Vol. 16(5), pp. 667-677, May, 2020
DOI: 10.5897/AJAR2020.14727
Article Number: E80A5DB63699
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

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African Journal of Agricultural Research

Full Length Research Paper

Technical efficiency in tomato production among smallholder farmers in Kirinyaga County, Kenya

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Received 17 January, 2020; Accepted 23 March, 2020

The study was conducted to assess tomato productivity and determine characteristics that influence technical efficiency among smallholder farmers in Kirinyaga County using the production function approach. Data were collected by administering structured questionnaires to a sample of 384 respondents randomly selected from six wards using multistage stratified and probability proportionate to size sampling procedures. The study adopted cross-sectional survey design and primary data on tomato yield, production system, input usage and farmer demographics were collected. The stochastic Cobb Douglas production function was used to estimate the frontier production and efficiency levels using maximum likelihood. Tobit multiple regression was used to determine farm and farmer characteristics that impact technical efficiency. Results showed that respondents were inefficient with an average technical efficiency of 39.55% with greenhouse more efficient than open field system. Household size, production systems, seed type, fertilizer, extension and market information significantly and positively influenced technical efficiency, while land size was significant and inversely influenced technical efficiency. Results revealed a possibility to increase technical efficiency in tomato production using certified seeds and recommended fertilizer levels. In addition, policy interventions aimed at subsidizing costs of establishing greenhouses would serve as an incentive to motivate farmers to use technologies in tomato production.

Key words: Cobb Douglas production function, production systems, technical efficiency, Tobit regression

INTRODUCTION

Comparable to other Sub-Saharan African countries, Kenya continues to rely on agriculture for food and economic development (Ochilo et al., 2019). The sector is a key economic pillar contributing 24% of the gross domestic product and about 65% of exports (Nyamwamu, 2016). Smallholder farmers dominate the sector with farms ranging from 0.2 to 3 hectares and produces over 70% of total agricultural output (Ndirangu et al., 2018). Horticulture forms the bulk of agriculture with vegetables accounting for 80% of growers and 60% of exports (Yabs and Awuor, 2016). Tomato is among the widely cultivated vegetables and is ranked second after potato in terms of production and value (Mitra and Yunus, 2018). In recent past, the Kenyan government has devised mechanisms to improve productivity among smallholder farmers (Wambua et al., 2019). In tomato

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production, this involved development of disease resistant varieties, quality fertilizers, effective pesticides and technologies aimed at reducing production costs (GoK, 2018).

Despite these efforts, the country has not attained food sufficiency like is the case in other developing countries. To overcome this, it is necessary to increase agricultural yield by improving production efficiency.

Tomato is among vegetables mainly grown in open fields and greenhouse production systems (Nyamwamu, 2016). The crop is extensively cultivated, accounting for about 7% of horticulture and 14% of vegetable production (Mwangi et al., 2015). On average, the country records 410,033 tons of tomato with area under cultivation escalating from 18,178 ha to 20,111 ha between 2011 and 2016. (Mitra and Yunus, 2018).This places Kenya among top tomato producers in Sub Saharan Africa (Ochilo et al., 2019). In Kenya, tomatoes are grown in areas with altitudes that range from 1150 and 1800m above sea level (Mwangi et al., 2015). Mwangi et al. (2015) also noted that Kirinyaga County leads (14%), in tomato production followed by Kajiado (9%) and Taita Taveta (7%). The crop contributes to income generation, foreign exchange, poverty alleviation, and employment creation especially to rural populations (Singh et al., 2017). In spite of this substantial contribution to rural economies in the region, tomato production encounters challenges of low productivity (Geoffrey et al., 2014). Chepng'etich et al. (2015) explains that actual yields remain below the maximum attainable levels with Sub Saharan Africa recording an agricultural produce that is below the global average.

In Kenya, despite efforts to improve tomato production by introducing modern technologies such as greenhouses, productivity declined from 22.4 tons in 2011 to 17.9 tons in 2015 and 16.9 tons in 2016 (Tabe and Molua, 2017). Ochilo et al. (2019) noted that deviations persisted in 2018 with an average yield of 12 tons/ha against a potential yield of 30.7 tons per ha. This was below an average of 35 tons/ha in Egypt and 120 tons/ha in France (Najjuma et al., 2016).

The low productivity in agriculture has resulted from the inability of farmers to fully utilize available technologies hence leading to inefficiencies in production (Kumar et al., 2018). Further, Wanjiku (2015) indicated that land available for agricultural production has reduced due to the enormous population growth, extensive soil degradation and intensified land fragmentation thus lowering productivity. Besides this, the high poverty levels entwined with the limitation of factors of production has made it difficult for farmers to increase production through use of more resources (Simwaka et al., 2013). The existence of inefficiencies in agricultural production implies the need to examine technical efficiency of agricultural production particularly among smallholder tomato farmers (Wahid et al., 2017). Kumar et al. (2018) explained that an understanding on levels of technical efficiency can be valuable in solving the problem of low productivity in agriculture.

