2,041,587 (2021) and an area of 413.69 square kilometers (CBS, 2024). Geographically, it lies between latitudes 85°10'N and 85°32N and longitudes 27°27'E and 27°49'E.

Sampling procedure and data collection

A purposive sampling method was used to select tomato growing areas using plastic tunnels in Chandragiri, Tarakeshwar, and Kirtipur Municipalities. From these areas, a sampling frame of 255 registered growers were identified as per information from Agriculture Knowledge Center (AKC), Lalitpur, and Project Implementation Unit (PIU), Kathmandu. A simple random sampling technique was used to select the sample. The sample size (n) was calculated using Yamane's (1967) formula (Eq. 1):

$$n = \frac{N}{1 + N * e2}$$

where N is the population size, n is the sample size and e is the margin of error (maintained at 5% in this study).

This study employed both primary and secondary data while following standard research ethics. The interview schedule was designed based on literature reviews and consultation with the study's advisory committee to gather primary data from selected households. Primary data was gathered through face-to-face interviews using a pre-tested questionnaire, piloted with 15 farmers, while secondary data was sourced from different related literatures. Key informant interviews and focus group discussions with significant active commercial farmers and agricultural staff were also conducted to support and validate findings. A
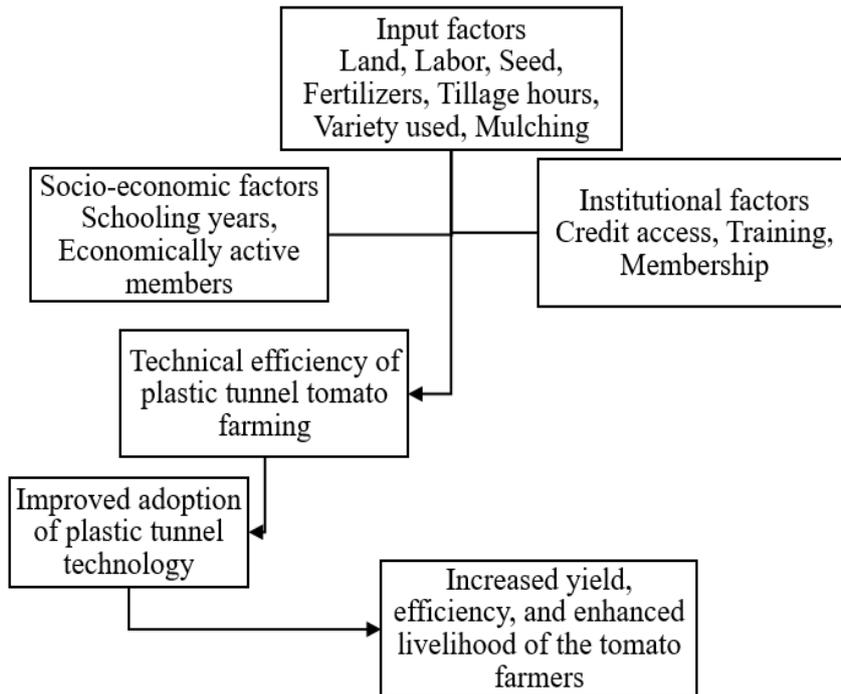
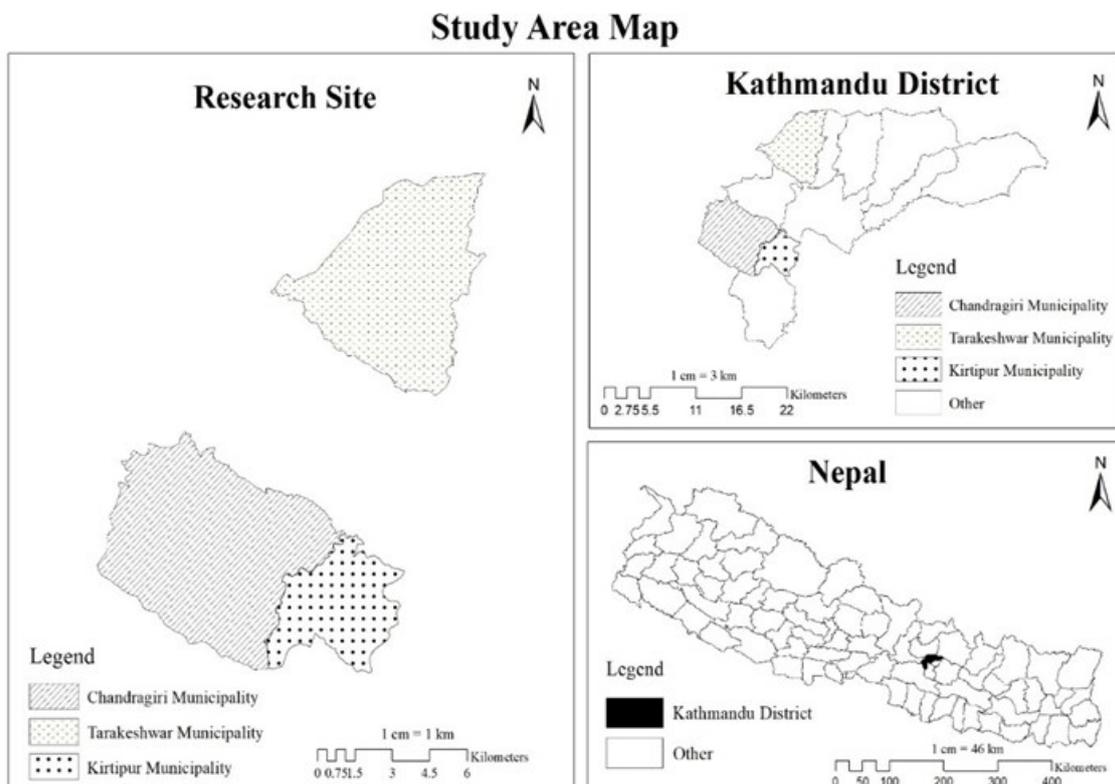**Figure 1.** *Conceptual framework of the study.*

