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Stochastic Frontier Analysis of Production, Socio-economic and Institutional Factors Affecting Technical Efficiency of Cowpea Production in Chuka Sub-county, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Cowpea is one of the most important vegetable that ranks third among pulses and top five leafy vegetables consumed in Sub Saharan Africa. In Kenya cowpea contributes to cheap supply of nutritious food, revenue and food security. Despite its importance, cowpea production levels are a fraction of the potential due to low technical efficiency of production which affects the revenue levels and food security of the smallholder farmers. This study aimed to determine the production,

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socio-economic and institutional factors affecting the level of technical efficiency among smallholder cowpea farmers in Chuka Sub County, Tharaka Nithi County, Kenya. Using semi structured questionnaire in a population of 12905 households and using multistage sampling technique from 389 households cross-sectional data on production factors, socioeconomic and institutional characteristics was collected. Data collected was analyzed using descriptive statistics and stochastic frontier production function. The results indicated that production factors, socioeconomic and institutional characteristics significantly affected cowpea production. The mean technical efficiency index was 0.34. The stochastic frontier analysis revealed that production factor coefficients of labour (0.825), topdressing fertilizer (0.635), manure (0.325), agrochemicals (0.221) and land size (0.628) were all positive and statistically significant at 5% level. The inefficiency model revealed that the coefficients of socio-economic factors age (0.038), education (-0.156) and farming experience (-0.053), and the institutional factors, information sources/extension contact (-0.669) and access to digital financial services (1.527) were negative but statistically significant, except for age and access to digital service that were positive and significant. These variables were the determinants of technical efficiency in cowpea production. The results suggest that there is potential for cowpea farmers to increase production and net profits in the long run by efficient utilization of the existing mix of production inputs and technologies. Formulation of policies revolving around the significant variables, input supply, technology transfer and subsidies; extension services, information exchanges and market linkages are recommended to palliate technical inefficiency in cowpea production among farmers.

Keywords: Cowpea; inputs and technologies; production levels; technical efficiency.

1. INTRODUCTION

Cowpea global annual production is estimated to be above 6.5 million Metric Tonnes (MT), with an average yield of 0.45 t/ha [1]. In Africa, the average yield is around 0.6 t/ha [2], with dry savanna areas of Sub-Saharan Africa obtaining low yields of about 0.35 t/ha [3], against a potential of 1.5-2.5 t/ha [4]. In Kenya, most cowpea farmers produce less than the potential yield making them highly inefficient [5] and actual yield of improved varieties is approximated at 0.53 t/ha [6], against a potential of 1.6 t/ha [7]. Efforts to boost production have been made but the levels have not met the potential yield [8]. The low cowpea yield is due to high costs of inputs, labour, seed, fertilizer, chemicals, inadequate access to extension services and credit among others [5], climate-related challenges, inappropriate use of inputs [9] among other factors.

Efficient use of resources and technologies, together with appropriate production methods may enable the farmers to bridge the gap between the actual and potential yields. Effective use of technologies to increase production or utilizing the smallest amount of resources to attain a certain level of output lead to technical efficiency [10]. Technical efficiency entails the use of fewer inputs sustainably to produce the same level of output or higher at the same level of inputs [3]. Farmers can scale up cowpea production by using improved technologies like seeds, optimally managing farm resources like water, labour, or increasing the area under production. However, variability in crop production occurs due to discrepancies in the scales of operation, production technologies, prevailing environmental conditions and operating efficiency [11]. The contribution of cowpeas to food security and poverty alleviation is linked to its production levels. In Kenya, many institutions such as Kenya Agricultural and Livestock Research Organization and NGO's have conducted scientific research to improve cowpea production levels where one of the solutions provided was improved varieties that have high production potentials. However, a wide gap between the actual and potential yield of cowpeas do exist due to high levels of technical inefficiencies. Identifying the actual and sources of technical inefficiencies is the first step towards achieving high cowpea production.