Ochilo et al. (2019) indicated that production and productivity in agriculture can be improved through increased input use and increasing technical efficiency levels of producers. Measuring technical efficiency helps compare the performance of farmers and identify factors that explain inefficiencies (Kassa and Demissie, 2019). Technical efficiency depicts the producer's ability to achieve optimal production from the available resources and level of technology (Shettima et al., 2015). Dessale (2019) explained that the performance of a producer and factors that affect production are important aspects in quantifying technical efficiency. Technically, efficient farms produce along the frontier while inefficient producers lie below the frontier production function (Tirra et al., 2019). In addition, farms closer to the production frontier are more technically efficient than those far from the frontier (Katungwe et al., 2017). Improving efficiency enables farmers increase yields without additional inputs and technologies thus enhanced productivity (Saavedra et al., 2017). Among smallholder farmers, inefficiencies may also arise from farm and farmer characteristics (Singh et al., 2017).

The Kenyan tomato industry is set to improve given the governments' pursuit to realize the Big Four Agenda which targets to achieve food security by boosting productivity among smallholder farmers (Tirra et al., 2019). Despite the significance of increasing productivity, literature on technical efficiency a key aspect in increasing agricultural production is scanty. In addition, very few studies have profiled and compared technical efficiency of tomato production between open field and greenhouse production systems in Kenya particularly Kirinyaga County. This is so despite the County leading in tomato production in Kenya. In addition, the component of describing tomato farmers based on production systems and determining their technical efficiency is limited. Besides this, it is necessary to investigate the causes of technical inefficiency and low productivity among the smallholder tomato farmers.

The main goal of this study was therefore to examine the level of technical efficiency of smallholder tomato farmers in Kirinyaga County and identify characteristics that influence technical efficiency. The study conducted an in depth analysis of technical efficiency by determining the frontier production function and the yield gap of tomato farmers from the maximum achievable output. This was computed given the existing technology and level of inputs by maximizing output per unit of input. This highlighted the extent to which factors of production such as seeds, fertilizers and pesticides account for variations in yields. The results revealed that technical efficiency for tomato farmers in Kirinyaga remained low with greenhouse farmers more efficient than open field farmers.

The study provides relevance in practical and theoretical setups. At the practical level, measuring technical efficiency and identifying factors that influence it among smallholder farmers provides meaningful information to policy makers in the formulation of strategies that are likely to improve the producer technical efficiency. From the microeconomic view, the identification of factors that improve farm performance is of utmost importance and through utilization of research based information from such studies farm efficiency may increase thus better returns. At the theoretical level, the study aims at contributing to existing literature and understanding of producer technical performance in rural areas of developing countries.

MATERIALS AND METHODS

Description of study area

The study was conducted in Kirinyaga central and Mwea west sub-counties of Kirinyaga County which are the major tomato growing zones in the County and are located in the lowland and midland agro-ecological zones (GoK, 2018). The County is located along the slopes of Mt. Kenya and lies between latitudes 0°1’ and 0°40’, and latitudes 37° and 38° East with altitude between 1158 and 5199 metres above sea level (Mwangi et al., 2015). Rainfall in the study area is bimodal with long rains occurring from March to May and short rains occurring from October to December with quantities ranging from 1,212 to 2,146 mm (GoK, 2018). On average, temperatures range from 8.1°C to 30.3°C. Agriculture is the major economic activity with majority (70%) of farmers being smallholders (MoA, 2011). Tomato is among the promising horticultural crops.

Sample size

The sample size of this study was 384 smallholder tomato farmers who were obtained from major tomato producing areas in Kirinyaga County. The following formula was used to determine the sample size as applied by Narcisse (2017).

$$n_o = \frac{z^2\ pq}{d^2} \qquad (1)$$

Where n_o is the desired sample size, z is the standard normal value (1.96), p is the proportion of households producing tomatoes in small scale in Kirinyaga County, q equals 1-p and d is the desired precision level or level of significance (5%). The study adopted a proportion of 50% that the respondents possess the characteristic being measured.