Figure 2. *Map of the study area (Source: ArcGIS, 2024).*

total of 150 households, 50 each from Chandragiri, Tarakeshwar, and Kirtipur, were randomly selected from a list of registered plastic tunnel tomato growers.

Methods and techniques of data analysis

The data were cleaned, coded, and entered into Microsoft Excel before being analyzed using SPSS and STATA. Descriptive statistical measures, including means, standard deviations, frequency distributions, and percentages, were then computed. The stochastic frontier model and the Tobit regression model evaluated technical efficiency and its determinants.

Estimation of technical efficiency

The stochastic frontier production function (SPF) method was used to estimate technical efficiency in tomato production under plastic tunnels. SPF was preferred for its parametric advantages and because it utilizes maximum likelihood estimation, which generally yields more reliable results than the non-parametric data envelopment analysis (DEA), which relies on mathematical programming. While research by Erkoc (2012), Zhang & Garvey (2008), and Cullinane *et al.* (2006) found a strong correlation between the efficiency estimates of SPF and DEA, DEA's sensitivity to outliers and deterministic nature can introduce bias in efficiency scores (Tran *et al.*, 2008). According to Erkoc (2012), SPF is more effective with high-quality data, whereas DEA is preferable when data quality is low, as in some panel data studies. The stochastic frontier model, introduced by Aigner *et al.* (1977), and Meeusen & Van den Broeck (1977), has been applied by Battese (1992) and Rahman (2003) to estimate technical efficiency. This method describes the maximum output achievable from a specific set of inputs using a production function. It will assume that the total inputs involved in the tomato production under plastic tunnel are seed, tillage, FYM, chemical fertilizer, irrigation and labor. The stochastic frontier production function (Eq. 2) can generally be stated as follows:

$$Y_i = f\,(X_i\beta)e^{\varepsilon i}$$

Where,
i = 1, 2, …. n
Y_i = Output of the ith farmer
X_i = Input vector used by the ith farmer
β = Vector of unknown parameters to be estimated
ε_i = A stochastic disturbance/error-term consisting of two independent factors U_i and V_i
i.e., $\varepsilon_i = V_i - U_i$
The stochastic variable $V_i - U_i$ sets a boundary for the output. The random error, V_i, is a two-sided error component that is independent of U_i and represents the usual statistical noise present in any connection, so that $V_i » N\,(0, s^2_v)$. The impacts of random shocks outside the farmer's control, observational and measurement errors on the dependent variable, and stochastic noise are all captured by the inefficiency parameter.
The error term U_i is a one-sided, non-negative ($U_i > 0$) efficiency component that represents technical inefficiency particular to

farms. It does this by measuring the shortfall in output (Y_i) from the maximum value that the stochastic frontier indicates. It is assumed in this study that U_i has a half-normal distribution with $N\,(0, s^2_u)$. The model's variance parameter is as follows:

$$s^2 = s^2_v + s^2_u$$

Where, the error term s^2 is the variance parameter that denotes the total deviation from the frontier, s^2_v is the deviation from the frontier due to stochastic noise, and s^2_u is the deviation from the frontier due to inefficiency.

$$\gamma = s^2_u / (s^2_v + s^2_u)$$

Where, $0 \le \gamma \le 1$ i.e., the parameter, γ, must lie between 0 and 1, is an indicator of relative variability of U_i and V_i that differentiates the actual yield from the frontier. It represents the level of technical inefficiency. When s^2_v tends to zero, it implies that U_i is predominant error, then γ = 1. This indicates that the main cause of yield differences is a failure to use best practices or techniques. When s^2_u tends to zero, it indicates that the V_i is the predominant error and γ = 0, that implies no technical inefficiency in the production process. This indicates that deviations in yield from the frontier yield are mostly caused by statistical error or by extraneous variables not accounted for in the model. The stochastic frontier production function model specified for tomato production under plastic tunnel is given below (Eq. 3):

$$lnY = lna + b_1\,lnX_1 + b_2\,lnX_2 + b_3\,lnX_3 + b_4\,lnX_4 + b_5\,lnX_5 + b_6\,lnX_6 + V_i - U_i \quad \text{(Cobb-Douglas type)}$$

Where,
Y = Yield of tomato under plastic tunnel (kg ha^{-1})
X_1 = Tomato cultivated area (ha)
X_2 = Labor (man days ha^{-1})
X_3 = Farm yard manure (kg ha^{-1})
X_4 = Seed (kg ha^{-1})
X_5 = Total chemical fertilizer (kg ha^{-1})
X_6 = Tillage by mini-tiller (hrs. ha^{-1})
a = intercept
ln = Natural logarithm
V_i = random error term
U_i = Farm specific technical inefficiency

The technical efficiency (TE) of the ith farmer can be estimated as (Eq. 4):

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{\exp(X_i b + V_i - U_i)}{\exp(X_i b + V_i)} = \exp(-U_i)$$

Where, Y_i is the observed output, and Y_i^* is the frontier or maximum potential output. TE_i is the ratio of observed output to the corresponding stochastic frontier output. Technical efficiency is measured on a range of values from zero to one. It compares the firm's output to what an entirely efficient firm could create with the same input vector (Eq. 5).
The average technical efficiency can be described as:

$$Mean\ TE = E\ [\exp[-E\{V_i\ -\ U_i\}]] = E\ [1 - E\{U_i/(V_i\ -\ U_i)\}]$$

Tobit regression model

The several factors, including socio-economic, demographic, and social capital conditions, influence technical efficiency, which is a continuous variable ranging from 0 to 1. Because of this limited dependent variable, logit and probit models, typically used for binary responses, were not suitable. Instead, the Tobit regression model was employed, as it handles equations with restricted thresholds such as efficiency estimates between 0 and 1 (Tobin, 1958). The analysis used maximum likelihood estimation. The study employs an empirical Tobit regression model (Eq. 6):