Technical efficiency (TE) is a farmer's capacity to achieve the maximum output level with a specific amount of resources. According to Kamau [12] TE is a combination of numerous factors that are either within the producers' control such as farmers' management abilities and demographic attributes or outside the producers' control such as institutional and climatic factors. Proper input utilization can improve the technical efficiency level and eventually bridging the gap between actual and potential yield. Cowpeas production is dominated by small scale farmers and their characteristics can majorly affect the decisions they make in production impacting the technical efficiency level attained. Improvement in the technical efficiency of farmers is a crucial factor in enhancing productivity within existing technology and in turn, create employment opportunities in the agricultural sector, increase household income, and facilitate food security [13]. The low level of technical efficiency can be attributed to different factors including socio-economic, production, marketing, or institutional factors among others. Socio-economic factors determine a farmer's decision-making demeanor [14] while institutional factors such as group membership allow accessibility to agricultural education, technologies and operations [15]. Resource-use efficiency dictate production, economic performance of technologies and farmer productivity [16]. Tamirat [17] reported that technical inefficiency is affected by age, sex, education status, landholding, livestock holding, credit uses, the extension uses, off-farm activity, land ownerships, seed, and variety of coffee planted. In Chuka Sub County, there is little or no information on production, socio economic and institutional factors effect on technical efficiency of cowpea production. This study was thus aimed at determining technical efficiency in cowpea production using descriptive and stochastic frontier analysis among farmers in Chuka Sub County, Kenya. Earlier studies have not underscored the factors affecting productivity and their implications on sustainable cowpea production. Hence, the findings of this study will help farmers maximize on cowpea production using a mix of existing production inputs and technologies efficiently to bridge the gap between the actual and potential yields, for food security in Kenya.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Chuka Sub-County, Kenya which has 53,210 persons spread in five wards (Mariani, Karingani, Magumoni, Mugwe and Igambang'ombe) in a total area of 323 Km^2 [18]. The Sub-County is located at 0° 19' 59" South latitude, 37° 38' 45" East longitude and 1237 m above sea level and lies on the eastern slopes of Mount Kenya. The temperatures range between 14 – 30^{0}C, with bimodal pattern of rainfall with an annual mean of 1323 mm. The soils are deep, well-weathered humic nitisols, with average to high intrinsic fertility [19]. Farm sizes vary from 0.1 to 2 ha, and a mean of 1.2 ha per household. Farmers practice rain-fed, non-mechanized agriculture. The major economic activity is crop and livestock production.

2.2 Research Design and Sampling Procedure

This study used descriptive research design was employed and a target population of 12,905 households derived from Magumoni, Karingani and Mugwe wards. Multistage sampling procedure was used to select a sample of 389 respondents. The first stage involved purposive selection of Chuka Sub-County, due to the prevalence of smallholder cowpea farmers and because the Sub-County was also part of a bigger project that focused on cowpeas. The second stage involved the random selection of three wards (Karingani, Magumoni and Mugwe). All the wards had an equivalent possibility of being selected. Lastly, cowpea farmers were randomly selected from the three wards to form the required sample size for the study. To determine the sample size per ward the study applied Yamane's [20] formula at 95% confidence level as follows;

$$n = \frac{N}{1+N(e)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where;
n is the sample size, *N* is the population size and *e* is the acceptable error (0.05). The obtained total sample size was 388 households as follows:

$$388 = \frac{12905}{1 + 12905(0.05)^2}$$

However, the sample size used was 389 respondents in order to accommodate for the proportionate sampling in the three wards as indicated in Table 1.

Table 1. Sample frame and size

Wards	Sample frame	Sample size
Karingani	3,709	112
Magumoni	6,470	195
Mugwe	2,726	82
Total	12,905	389

Source: KNBS [16]

Table 2. Reliability analysis using cronbach alpha test

Variables	Value
Average interim covariance:	1.36
Number of items in the scale:	9
Scale reliability coefficient:	0.75

The sample size was proportionately disaggregated using the formula:

$$n_h = \left({}^{Nh}/_{N}\right) * n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

where;
n_h is the sample size for the h^{th} stratum, *Nh* is the population size of the h^{th} stratum, *N* is the entire population size and *n* is the entire sample size.

2.3 Data Collection

Data was collected using a semi-structured questionnaire with open and closed ended questions between April and May 2022. Piloting of the questionnaire was done in Mwanganthia ward in Meru County as the ward also produces cowpeas and has similar ecological conditions like Chuka Sub-County. Piloting was done on 39 farmers which according to Ramchandani [21] should be 10% of the sample size. The questionnaire content validity and reliability analysis were examined by agricultural economists, experts and extension officers to ascertain whether the questions, as well as the scores associated with the questions represented all relevant queries about the objectives. The reliability test on the questionnaire was assessed by the Cronbach's Alpha test [22] using STATA version 15 software. Cronbach alpha coefficient of $\alpha > 0.9$ is termed excellent, $\alpha > 0.8$ - good, $\alpha > 0.7$- acceptable, $\alpha = 0.6$ - questionable, $\alpha = 0.5$ - poor, and $\alpha < 0.5$ – unacceptable [23]. Cronbach alpha coefficient of $\alpha = 0.75$ was obtained (Table 2)

2.4 Data Analysis

Data collected was analyzed using STATA 15 software. Descriptive statistics was used to calculate measures of central tendency (mean, mode and median) and measures of dispersion (coefficient of variation, variance, standard deviation and range) on production, socio-economic and institutional factors. The stochastic frontier model under one step approach approximated technical efficiency on production factors and the technical inefficiency as a result of socio-economic and institutional factors using Maximum Likelihood Estimation (MLE) and the Cobb Douglas production function. The stochastic frontier function measured technical efficiency in cowpea production. The MLE of the parameters of the stochastic production frontier model were obtained using the STATA version 15 program. The Cobb-Douglas production function was fitted using stochastic production frontier one step approach.