Research design and sampling technique

The study employed a cross-sectional survey research design which ensures accuracy *(*Bhattaraiet al., 2016) and estimates the extent of realizing sample outcome for a given population (Okonya and Kroschel, 2015). The study embraced multistage stratified random sampling to sample respondents to be interviewed. The two sub counties were purposively selected and from each sub county, wards were selected based on the concentration of tomato production. Six wards that mainly grow tomatoes in small-scale were considered. Since the expected number of greenhouse farmers was low, a census survey was conducted and a total of 78 greenhouse farmers obtained. Consequently, from each ward, probability proportionate to size sampling technique was applied using the sampling frame to select 306 open field farmers. The number of farmers from each ward was determined using the following formula as applied by Wambua et al. (2019).

$$K = \frac{P}{M} * 306 \qquad (2)$$

Where, k = number of farmers to be interviewed from each ward; P= the number of smallholder tomato farmers in each selected ward and M= total number of smallholder tomato farmers in the selected wards.

Data analysis

The study collected both qualitative and quantitative data. The Statistical Packages for Social Sciences (SPSS) was used for descriptive analysis. The stochastic frontier production function and the censored Tobit regression model in STATA version 13.0 were used as econometric models. Means, percentages and standard deviations were used to describe the distribution of technical efficiency scores, socioeconomic characteristics of the respondents and the farm characteristics. The maximum likelihood estimation procedures were used to estimate the stochastic production function of the Cobb Douglas functional form. The estimated efficiency scores were regressed against the selected farm and farmer characteristics using Tobit multiple regression model to identify factors that influence technical efficiency.

Theoretical framework

The economic theory of production provides a methodical background for most studies on efficiency and productivity (Katungwe et al., 2017). Efficiency is regarded as the relative performance of transforming inputs into outputs. Agricultural productivity can be defined as the ratio of the value of total farm output to the value of the total inputs used in the farm production (Tabe and Molua, 2017). The economic theory gives a distinction between two forms of efficiency, allocative and technical efficiency and a farm that meets both is said to be economically efficient (Ndirangu et al., 2018). Frontier measures of efficiency imply that efficient farms operate along the production frontier. In addition, the amount by which a farm deviates from its frontier production is regarded as a measure of inefficiency (Chepng’etich et al., 2015). Tabe and Molua (2017) noted that research has categorized measures of efficiency into non-parametric and parametric approaches. The most common non parametric approach is the data envelopment analysis (DEA) which does not separate deviations in output into inefficiency and random errors. Further, it does not allow hypothesis testing for the fitness of the model (Parman and Featherstone, 2019). The stochastic frontier production is the frequently used parametric approach. This approach entails the description of the technology which may be restrictive in most cases (Ajibefun, 2008). Further, the stochastic frontier model attributes deviations from the frontier function into inefficiencies and random errors thus accurate and less sensitive to measurement errors in data (Ndirangu et al., 2018). In addition, it allows testing of hypothesis regarding the goodness of fit for the model. This model estimates the production function by fitting observed data and minimizing measures of their distance from the expected frontier

(Abdul and Isgin, 2016).The stochastic production frontier was initially proposed by Aigner et al. (1977) and Mueesen and Broeck (1977). The model is generally expressed as:

$$Y_i = f(X_i;\ \beta)\exp(V_i - U_i) \tag{3}$$

Where, 1 = 1, 2, 3… n, X_i is vector of input quantities used by the i^{th} farmer, Y_i is tomato output of the i^{th} farmer, β is a vector of parameters to be estimated. V_i is the distinctive error term that arises from measurement errors in input use and yield. U_i is a non-negative (U_i ≥0) random variable with half normal distribution. It measures technical efficiency relative to the frontier production function (Battese and Coelli, 1995).

The computation of technical efficiency of an individual farm was achieved by comparing actual yield to optimal outputs. Technical efficiency of an individual farmer was defined as the ratio of actual output to the optimal production, constrained by the input levels used as shown below:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{[F(B,X) + (v_i + u_i)]}{[(B,X) + V_i)]}$$

Where, TE_i is the technical efficiency of an individual farmer, Y_i represents actual output and Y_i^* represents optimal output.

Empirical model

In this study, technical efficiency among smallholder tomato farmers in Kirinyaga County was measured using the stochastic frontier production which was based on the Cobb Douglas production function. Despite the limitation of the Cobb Douglas production functional form, it provides suitable representation of any production technology used. Further, it is capable of holding multiple input modelling and efficient in managing multicollinearity, heteroscedasticity, and correlation (Mitra and Yunus, 2018). The Cobb Douglas stochastic production frontier function is specified as:

$$\text{Ln}\,Y_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + V_i - U_i \tag{5}$$

Where, X_1 is seed quantity (g), X_2 is labour used (Mds/ha), X_3 is pesticides (L/ha), X_4 is fertilizer quantity (Kg/ha), X_5 is farm size (ha).