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + b_7 X_7 + b_8 X_8 + e$$

Where, Y = Technical efficiency scores (%); X_1 = Schooling of the household head (years); X_2 = Economically active members (No.) X_3 = Membership in farmers group (Yes = 1); X_4 = Tomato cultivated area under plastic tunnel (ha); X_5 = Training received about plastic tunnel tomato farming (Yes = 1); X_6 = Access to agricultural credit (Yes = 1); X_7 = Variety used (Srijana = 1); X_8 = Use mulch (Yes = 1); b_0 = constant; e = error term

RESULTS AND DISCUSSION

Socio-economic and demographic information

A summary of the socio-economic characteristics of the 150 randomly sampled tomato farmers cultivating under plastic tunnels is presented in Table 1. Continuous variables included schooling of the household head (HHH), number of economically active members, and tomato cultivated area; categorical variables included group membership, access to agricultural credit, training received, use of mulch, and adoption of improved variety (Srijana). The results showed that the average schooling of household heads was 7.7 years, indicating a moderately educated farming population, consistent with (Pal, 2022), who noted generally low education levels among farmers. The average number of economically active household members was 3.25 (aged 15–59), with 68.3% of the population economically active, aligning with Chhatkuli (2004), who reported 66.7%. The mean tomato cultivated area under plastic tunnels was 0.25 hectares. Only 56.7% of farmers belonged to groups like farmers' or women's groups or cooperatives, with 42% specifically involving in farmer groups, and 42.7% had access to agricultural credit. Only 36% had received agricultural training, though higher than the 4.1% reported by Pal (2022). Four tomato varieties were used, with Srijana being the most popular, solely adopted by 72.7% of farmers, indicating its strong suitability and preference. Only 23.3% of households used mulch, all preferring black plastic for weed control. These results suggest good adoption of improved varieties, but limited uptake of other supportive practices like training and mulching.

Descriptive statistics of inputs used and output from tomato farming using plastic tunnel

Tomato farmers in the study area used an average of 0.14 kg of seed per cycle, ranging from 0.05 to 0.26 kg. They applied about 28,139.3 kg of farmyard manure ranging from 19,660 to 52,426.67 kg, and 621.82 kg of chemical fertilizer, with usage varying from none to 1,966 kg. Tillage took an average of 26.07 hours, from fully manual labor without any use of machinery to a maximum of 49.15 hours. Labor input averaged 450.69 man-days, ranging from 180.87 to 1,081.3 man-days, indicating significant variation in resource use (Table 2). Average production was 16,895.23 kg per farm, ranging from 1,836 to 184,128 kg. Mean productivity was 65,916.94 kg/ha, with yields varying from 22,353.42 to 132,311.8 kg/ha, reflecting significant differences among farmers (Table 2).

Table 1. Socio-economic and demographic characteristics of the respondents in the study area.

Continuous variables	Unit	Mean	SD
Schooling of the HHH	Year	7.70	5.62
Economically active population	Number	3.25	1.30
Tomato cultivated area under plastic tunnel	Hectare	0.25	0.23
Categorical variables	**Unit**	**Frequency**	**%**
Membership	Involved in farmers group, Yes=1	63	42
Training received	Yes=1	54	36
Access to agri. credit	Yes=1	64	42.7
Variety used	Srijana=1	109	72.7
Use mulch	Yes=1	35	23.30

Source: Field Survey, 2024

Table 2. Inputs used and outputs from tomato farming under plastic tunnel per hectare.

Variable	Mean	SD	Minimum	Maximum
Inputs used				
Seed (kg)	0.14	0.04	0.05	0.26
FYM (kg)	28139.30	6025.67	19660	52426.67
Chemical fertilizer (kg)	621.82	381.7	0.01	1966
Tillage (hour)	26.07	7.33	0.01	49.15
Labour (MD)	450.69	166.96	180.87	1081.3
Outputs				
Production (kg)	16895.23	22081.20	1836	184128
Productivity (kg/ha)	65916.94	24575.88	22353.42	132311.8

Source: Field Survey, 2024

Table 3. Stochastic production frontier of tomato production using plastic tunnel.