2.4.1 Technical efficiency estimation model

The stochastic production function was written as:

$$Y_i = f(X_i; \beta) + \varepsilon_i \qquad \text{i =1, 2…, 389 farmer…….(3)}$$

Subscripts *i* refers to the total observation of i^{th} farmers,

where;
Y_i= Total output for the i^{th} (389) cowpea farmers
$f(X, \beta)$ = Cobb - Douglas production function
X_i= [X_1, X_2, X_3, X_4, X_5] = the vector of production factors (inputs) used in cowpea production
β_i= [β_1, β_2, β_3, β_4, β_5] = a vector of production factors coefficients to be estimated
ε_i = error term consists of two distinct elements v_i and u_i

$$\varepsilon_i = v_i - u_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

where,
Vi = Random error outside farmer's control
Ui = Technical inefficiency effects
NB: Stochastic production function splits the error term into two components to accommodate factors which are purely random and are out of the control of the farmer like random shocks (white noise) such as bad weather, measurement error, and omission of variables and the technical inefficiency of a farmer.

The Cobb-Douglas form of stochastic frontier production was stated as follows:

$$ln\, Y = \beta_0 + \sum \beta_i\, ln\, X_i + V_i - U_i \quad \ldots \ldots\ldots \text{(5)}$$

where $ln\, Y$ is specified as;

$InYj = \beta0 + \beta_1 InX_1 + \beta_2 InX_2 + \beta_3 InX_3 + \beta_4 InX_4 + \beta_5 InX_5 + \beta_6 InX_6 + \beta_7 InX_7 + \beta_8 InX_8 + Vi - Ui$

where;
In = The natural logarithm.
Y = Total output of cowpea (kg) produced by the i^{th} (389) farmers.

β_0 = Constant.
$\beta_1 - \beta_8$ = Parameters to be estimated.
X1-X8 = Production factors {seed (kg), labour (man-days), planting fertilizer (kg), top-dressing fertilizer (kg), foliar fertilizer (litres), manure (kg), agrochemicals (litres) and land size (acres)}.
Vi = Random noise (white noise) or variations owing to the random factors outside the control of the farmer.
U i = Inefficiency effect of the farmer.
V_i component contain arbitrary factors beyond the farmers control such as natural disasters, weather, and measurement errors.
U_i component represent technical inefficiency effects of the farmers.
A farmer's production is said to be technically efficient if u_i=1 and technical inefficiency endures if, u_i> 0 and u_i<1 irrespective of the value taken by u_i.

Technical efficiency was described as the ratio between the observed actual cowpea production of farmers to the potential and frontier cowpea production, considering the existing technology. The level of technical efficiency was represented as:

$$TE = {}^{Y_i}\!/_{Y^*} = \frac{\exp(\beta X_i + V_i - U_i)}{\exp(\beta X_i + V_i)} \ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

where;
TE= technical efficiency of the i^{th} farmer in cowpea production.
Y_i= the actual output of the i^{th} farmer in cowpea production.
Y^*= the frontier output of the i^{th} farmer in cowpea production.

2.4.2 Technical inefficiency estimation model

The technical inefficiency in production (output divergence from the frontier owing to socio-economic and institutional factors) expressed by the non-negative random variable 'u_i' was estimated using the equation:

$$u_i = Z_i \delta_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

where,
Z_i = [Z_1, Z_2, …Z_9] = vector of farmers' socio-economic and institutional factors,
δ_i = [δ_1,δ_2, … ,δ_9] = vector of coefficients to be approximated.

where *Ui* is specified as;

$$Ui = \delta_0 + \delta_1 \ln Z_1 + \delta_2 \ln Z_2 + \delta_3 \ln Z_3 + \delta_4 \ln Z_4 + \delta_5 \ln Z_5 + \delta_6 \ln Z_6 + \delta_7 \ln Z_7 + \delta_8 \ln Z_8 + \delta_9 \ln Z_9$$

where;
Ui = Technical inefficiency of the i^{th} farmer
δ_0 = Constant
$\delta_1 - \delta_{11}$ = Parameters to be estimated
Z1-Z9 = Socio-economic factors (age, household size, gender, education, farming experience) and institutional factors (group membership, access to credit services, information sources and extension services and access to digital financial services).