The Tobit censored regression model was used to investigate characteristics that affect technical efficiency among smallholder tomato farmers in Kirinyaga County. Since efficiency ranges from a minimum of 0 to a maximum of 1, the model was appropriate as it is a limited dependent variable model (Chepng'etich et al., 2015). The model, based on Battese and Coelli (1995) and applied by Tabe and Molua (2017) is specified as:

$$U_i = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \cdots + \alpha_{17} X_{17} \tag{6}$$

Where,U_i= Technical efficiency scores, X_1 =Age, X_2 =Gender, X_3 =Household size, X_4 =Farmer group membership, X_5 = Experience in tomato production, X_6= Education, X_7= type of production system, X_8=Land tenure, X_9 =Seed type, X_{10}= Off farm income, X_{11}= Farm income, X_{12} =Land size under tomatoes, X_{13} = Fertilizer quantity, X_{14} = Access to extension services, X_{15}= Distance to market, X_{16} = Access to market information, X_{17} =Credit value.

RESULTS AND DISCUSSION

Continuous farm and farmer characteristics

The research conducted a descriptive analysis of the farm and farmer characteristics of the smallholder tomato producers in Kirinyaga County. The respondents used both open field and greenhouse production systems. Table 1 shows a comparison of the continuous factors of the respondents using open field and greenhouse production systems. In this study, open field system was considered as a conventional method of commercial tomato production in the open-air space without any protection from the environment. Further, the greenhouse system was conceptualized as growing tomatoes under a structure covered with transparent materials that transmit light for the growth of the plants as explained by Wachira et al. (2014).

From Table 1, the average age of the respondents was 37.03 years for the sample and ranged from 25 to 75 years. The results also revealed a mean of 36.36 and 39.64 years for open field and greenhouse farmers, respectively. The age differences between farmers in the two production systems were different at 1% level implying that greenhouse farmers were significantly advanced in age than their open field farmers. This shows that as tomato farmers progressed in age, they were more receptive to modern technologies of production.

Besides, the respondents apportioned an average credit of Ksh 29,930 for tomato production with Ksh 9,998 for open field and Ksh 108,121 for greenhouse farmers. Credit availability showed that farmers were empowered to timely procure improved inputs and adopt modern technologies. Differences in value of credited used in tomato production between the two production systems differed significantly at 1%. The large proportion used by the greenhouse farmers was informed by the high initial costs of investments required in this system while establishing the structures.

On average, the household size was 5.14 members for the sample, 5.16 members for open field and 5.08 members for greenhouse farmers. However, there were no statistical differences in household sizes between the two tomato production systems. In addition, the respondents recorded an average experience of 9.06 years in tomato farming. The mean number of years in tomato farming for open field system was 10.55 years and 3.26 years for the greenhouse farmers and the differences were significant. This suggests that open field farmers were significantly more experienced thus had more knowledge and understanding of tomato production than the greenhouse farmers. Regarding years spent while schooling by the head of household, open field smallholder farmers had a mean of 8.74 years of education compared to 14.49 years of schooling among greenhouse producers. Some open field farmers had 0

Table 1. Descriptive analysis of continuous characteristics.

Variable	Sample N=384	Open field (n=306)			Greenhouse (n=78)			t-value	Sig
		Mean	Min	Max	Mean	Min	Max		
Age (Years)	37.03	36.36	25	75	39.64	25	68	-2.76	.006***
Credit (Ksh)	29930	9998	0	300000	108121	0	500000	-8.40	.000***
Household size (No)	5 .14	5.16	1	10	5.08	2	10	0.34	.734
Experience (Years)	9.07	10.55	1.5	25	3.26	2	5	21.2	.000***
Education (Years)	9.90	8.74	0	16	14.49	10	18	-23.3	.000***
Land size (ha)	0.709	0.649	0.09	2	0.95	0.18	1.80	-4.99	.000***
Farm size (ha)	2.30	2.294	1.60	8.40	2.32	1.60	4.9	-0.29	.766
Fertilizer (Kg/ha)	208.8	236.5	18.5	1200	99.68	20	350	10.0	.000***
Seeds (g/ha)	46.87	54.21	2.50	300	18.10	2.78	138.9	9.34	.000***
Pesticides (L/ha)	8.0	8.34	1	48	6.69	1.33	29.2	1.99	.048**
Labour (Mds/ha)	303.7	349.7	42.2	2175	122.8	35	545	11.4	.000***
Productivity(Kg/ha)	8225	7046.	556	23480	12851	3055	21600	-7.94	.000***
Market distance (Km)	9.72	11.11	3	28	4.25	2	8.5	19.0	.000***

***Significance at 1%; ** Significance at 5%.
Source: Field survey data (2019).

years of education implying that they had no formal education. Years spent in school by farmers in either systems were different at 1%.This exhibited that greenhouse farmers were significantly more educated thus had enhanced skills and ability to better utilize market information and understand modern technologies.