Variables	Coefficient	SE	Z	Multicollinearity statistic	
				VIF	1/VIF
Tomato cultivated area (ha)	0.121***	0.043	2.81(0.005)	1.40	0.713
Labor (man-days ha^{-1})	0.431***	0.104	4.14(0.000)	1.32	0.756
FYM (kg ha^{-1})	-0.010	0.140	-0.07(0.941)	1.09	0.915
Seed (kg ha^{-1})	0.394***	0.095	4.15(0.000)	1.06	0.940
Total chemical fertilizer (kg ha^{-1})	-0.011*	0.007	-1.67(0.094)	1.05	0.956
Tillage by mini-tiller (hours ha^{-1})	0.009	0.023	0.41(0.681)	1.03	0.971
Constant	9.782***	1.546	6.33(0.000)		
sigma v	0.289	0.074			
sigma u	0.303	0.198			
sigma-squared	0.176	0.081			
Lambda	1.048	0.269			
Other statistics					
Log-likelihood	-51.769				
Prob> chi^2	0.000				
Number of observations	150				
Wald Chi^2(6)	35.68				

Note: Figures in parentheses indicate p value. *, and *** indicate level of significance at 10%, and 1% respectively; Source: Field survey, 2024.

Table 4. Distribution of technical efficiency of tomato farmers using plastic tunnel.

Efficiency level	Frequency	Percent	Cumulative
0.5-0.59	2	1.33	1.33
0.6-0.69	15	10.00	11.33
0.7-0.79	48	32.00	43.33
0.8-0.89	82	54.67	98.00
0.9-0.99	3	2.00	100.00
Total	150	100	100
Mean	0.797		
SD	0.073		
Minimum	0.590		
Maximum	0.922		

Source: Field Survey, 2024

Technical efficiency measurement

Stochastic production frontier estimates

The technical efficiency of tomato production under plastic tunnels was analyzed using a stochastic production frontier model, with yield (kg/ha) as the dependent variable. Six log-transformed independent variables were included: tomato cultivated area (ha), labor (man-days), farmyard manure (kg), seed (kg), chemical fertilizer (kg), and tillage by mini tiller (hours). The model diagnostics showed strong significance (Wald Chi^2 = 35.68, p = 0.000; log-likelihood = -51.769), with a lambda slightly above one. This implies that the independent variables effectively explained the variation in the dependent variable. Low VIF values confirmed no multicollinearity, which supports the reliability of the coefficient estimates. The sigma values and the lambda parameter indicated inefficiencies in the production process. The model found that a 1% increase in labor, seed, and cultivated area raised tomato output under plastic tunnels by 0.431% (p<0.01), 0.394% (p<0.01), and 0.121% (p<0.01), respectively. The results align with Lamichhane *et al.* (2019), who identified labor and seed as key contributors to potato yield. Conversely, a 1% rise in chemical fertilizer slightly reduced yield by 0.011% (p<0.01). This suggests that the increased application of chemical fertilizer slightly reduced output, with a 0.011% decline in tomato production per unit increase in fertilizer use. This result supports the findings of Abedullah *et al.* (2006), who also observed negative effects from

chemical fertilizers, but contrasts with Lamichhane *et al.* (2019). FYM and tiller hours were not statistically significant, suggesting they did not have a substantial effect on production under the studied conditions (Table 3).