Technical inefficiency model expressed as a function of socioeconomic and institutional variables was:

$$u_i = \delta_0 + \delta_1 W_1 + \delta_2 W_2 + \delta_3 W_3 + \delta_4 W_4 + \delta_5 W_5 + \delta_6 W_6 + \delta_7 W_7 + \delta_8 R_1 + \delta_9 R_2 + \delta_{10} R_3 + \delta_{11} R_4 + e_i \quad \text{(8)}$$

where,
δ_0 = Intercept term.
δ_1 - δ_5 = socio-economic (age, household size, gender, education, farming experience) and δ_6 - δ_9 = institutional factors (group membership, access to credit services, information sources and extension services and access to digital financial services) parameters coefficients to be estimated.
$W_1 - W7_7$= farmer socio-economic factors (age, gender, education, household size and farming experience) and R_1 –R_4 = institutional factors (group membership, access to credit services, information sources and extension services and access to digital financial services).
U_I = Inefficiency model
ε_i = Error term.

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistical Analysis

The target respondents were achieved at 100%, but there was variation in the response rate in the selected wards due to unwillingness by some farmers to participate in the survey. The survey was considered successful as the number of the respondents surpassed the 60% recommended by Fincham [24].

3.1.1 Production factors

Production factors comprised of seed, land, labour, fertilizer and agrochemicals. In the study, 61.18% of the farmers used improved seed varieties, 36.25% local seed and 2.57% both improved and local seed (Table 3). Utilization of improved seed by majority of the farmers was attributed to their ability to yield high and tolerance to drought since part of the study area is semi-arid. Soe [25] reported higher level of average technical efficiency in improved varieties, compared to local ones. Most farmers (49.87%) obtained seed from cereal stores, 39.59% from other sources and 21.85% from neighbours. This indicated that majority of the farmers did not acquire seed from formal sources. Sisay [26] reported most farmers use home preserved seed. Inability of the formal seed system to supply high quality seed compel farmers to save seed for subsequent seasons and only obtain seed from off-farm sources when there is a binding need [27]. In the study, the mean amount of cowpea seed planted was 3.9 kg with a minimum of 0.25 kg and a maximum of 10 kg.

In the study, family and hired male labour were the most employed. The variations in labour types was attributed to differences in gender and the type of crops grown. Female farmers were more involved in household activities, and males in crop production and livestock rearing. Family labour was the most preferred since majority of the farmers practiced subsistence cowpea production and family labour was readily available and affordable. Labour is a significant input in the production of crops [28] and an increase in labour days can significantly raise yields [29].

Majority (63.5%) of cowpea farmers preferred organic manures compared to inorganic fertilizers. This could be due to availability and affordability of manure. Other types of fertilizers used included planting, top dressing, and foliar fertilizers. Agrochemicals enhance productivity of crops by eliminating pests and diseases that destroy and reduce the yield of crops. In the study area, most farmers used insecticides compared to fungicides. Lack of use of agrochemicals by some farmers in the study area was attributed to cost and subsistence production of cowpeas. Danquah [30]. Horezeanu [31] and Soe [25] reported significant improvement of production efficiency by using of pesticides. In the study area, the land allocated for cowpea production averaged 0.12 ha with a minimum of 0.004 ha and a maximum of 1.62 ha. This implied that cowpeas were produced in small quantities possibly for subsistence purposes. Land has been reported as a major factor that positively affect variations in yield of crops [32].

Table 3. Production factors influencing technical efficiency in cowpea production

Characteristic	Mean	Std Dev	Min	Max	Freq	Percent
Seed	3.90	2.17	0.25	10		
Improved seed					238	61.18
Local seed					141	36.25
Both Improved + Local Seed					10	2.57
Seed Source						
Cereal stores					194	49.87
Neighbor					85	21.85
Cooperative					8	2.06
Produce buyer					16	4.11
Service provider					3	0.77
Others					154	39.59
Labour Types						
Family male	142.49	114.30	20	300		
Family female	135.25	82.07	40	244		
Hired male	154.74	149.49	0	360		
Hired female	105.66	115.97	0	272		
Fertilizer						
Planting fertilizer	2.95	5.86	0	25	170	43.7
Topdressing fertilizer	2.52	4.67	0	15	162	41.65
Foliar fertilizer	0.82	1.75	0	10	106	27.25
Manure	6.44	15.20	0	100	247	63.5
Agrochemicals						
Fungicides					69	17.74
Insecticides					374	96.14

3.1.2 Socio-economic factors

In the study, socio economic factors included gender, age, household size, education and land tenure. The mean age of farmers was 52 years (Table 4), which indicated that most of the farmers were old. it has been reported that old farmers are more productive than the young ones [33] as old farmers are more experienced and decisive [34]. During the study it was observed that the average years of education among farmers was 10 years. In the study, most farmers attained primary education (23.65%), tertiary (14.91%) and none/preschool education (6.17%) [Table 4]. This implied that majority of farmer's had formal education. This imply that majority of the farmers could achieve high levels of technical efficiency. Abate [35], Ambetsa [36] and Okoror [37] reported that education level positively and significantly influences the level of technical efficiency. However, Dessale [38], reported negative but significant influence of education on production.