On average, the respondents were located 9.72 km from the markets. Open field and greenhouse producers were situated 11.11 and 4.25 km from the nearest markets, respectively. Differences in market distances between open field and greenhouse farmers were statistically different implying that open field farmers were located farther away from the markets compared to greenhouse farmers. Further, this shows that greenhouse farmers had adequate access to market information and market benefits on provision of key inputs such as improved seeds and fertilizers. Regarding farm sizes, respondents had an average of 2.30 ha while land size under tomatoes averaged at 0.7096 ha. This shows that the farms were highly fragmented and that tomato production faced competition from other farm enterprises. While farm sizes between open field and greenhouse tomato producers were insignificant, the differences in size of land planted with tomatoes between the two production systems were significant at 1% level. This implies that on average, area under tomato cultivation for greenhouse farmers was considerably large than that of the open field farmers thus expected to give higher outputs.

As regards fertilizer application, di-ammonium phosphate (DAP) and nitrogen, phosphorus, potassium (NPK) fertilizers were the most common during land preparation and planting. Urea and calcium ammonium nitrate (CAN) were frequently used during top dressing. Respondents used a mean of 208.8 kilograms of fertilizer per hectare. From the results, open field farmers used significantly more fertilizer quantity per hectare than the greenhouse producers. The recommended levels of fertilizers in tomato production are approximately 1,186 kilograms per hectare (Tabe and Molua, 2017). Compared with the amounts applied in Kirinyaga, farmers used less than the recommended fertilizer amount.

Seed quantity averaged 46.87 g per hectare and significantly varied between open field and greenhouse tomato farmers in the study area. The most common pesticides Were ridomil and Milraz (fungicides), Karate and Bestox (insecticides) and Oxy gold (herbicide). On average farmers used 8.0 litres of pesticides during the season with 8.34 L per hectare for open field and 6.69 L per hectare for greenhouse farmers. Pesticide application between the two systems differed significantly at 5% level with open field farmers using more per unit of land compared to the greenhouse farmers. This was possibly due to high pest and disease infestation in the open field system.

During the tomato growing season under review, a mean of 303.7 man days per hectare were employed in tomato production. Open field system substantially required more labor in tomato production per hectare (349.76 Mds/ha) compared to greenhouse systems (122.8 Mds/ha). This was attributed to that tomato production under the greenhouse system is highly automated with a drip irrigation which enables distribution of liquid fertilizers and irrigation water thus drastically reducing labour requirements. The mean yield for the sample was 8225 kg/ha (8.225 tons/ha) which was below

Table 2. Descriptive statistics on categorical variables.

Variables	Sample (N=384)		Open field (n=306)		Greenhouse (n=78)		Chi-square test	Sig
	No.	%	No.	%	No.	%		
Gender								
Male	291	75.8	231	75.5	60	76.9	0.070	0.792
Female	93	24.2	75	24.5	18	23.1		
Group membership								
No	240	62.5	188	61.4	52	66.7	0.725	0.394
Yes	144	37.5	118	38.6	26	33.3		
Land tenure								
Without title	196	51.1	159	51.9	37	47.4	0.509	0.475
With title	188	48.9	147	48.1	41	52.6		
Type of seed								
Uncertified	167	43.5	167	54.9	0	0	76.94	0.000***
Certified	215	56.5	137	44.8	78	100		
Extension								
No	300	78.1	245	80	55	70.5	3.319	0.068**
Yes	84	21.9	61	20	23	29.5		
Market information								
No	26	6.8	22	7.2	4	5.1	0.418	0.518
Yes	358	93.2	284	92.8	74	94.9		
Total	384	100	306	100	78	100		

***Significance at 1%; ** Significance at 5%.
Source: Field survey data (2019).

a potential of 30.7 tons per hectare (Wachira et al., 2014). The average productivity was significantly different between production systems with 7046.57 kg per hectare (7.05tons/ha) for open field and 12850.47 kg per hectare (12.85tons/ha) for greenhouse. The greenhouse system was more productive than the open field system in tomato production among farmers in the sample. However, this productivity remained low compared to 23 tons per hectare for open field and 161 tons per hectares for greenhouse system (Van der Spijk, 2018).

Categorical farm and farmer characteristics

Table 2 gives a comparison of categorical factors of respondents in the sample. From Table 2, of the sampled household heads, 306 (79.68%) grew tomatoes under the open field system while 78 (20.32%) adopted the greenhouse production system. The low adoption could be attributed to limited knowledge on emerging innovations in tomato production and high initial cost of investments required to establish greenhouse structures.