Level of technical efficiency of tomato farmers using plastic tunnel technology

The distribution of technical efficiency estimates from the stochastic frontier model provided key insights (Table 4). A post-estimation normality test using a Kernel Density graph, assuming a half-normal distribution with standard bandwidth, showed a curve closely resembling a normal distribution (Figure 3). The model estimated an average technical efficiency of 79.7% for tomato farmers using plastic tunnels, with most farmers (54.67%) achieving 80-89% efficiency, reflecting relatively high proficiency. However, efficiency varied across five groups, with some farms as low as 59.0% and others reaching up to 92.2%. Specifically, 43.33% of farmers had efficiency below 80%, 54.67% were between 80-89%, and only 2% exceeded 90% (Table 4). This suggests, on average, farmers achieved 79.7% of their potential output with the available inputs, indicating scope to increase production by about 20.3% through better practices and minimizing costs. Greater technological efficiency has the potential to enhance both profitability and cost efficiency in the study area. Similar findings were reported by Lamichhane *et al.* (2019) where the mean technical efficiency was 79% for potato
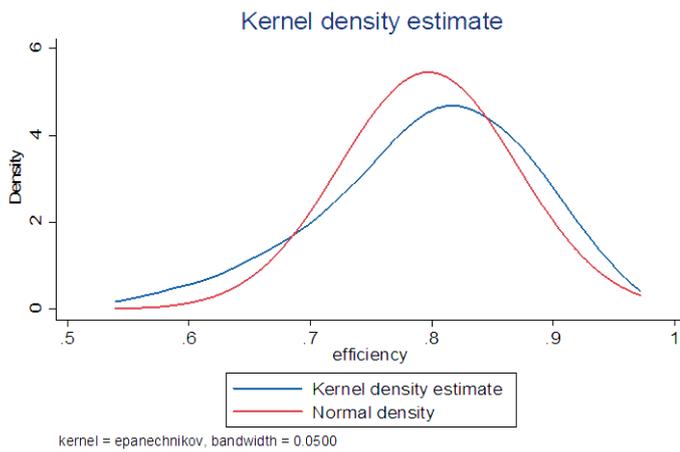
Figure 3. *Kernel density distribution for technical efficiencies (Source: Field survey, 2024).*

farmers in Nepal's mid-western Terai region, suggesting a 21% potential efficiency increase with current inputs and technology. However, the estimated technical efficiency for tomato growers using tunnels in this study area was lower than reported for tomato producers in Ethiopia (80.9%) by Asfaw (2021), off-season tomato production in Punjab (88.9%) by Ali *et al.* (2017), and potato farming (84%) by Abedullah *et al.* (2006).

Determinants of technical efficiency in tomato production using plastic tunnel

The study used a Tobit regression model to examine how farm and farmer characteristics influence technical efficiency in tomato production under plastic tunnels. Technical efficiency scores were the dependent variable, with various socioeconomic and farm factors as independent variables. The model showed strong explanatory power (likelihood ratio = 64.56, significant at 1%). Key positive factors included education, group membership, training, access to agricultural credit, tomato variety, and mulch use (Table 5).

Education

The schooling years of the household head were significantly associated at the 10 percent level ($p < 0.01$), with each additional year increasing efficiency by 0.001%. This outcome aligns with previous studies by Ali *et al.* (2017); Asfaw (2021); Subedi *et al.* (2020), all of which reported a positive association between education and farm efficiency. Educated farmers are likely better at adopting technologies and accessing information. Thus, policies aimed at improving educational opportunities could boost farmers' skills and efficiency.

Membership

Membership in farmer's groups significantly increased technical efficiency by 0.046% ($p < 0.01$). The findings was in accordance with the Ghimire *et al.* (2023); Khatiwada & Yadav (2022); Subedi *et al.* (2020), who found that the farmer involved in groups and cooperatives were technically efficient than the farmers who are not involved in such organization. This may be because farmers with more engagement in farmers group are likely to have better access to technical knowledge, quality inputs, and improved management and farming practices among group members with

effective use of resources that contribute to higher efficiency levels.

Training

Training is vital for building farmers' capacity to adopt new techniques, manage resources, and tackle challenges like pests and diseases. Farmers trained in plastic tunnel tomato farming showed a 0.025% efficiency increase ($p < 0.01$). Expanding such training programs could boost farmers' technical efficiency and productivity. The finding was in conformity with the finding of Asfaw (2021); Khatiwada & Yadav (2022); Mitra & Yunus (2018) who found that training significantly improved technical efficiency of the farmers.

Access to agricultural credit

The study observed that access to credit allows farmers to boost their technical efficiency by 0.035% ($p < 0.01$), which is consistent with Ali *et al.* (2017), who also reported that credit access improves farmers' efficiency. Asfaw (2021) also reported that access to credit significantly boosts technical efficiency. This finding suggests that farmers who secured agricultural credit might be able to invest in better inputs and technologies, leading to enhanced productivity and efficiency in their tomato farming operations.