The study sought to understand the influence of gender on the level of technical efficiency. It was observed that majority (80.72%) of the respondents were male and 19.28% female (Table 4). The high number of male respondents in the study area was attributed to the patriarchal nature of the community and cowpea was considered a "woman's" crop which consigned its production into the hands of women who continued to sustain its production. This imply that female farmers were more technically efficient than male counterparts in cowpea production. Yegon [16] reported males being more inefficient in soybean production compared to females. However, Chimai [39] reported males having higher levels of efficiency than female due to additional roles of females of taking care for the basic needs of household members. During the study it was also observed that males were the main land owners and decision makers and they influenced the type of crop planted and land allocated to each crop. This could have affected the levels of technical efficiency either negatively or positively.

Table 4. Socio-economic factors affecting technical efficiency of cowpea farmers

Characteristic	Description	Mean	Std Dev	Min	Max	Freq	Percent
Household characteristics	Age	52.41	13.74	26	99		
	Education	10.17	4.40	0	18		
	Household size	3.87	1.56	1	12		
	Farming experience	16.01	13.27	1	60		
Gender	Female					75	19.28
	Male					314	80.72
Education level	College/university					58	14.91
	Primary education					92	23.65
	Secondary education					81	20.82
	Incomplete primary education					81	20.82
	Incomplete secondary education					53	13.62
	None/preschool					24	6.17
Land Tenure	Family					120	30.85
	Family + Self-owned					27	6.94
	Family + Rented in /lease					7	1.8
	Family + Shared in					1	0.26
	Self-owned					205	52.7
	Self-owned + Family + Rented in/lease					2	0.51
	Self-owned + Family + Rented out					1	0.26
	Self-owned + Rented in/lease					22	5.66
	Self-owned + Shared out					1	0.26
	Rented in/lease					3	0.76

Women were observed to participate in cultivating food and cash crops and Masterson [40] noted that women's land rights can lead to increased productivity and efficiency. In the study area, the average number of individuals in a household was 3.87 (Table 4). The size of the household affects the level of technical efficiency by determining the availability of labour. It has been reported that the higher the household size the more the supply of family labor and less the cost on hired labor for production purposes [3]. The size of the household can also negatively affect technical efficiency [37], due to an increase in land fragmentation among the household members [41].

Farming experience tend to increase farmers' capacity to do better, and become more technically efficient. In the study area, farming experience on average was 16 years (Table 4). It has been reported that older farmers expended more time on cowpea production which resulted to high technical efficiency [16]. In the study area, majority (52.7%) of the respondent's owned land and 30.85% utilized family land. Only 0.76% of the respondents had rented land (Table 4). This imply that most farmers could attain high level of technical efficiency due to tenure of security. Owoo [42]. indicated that land tenure security is a key factor that significantly influences productivity. Tenure status has been found to greatly affect the level of technical efficiency [15]. In the study area, 15.69% of the respondents had different ownership rights. Tenure security motivates the farmer to develop the land and use it optimally. Abate [35] indicated that a producer with many plots of land was more technically effective than one with fewer plots.

3.1.3 Institutional factors

In the study institutional factors included group membership, information sources/extension services, access to credit services and access to digital services. Institutions establish the price of economic transactions, they inspire growth through contracts and contract enforcement, as well as improve information accessibility, which reduce transaction costs, risk, and uncertainty. In the study, majority (53.73%) of the farmers belonged to a group, while 46.27% did not belong to any group (Table 5). The farmer groups were not necessarily on cowpea production. Farmers in a group may learn more cultivation techniques, have positive peer impact and learn excellent habits from their peers [43]. Farmer groups also boost the level of technical efficiency by providing improved access to agricultural education and they allow for the transfer of knowledge of best methods and operations amongst members [15].

During the study, it was observed that most (44.09%) of the respondents were in women groups, 18.65% SACCOs, 15.76% producer and marketing groups, and 12.54% farmer cooperatives. Other respondents were in input supply groups, youth groups and peoples with disability, welfare and family groups. This imply that most of the farmers belonged to at least one group. Ondiba [44], Nwafor [45], and Obiero [46] reported consistent results that a number of the respondents had membership to at least one group. During the study it was observed that the group functions were mainly savings and credit services (30.33%), produce marketing (27.51%) and farmer training (11.05%). Other group functions included input access and distribution, and transport services. However, savings and credit services was the most embraced by majority of groups, because it helped farmers improve their level of production through provision of credit services and also encouraged savings. Ochieng [47] reported group's functions such as marketing, supporting services for production, product improvements, financial and technical advice, input purchase and policy advocacy. Farmers in a group persuade one another to use the most up-to-date technology. Utilization of farming extension, researchers and fellow farmers is positively influenced by group participation [48]. Further, Eshete [49] indicated that the farmer-to-farmer extension method, enables farmers to learn from their neighbors and creating a wider access to improved seeds through seed loans and vouchers.