Majority (75.78%) of the sampled households were male headed, with only 24.22% being female headed. However, the results show that there was no statistically significant relationship between gender and the type of system used. Concerning farmers groups, only 37.5% of the respondents had group membership but the connection between group membership and production systems was not statistically different. The results show that 51.04% of the respondents owned land with title deeds while 48.96% operated farms that were either leased, communally owned or had permission to use from the land owners. Linkages between land tenure and the two production systems did not differ significantly. Further, relations between seed type used by the respondents in either production systems were statistically different as shown by the chi-square value. All the sampled greenhouse producers used certified seeds with a sizeable proportion of the open field farmers using uncertified seeds. This was motivated by allocation of credits in tomato production which enabled farmers to timely procure of improved seeds for production.

Access to extension services was limited in the study with only 21.87% of the respondents having contact with extension agents. Similar results were obtained within systems, with only 20% of the open field farmers and 29.5% of the greenhouse farmers having access to extension and training. The relation between access to extension and type of tomato production systems differed at 5% level. This implies that farmers most of the greenhouse farmers were adequately trained better agricultural

Table 3. Maximum likelihood estimates of the stochastic production function.

Variable	Parameter	Coefficient	Std. error	z	P >|z|
Constant	β_0	1.7133	0.5244	3.27	0.001***
Land size (Hectares)	β_1	0.5917	0.0535	11.07	0.000***
Fertilizer (Kilograms)	β_2	0.4761	0.0748	6.36	0.000***
Seed quantity (Grams)	β_3	-0.1089	0.0508	-2.14	0.032**
Chemicals (Litres)	β_4	0.0617	0.0579	1.07	0.287
Labour (Man days)	β_5	-0.0336	0.0583	-0.58	0.564
Log likelihood		-447.5662			0.000***
Wald chi2(5)		472.13			0.000***
Lambda		10.7508	0.0923	116.42	0.000***
Likelihood ratio (5, 5%)		15.1389			0.000***
Sigma squared (σ^2)		2.097			0.000***
Gamma (γ)		0.6876			0.000***

***Significance at 1%; ** Significance at 5%.
Source: Field survey data (2019).

techniques and technologies that have potential to increase yields. Majority (93.23%) of the respondents were privy to trends in both input and output markets with 92.8% open field and 94.9% greenhouse farmers having access to market information. Relations between access to market information between farmers in either open field or greenhouse system did not differ significantly.

Parametric estimates of frontier production function

The maximum likelihood estimation procedures were used to estimate the stochastic Cobb-Douglas production frontier function using STATA software and the results is given in Table 3.

The value of gamma parameter (γ) shows that 68.76% of the deviations in tomato production resulted from technical inefficiencies. The results yielded a sigma squared (σ^2) value of 2.097 that was significant at 1% level. This denotes a perfect goodness of fit with the Cobb Douglas stochastic frontier model. The value (15.1389) of the likelihood ratio (LR) test was significant at 1% level and greater than the critical value of chi-square (11.070) with 5 degrees of freedom. This shows that the Cobb Douglas functional form was appropriate for data. The results show that area under tomato cultivation (land size), fertilizer quantity applied and seed quantity used were important in determining tomato production in the study area.

Acreage under tomato cultivation (land size) and fertilizer quantity had positive coefficients that were significant at 1% level. Thus increasing acreage under tomato production and fertilizer usage by 1% would increase tomato output by 0.5917 and 0.4761%, respectively. In addition, seed quantity had a negative and significant coefficient at 5% level showing that a 1% increase in seed quantity would reduce tomato output by 0.1089%. This is reasonably due to use of local uncertified seeds by a sizeable proportion of respondents that contain high levels of impurities which reduce the germination potential. This reduces the plant population per unit of land leading to low yields. These result concurred with Wabomba (2015). Output was highly responsive to tomato acreage, followed by fertilizer and seed quantity.

Comparison of technical efficiency in open field and greenhouse production systems

Table 4 shows the distribution of technical efficiency scores of the sample and the comparison of the efficiency between open field and greenhouse tomato production systems.

The mean technical efficiency for the sample was 39.55. This shows that there exists an opportunity to improve technical efficiency by more than 60% if all restrictions that make smallholder tomato farmers in Kirinyaga County inefficient are improved. The results coincided with the findings of Zalkuw et al. (2014). The mean technical efficiency for open field farmers was 31.48% and 71.22% for the greenhouse farmers. This implies that greenhouse farmers had a higher technical efficiency value compared to that of open field farmers. This result negated the findings of Najjuma (2016) who estimated mean technical efficiency of 40.43 and 33.71% for open field and greenhouse farmers, respectively. In addition, technical efficiency ranged from 3.63% to 94.62%. The wide range indicates that most of the smallholder farmers utilized available resources inefficiently.