Variety used

The Srijana tomato variety grown in a plastic tunnel significantly enhanced technical efficiency by 0.018% ($p < 0.01$). This finding align with those of Ghimire *et al.* (2023), who reported that improved seed varieties increase efficiency more than local or home-saved seeds. Lim *et al.* (2019) also compared improved and local seeds, concluding that farmers using improved seeds are generally more technically efficient. NARC (2016) also identified srijana variety of tomato as a high yielding and preferable variety particularly in plastic tunnels. This implies that the Srijana variety may have had better yield characteristics or was more suited to the conditions under plastic tunnel technology, thereby contributing to higher efficiency levels among the farmers who used it.

Use of mulch

The practice of mulching under plastic tunnel also significantly increased technical efficiency by 0.023 ($p < 0.05$). This may be because mulching conserve soil moisture and control weeds, which in turn enhanced the overall productivity and efficiency of tomato farming under plastic tunnels. Sharma *et al.* (2023) discovered that mulching significantly influences the growth and yield of tomatoes and is a cost-effective technique that farmers can use to enhance farm productivity. Tipu *et al.* (2014) also found that using mulches such as rice husk mulch resulted in a higher number of fruits per plant and greater yields compared to not using mulch.

Economically active family members had a positive but insignificant effect, while tomato cultivation area showed a negative but insignificant impact.

Table 5. Factors affecting the technical efficiency of tomato production using plastic tunnel.

Variables	Coefficient	S.E.	t	p-value	Marginal effect dy/dx
Schooling of HHH (Years)	0.001*	0.001	1.78	0.077	0.001
Economically active members (No.)	0.005	0.004	1.32	0.188	0.005
Membership in farmers group (1=Yes)	0.046***	0.014	3.23	0.002	0.046
Tomato cultivated area (ha)	-0.001	0.001	-0.51	0.614	-0.010
Training received (1=Yes)	0.025*	0.015	1.68	0.096	0.025
Access to agri. credit (1=Yes)	0.035***	0.010	3.40	0.001	0.035
Variety used (1=Srijana)	0.018*	0.010	1.76	0.080	0.018
Use mulch (1=Yes)	0.023**	0.011	2.16	0.032	0.023
Constant	0.712***	0.017	42.17	0.000	
/sigma	0.054	0.003			
Statistics					
LR chi^2(8)	93.35				
Log likelihood	223.01				
Prob> chi^2	0.000				
Number of observations	150				

Note: *, **, and *** indicate level of significance at 10%, 5%, and 1% respectively. dy/dx is marginal effects after the Tobit; Source: Field survey, 2024.

Conclusion

The average technical efficiency of tomato production under plastic tunnel technology in the study area was 79.7%, with most farmers operating at 80–89% efficiency. This indicates while input use is relatively effective, output could still increase by 20.3% through better use of existing resources and improved farming practices. The stochastic frontier analysis identified cultivated area, labor input, and seed quantity as key factors positively influencing tomato productivity, while chemical fertilizer had a slight negative effect, highlighting the importance of precise input management. Farmers should therefore expand cultivated area where feasible, use labor efficiently, and optimize seed use to enhance efficiency. Further, technical efficiency was positively influenced by farmer education, group membership, access to credit, training, and the adoption of improved varieties and mulching practices. Strengthening both formal and informal education such as training and farmer-to-farmer knowledge sharing can enhance efficiency. Farmers should be encouraged to join farmers' groups, which provide access to technical knowledge, quality inputs, and shared experiences. Also, collective resource sharing within groups can reduce costs and expand production. Improved and easier access to agricultural credit should be actively promoted to empower farmers to invest in quality inputs and modern technologies. Additionally, promoting the use of improved practices such as high-performing tomato varieties and mulching can lead to better input utilization, higher yields, and increased profitability. Policies that promote access to training, quality inputs, and institutional credit, along with the dissemination of effective agronomic practices, can help farmers close the efficiency gap, substantially raise production and support sustainable agricultural growth.

DECLARATIONS

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