Farmer-related organizations and associations improve the likelihood that extension personnel will interact with members, lowering the service delivery and providers' cost thus improving the technical efficiency. In the study, only 20.05% of the respondents had access to information sources, while 79.95% did not have access to information sources. This imply that only very few farmers had access to information sources. Information sources included extension services, televisions, radio and internet. Low access to information sources was attributed to subsistence production of cowpeas by most farmers. This lowered their technical efficiency. Kelemu [50] reported high technical efficiency level for farmers that had radio than those who had none. Falola [51] found use of mobile telecommunication services to be positively and significantly connected to the producer's technical efficiency. Use of Information Communication Technology has been reported to be effective in improving TE in vegetable production due to special marketing conditions [52]. Jara-Rojas [53] reported farmer training having a significant and positive influence on technical efficiency. In the study area, agricultural officers (28.21%), agro input suppliers (12.82%), media (20.51%), and other farmers (21.79%) were the main sources of information (Table 5). Kansiime [54] reported neighbors and relatives, government extension officers, farmer field days and programs on TV and radio as sources of information. In the study area, information on pests and diseases, good agronomic practices, postharvest management, markets and prices, government initiatives, finance and weather forecasts was received by farmers from agricultural officers, agro input supplier agronomist, field days among others which helped in improving farmer's level of technical efficiency.

In the study, majority (56.04%) of the respondents relied on other farmers and local agro-vets for extension information (Table 5). This show that formal extension services are not readily available to farmers in the study area which could have led to low technical efficiency. These findings agree with those of Elahi [55] that most of the farmers acquired advisory services through informal methods such as co-farmers, friends and relatives and also through public and private institutions. It has been reported that extension services act as a catalyst for technology [56]. However, during the study it was observed that, majority (64.27%) of the respondents did not contact the extension officers, 20.05% contacted the extension officers once, 6.94% twice and 3.34% thrice. Lack of majority of the respondents to contact extension officers could have lowered the levels of technical efficiency. Joblaew [57] reported a great number of the producers contacting agricultural extension officers once or twice in a month.

Table 5. Institutional characteristics of cowpea farmers

Characteristic	Description	Frequency	Percent
Group membership	No	180	46.27
	Yes	209	53.73
Information Sources	Agricultural officers	22	28.21
	Other farmers	17	21.79
	Plant clinic	1	1.28
	Local Agro-vet	5	6.41
	Agronomist from agro input suppliers	10	12.82
	Buying company agronomists	1	1.28
	Spray service providers	1	1.28
	Field day	3	3.85
	Others (Media)	16	20.51
	Barazas / social events	2	2.56
Extension services	Other farmers	218	56.04
	Agricultural officer	113	29.05
	Plant clinic	1	0.26
	Local agro-vet	218	56.04
	Agro input supplier agronomist	23	5.91
	Buying company agronomists	5	1.29
	Spray service providers	3	0.77
	Field day	16	4.11
	Others	18	4.63
	Brochures/ newspapers	2	0.51
	Public Gatherings	5	1.29
	e-services	2	0.51
Access to credit services	No	361	92.8
	Yes	28	7.2
Access to Digital Financial Services	Yes	74	19.02
	No	315	80.98

Access to credit is a significant source of financing for farmers as it allows timely purchase of farm resources enhancing productivity [36]. Although access to credit help farmers boost their technical efficiency during the study only 7.2% of the respondents accessed credit services, while 92.8% did not (Table 5). The low credit access could have been attributed to subsistence production and low incomes of farmers. Other reasons included high interest rates (27.7%), the fear of unfriendly loan recovery process (21.33%), delay to process or disburse loans when needed (18.84%), fear of harsh defaulting penalties (17.45%), demand of title deeds as collateral as some of the farmers lacked title deeds. it has been reported that lack of guarantee, high interest rates and lengthy procedures [55, 58]), fear of punishments from the incapacity to repay back the credit within the stipulated time [59] as the reasons why most of the farmers did not access credit. In the study area, micro finance institutions, SACCOs, formal banks, community groups and mobile money were key sources of credit showing that farmers access credit from both formal and informal institutions. Ume [60] reported that farmers get credit from microfinance institutions, commercial banks and informal sources.

Digital financial services like online banking, digital credit via mobile phone for the unbanked, mobile phone banking, M-Pesa services and Whatsapp fundraising may help farmer's access funds where banking services are lacking. In the study area, 19.02% of the respondents accessed digital financial services, while 80.98% did not access (Table 5). This imply that majority of the farmers did not benefit from the digital financial services which could have lowered the level of technical efficiency. Access to digital financial services can contribute to raising the level of technical efficiency. Digital financial services improve farmer's efficiency since they can access money easily to purchase the required inputs. Digital financial services have also proven to be time saving because the queues at the physical financial institutions are avoided [61]. They also increase the scale of transformation by connecting the farmers to opportunities and benefits [62].