Majority (80.4%) of the open field farmers had efficiency levels below 50% with only 12.8% greenhouse

Table 4. Frequency distribution of technical efficiency.

Description	Efficiency range	Sample		Open field		Greenhouse	
		No.	%	No.	%	No.	%
Low	0 < to < 0.25	159	41.4	158	51.6	1	1.3
Moderately low	0.25 < to < 0.50	97	25.3	88	28.8	9	11.5
Moderately high	0.50 < to < 0.75	68	17.7	40	13.1	28	35.9
High	0.75 < to ≤ 1.00	60	15.6	20	6.5	40	51.3
Mean		0.3955		0.3148		0.7122	
Minimum		0.0363		0.0362		0.9462	
Maximum		0.9462		0.1536		0.9361	
Standard deviation		0.2667		0.2220		0.1763	

Source: Field survey data (2019).

Table 5. One way ANOVA comparison of technical efficiency.

Technical efficiency	Sum of squares	df	Mean squares	F	Sig
Between groups	9.816	1	9.816		
Within groups	17.433	382	0.046	215.098	0.000***
Total	27.249	383			

***Significance at 1%.
Source: Field survey data (2019).

farmers below this level. The results also noted that 66.7% of the smallholder tomato farmers had efficiency scores below 0.5. This implies that by increasing technical efficiency, 66.7% of the sampled farmers could increase tomato output by more than 50% with majority being open field farmers. The results agreed with the studies of Khan and Shoukat (2013) in northern Pakistan, Ayerh (2015) in Ashanti region of Ghana. Within the production systems, only 19.6%of open field and 87.2% greenhouse farmers, attained efficiency levels of 50% and above. In addition, 33.3% of the farmers attained efficiency levels of 50% and above.

The variations observed in technical efficiency between farmers in open field and greenhouse tomato production systems were statistically different at 1% level. This confirms that among smallholder tomato farmers in Kirinyaga County, greenhouse system of production was significantly more technically efficient than the open field system as shown in Table 5. The plausible explanation is that farmers who use greenhouses adopted certified seeds and were significantly more educated thus understood the role of modern technologies in production.

Socio-economic and institutional factors affecting technical efficiency

The effect of selected factors on technical efficiency was ascertained using censored Tobit regression model as specified in Equation six (6). Table 6 shows the results of Tobit multiple regression analysis. The existence of inefficiency was determined using the log likelihood which gave a value of 88.22 that was significant at 1% level. The Tobit regression denoted a likelihood ratio (LR) of 250.27. The critical value of chi-square (27.857) at 5% level of significant with 17 degrees of freedom was less than the LR. This denotes that the Tobit regression model was appropriate in determining factors that affect technical efficiency in the study area.

Households size had a significant coefficient at 1% level and positively influenced technical efficiency. This implies that as the households size expands, technical efficiency among smallholder tomato farmers in the study area increases. This implies that farmers with large households are more technically efficient compared to farmers whose households are small. The plausible explanation is that big households strive to meet their subsistence thus endeavor to achieve higher outputs.

Further, since tomato production is labour intensive, large household afford labor endowments necessary to execute farm decisions. The results coincided with the studies of Ayerh (2015) and Ibitoye et al. (2015). On the contrary, the results negated the findings of Folorunso and Adenuga (2013).They argued that households provide family labor which is associated with inefficiency, thus its increase at farm level reduces technical efficiency.

Type of production system, presented as a dummy of

Table 6. Tobit regression results on factors affecting technical efficiency.

Variable	Coefficient	Std. error	t	p>/t/
Age (Years)	-0.000835	0.001360	-0.61	0.540
Gender (0= Male, 1= Female)	-0.023283	0.023651	-0.98	0.326
Household size (Number)	0.019196	0.005652	3.40	0.001***
Group membership (0=No, 1=Yes)	0.028206	0.021185	1.33	0.184
Experience (Years)	0.000163	0.025128	0.06	0.949
Education (Years)	-0.003479	0.003729	-0.93	0.351
Type of system (0=open field, 1= Greenhouse)	0.446175	0.047588	9.38	0.000***
Land tenure (0=without title, 1=with title)	0.006994	0.091979	0.33	0.740
Seed type (0=uncertified, 1= certified)	0.043299	0.022004	1.97	0.050**
Off farm income (Kenyan shilling)	1.45e-06	1.01e-06	1.44	0.150
Farm income (Kenyan shilling)	7.92e-08	1.43e-07	0.55	0.580
Land size (Hectares)	-0.15262	0.022399	-6.81	0.000***
Fertilizer used (Kilograms)	0.000754	0.000241	3.14	0.002***
Extension (0=No, 1=Yes)	0.041649	0.025128	1.66	0.098
Market distance (Kilometres)	-0.00291	0.002152	-1.35	0.178
Market information access (0=No,1=Yes)	0.078295	0.042304	1.85	0.065
Credit value (Kenyan shilling)	-2.98e-07	2.03e-07	-1.47	0.143
Constant	0.205409	0.091979	2.23	0.026