3.2 Stochastic Frontier Model Analysis

3.2.1 Technical efficiency (TE) distribution indices

Technical efficiency indices among cowpea farmers derived from the analysis of stochastic production function ranged from 0.02 to 0.98. The indices were all less than 1, which indicated that cowpea production was below the efficiency frontier level. The index for majority (27.76%) of the farmers was between 0.21 - 0.3, with only 2.57% having an index above 0.80 (Table 6). In the study, mean TE was estimated at 0.34 with a minimum of 0.02 and a maximum of 0.98. This implied that on average, cowpea farmers were 34% technically efficient and the scope for increasing TE was 66% when using a combination of available inputs and technologies. Alternatively, the farmers could use their resources efficiently and also cut on the production factors by 66% and maintain the same level of production. Onuwa [3] obtained a mean TE of 59% showing 41% room for increasing TE in cowpea production. The low mean TE (34%) in the study indicated that most farmers were technically inefficient in cowpea production. This suggests a need for more effort in improving efficiency of cowpea farmers in the study area. The differential in TE between the most and least efficient farmer in the study was 96%, indicating a very wide gap. To reduce the gap, require application of strategies such as farmer training, efficient use of resources, technologies and practices that increase cowpea productivity. Oaya [63] obtained a differential of 54% in sole cowpea farmers. If the average farmer in the study area was to achieve the TE of the most efficient, the farmer should attain a 65% cost savings (1 - [34/98]) and the least efficient farmer a 97.9% cost saving (1 - [2/98]) [34]. Studies by Oseni [34] reported a 22% cost savings for an average cowpea farmer and 84% for the technically inefficient farmer.

3.2.2 Technical efficiency analysis

The maximum likelihood estimates of variables of the stochastic frontier production function, and inefficiency model analysis are shown in Table 7. The findings show that most of the variable coefficients have the expected positive sign, except for planting fertilizer which has a negative coefficient. A positive sign indicate that the variable has the effect of increasing technical efficiency, while a negative sign show it has the effect of decreasing technical efficiency. The variable coefficients of labour, topdressing fertilizer, manure, agrochemicals and land size were significant at 5% level. Oaya [63] stated that more output would be expected by using additional quantities of these inputs ceteris paribus. This also show the relative importance of these variables in the production of cowpeas.

Table 1. Distribution of technical efficiency indices for cowpea farmers

Technical efficiency indices	Frequency	Percentage
0.01-0.10	13	3.34
0.11-0.20	74	19.02
0.21-0.30	108	27.76
0.31-0.40	90	23.14
0.41-0.50	39	10.03
0.51-0.60	32	8.23
0.61-0.70	12	3.08
0.71-0.80	11	2.83
0.81-0.90	4	1.03
0.91-1.00	6	1.54
Total observations	389	100
Mean Technical Efficiency	0.34	
Minimum Technical Efficiency	0.02	
Maximum Technical Efficiency	0.98	

Table 7. Maximum likelihood estimates of variables of the stochastic frontier production function for cowpea

Variable	Parameter	Coefficient.	Std. Error.	P>z
Production Function				
Constant	β_0	-0.734	0.602	0.223
Planting seed (X_1)	β1	0.017	0.088	0.847
Labour (X_2)	β_2	0.825**	0.112	0.000
Planting fertilizer (X_3)	β_3	-0.047	0.067	0.483
Top dressing fertilizer (X_4)	β_4	0.635**	0.073	0.000
Foliar fertilizer (X_5)	β_5	0.185	0.107	0.084
Manure (X_6)	β_6	0.325**	0.059	0.000
Agrochemicals (X_7)	β_7	0.221**	0.036	0.000
Land size (X_8)	β_8	0.628**	0.070	0.000
Inefficiency model				
Constant	δ_0	0.241	1.331	0.856
Age (Z_1)	δ_1	0.038**	0.019	0.049
Gender (Z_2)	δ_2	-0.134	0.565	0.812
Education (Z_3)	δ_3	-0.156**	0.066	0.018
Household size (Z_4)	δ_4	-0.246	0.154	0.110
Farming experience (Z_5)	δ_5	-0.053**	0.025	0.032
Group membership (Z_6)	δ_6	-0.612	0.522	0.241
Access to credit services (Z_7)	δ_7	-1.792	1.328	0.177
Information sources/extension services (Z_8)	δ_8	-0.669**	0.296	0.024
Access to digital financial services (Z_9)	δ_9	1.527**	0.594	0.010
Total observations		389		
Log likelihood		-573.715		
Prob > chi2		0.000		

*** Represents level of significance at 5%*

During the study, labour was measured in terms of man days. The coefficient of labour (0.825) was positive and statistically significant at 5%, which implied that an increase in labour by 1% would result in an increase in cowpea output by 0.825%. These findings are agreement with Mukhtar [64] and Abunyuwah [65] that an increase in labour results to an increase in production. Onuwa [3] posited that farmers interested with farm efficiency should maximize their output per unit of resource used, especially the amount of farm labour employed. In the study area, labour was required in carrying out planting, weeding, insecticide application and harvesting. The coefficient of topdressing fertilizer (0.635) was positive and statistically significant at 5%, this implied a 1% increase of topdressing fertilizer would result in 0.635% increase in cowpea production. Based on the findings of this study, fertilizer significantly and positively affects technical efficiency. Modu [66] reported positive influence of fertilizer in cowpea production. Fertilizer increases and improves agricultural output per hectare [63].