Log Likelihood = 88.22***; Likelihood Ratio (LR) = 250.27***.***Significance at 1%; ** Significance at 5%.
Source: Field survey data (2019).

open field and greenhouse systems had a positive and significant coefficient. This concurred with prior anticipations and inferred that by farmers embracing greenhouse systems, technical efficiency increased. The likely explanation is that greenhouse system enables prolonged cultivation hence increased tomato production. Further, adverse climatic conditions are largely controlled in the greenhouses which lead to increased yields. Additionally, greenhouse farmers used certified seed in production with majority of the farmers in this system engaging in mono-cropping, thus adequate time and resources are allocated with reduced nutrient competition. The results concurred with Wachira et al. (2014). Further, the results drew a discrepancy with the findings of Najjuma (2016) who reported that due to under exploitation of technologies, open field system was more efficient in tomato production compared to the greenhouses in Kiambu County.

Type of seed used in production was significant at 5% and positively related to technical efficiency. This suggests that by using certified seeds, technical efficiency among smallholder tomato farmers increased. This was facilitated by a sizeable proportion of the respondent apportioned credits in tomato production which enabled them to timely procure improved seeds. In addition, majority of the farmers had adequate information regarding the role of markets in the provisions of affordable inputs. These aspects allowed timely uptake of techniques that increase technical efficiency and efforts in research to generate improved planting materials. The results agreed with the findings of Tasila et al. (2019) and Mukhtar et al. (2018).However, the findings differed with those of Abdul and Isgin (2016) who found an inverse relation between improved seeds and technical efficiency.

The area under tomato cultivation portrayed a significant coefficient at 1% level and was inversely related to technical efficiency. This implies that farmers with small land sizes were more technically efficient than farmers with large plots of land. The reasonable justification is that, farmers with small land sizes give more attention to their farms since they depend on farming for occupation. This prompts them to be more committed in farming and ensure prudent resource combination thus reducing inefficiencies. This result coincided with a study by Dessale (2019) negated the findings of a study by Ibitoye et al. (2015) who found a positive relation between land under cultivation and technical efficiency. In addition, fertilizer quantity had a significant coefficient at 1% level and positively influenced technical efficiency. This positive effect symbolizes that, increased fertilizer application in the study area increased technical efficiency among smallholder tomato producers. This is possibly due the fact that the nutritional composition of fertilizers upgraded soil fertility an element that is of utmost importance in tomato production. The results agreed with the findings of Shettima et al. (2015).

Conclusion

A number of studies on technical efficiency have been conducted in developing countries. However, studies on technical efficiency of tomato farmers in Kirinyaga County have been limited. Therefore, this study sought to estimate technical efficiency and identify characteristics that affect technical efficiency among smallholder tomato farmers in Kirinyaga County of Kenya. The results shows that farmers inefficient with a mean technical efficiency of 39.55% with greenhouse farmers more technically efficient compared to open field farmers. The distribution of efficiency scores ranged from 0.0363to 0.9462 with majority of the households below 50% and 15.6% above 75% efficiency level. This shows a wide range in the technical efficiency scores and a chance to increase technical efficiency by more than 60% if all restrictions that make smallholder tomato farmers inefficient are improved.

Recommendations

Given that the findings of the study showed that technical inefficiencies existed in tomato production among smallholder farmers in Kirinyaga County, the study developed the following recommendations to guide farmers and policy makers in increasing tomato production and productivity at farm level:

i) The farmers should embrace use of certified seeds which are disease resistant and possess high yielding potential. This will reduce cost on pesticides application and ensure high yields. In addition, farmers should apply fertilizers at recommended levels of 1,186 kilograms per hectare since fertilizer application has been found to increase tomato output. This will ensure high yields and better net returns.

ii) The County Government of Kirinyaga should ensure enhanced accessibility of extension services to educate smallholder farmers on emerging innovations and technologies in tomato production. The Kenyan Government should develop policy interventions geared towards subsidizing the costs of establishing greenhouse structures and stabilizing the factor prices of key inputs such as fertilizers and certified seeds. This is because they were found to be important components towards increased technical efficiency levels in tomato production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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