The coefficient of manure (0.635) was positive and statistically significant at 5%, implying a 1% increase in manure application would result in 0.325% increase in cowpea production. Mukhtar [64] reported a positive coefficient of manure and increased pearl millet output. Manure application could have assisted in improving the soil structure, prevention of nutrient leaching through slow release and water retention. The lower areas of the study area are semi-arid with very high temperatures and evaporation of water. The coefficient of agrochemicals (0.635) was positive and statistically significant at 5%, implying a 1% increase in the use of agrochemicals would result in 0.221% increase in cowpea production. These results affirm findings by Abubakar [67] and Onuwa [3] who reported a 1% increase in the use of agrochemicals increasing maize and cowpea output, respectively. Agrochemicals help in reducing fatigue and drudgery affiliated with weeding, hence enhance productivity and also enable farmers to cultivate large hectares of land which in turn increase the output [3]. The coefficient of land size (0.628) was positive and statistically significant at 5%, which indicated that a 1% increase in the size of land would result in 0.628% increase in cowpea production hence showing the relative importance of land in crop production. Joseph [68] found no statistical evidence to show that the size of land affects the technical efficiency of farmers.

During the study, the coefficient of seed was positive but statistically insignificant at 5%, which may imply that use of additional seed cannot lead to a further increase in cowpea production. This can be attributed to the use of local saved seed or seed from local market, or seed borrowed from neighbors of low quality by farmers. Local seed provides low cost, ease of accessibility, often with little or no cash, where no seed companies operate [69]. Farm seed saving practice led to recycling of seed that have been exhausted through generations [70], which result to low yields [71]. A weak seed supply system in the study area could have contributed to this phenomenon. Planting fertilizer coefficient was negative and statistically insignificant at 5%, which implied application of additional planting fertilizer could result to a decrease in cowpea production. This could be due to low absorption of planting fertilizer by young plants that have not yet developed proper root system. The coefficient for foliar fertilizer was positive but statistically insignificant at 5%, which implied that an additional application of foliar fertilizer cannot result to further increase in cowpea production. This could be due to excessive vegetative growth necessitated by foliar fertilizer at the expense of reproduction development.

3.2.3 Technical inefficiency analysis

In the study, the inefficiency model variables were used to explain the determinants of inefficiency in cowpea production among the farmers. The results for all the variables except in age and access to digital financial services had the expected negative sign. The gender, household size, group membership and access to credit coefficients were not significant at 5% level (Table 7). The sign of the variable explains the level of technical efficiency. A negative sign indicate that the variable has the effect of reducing technical inefficiency, while a positive sign show it has the effect of increasing inefficiency [3]. The inefficiency model variables in the study were related to farmers' specific socio-economic characteristics (age, education, farming experience, household size and land tenure), and institutional characteristics (group membership, access to information sources and extension services, access to credit, and access to digital financial services). The coefficient of age (0.038) was positive and statistically significant at 5%, which implied that older farmers were more technically inefficient in cowpea production. This suggested that old age enhances technical inefficiency of farmers. As age of farmers rises, energy and interest for farming activities decline due to fatigue slowing down production. Elderly farmers may also be risk-averse and sluggish to adopt new ideas and technologies. However, these finding contradict those of Oseni [34] who reported a negative age coefficient which was statistically significant at 10%, which implied that older farmers tend to be more efficient in production as the experience increases with age and resource endowment.

The coefficient of education (-0.156) was negative but statistically significant at 5%, which implied that educated farmers were more technically efficient in cowpea production. This suggest that the literacy level of cowpea farmers affects their technical inefficiency. Farmers with high level of education tend to be more receptive in adopting improved farming technology and hence increase their output level [3]. These findings agree with those of Ebukiba [72], Dessale [38] and Khanal [73] who reported that high education level of farmers decrease the technical inefficiency and increase the efficiency that eventually results to an increase in production. Hence, cowpea farmers who are more educated are more likely to be efficient compared to those who are less educated. Education exposes and entices farmers to adopt new technologies, new farming practices, and also gives farmers ability to utilize resources more efficiently. The coefficient of farming experience (-0.053) was negative but statistically significant at 5% level. This implied that farmers with more years of farming experience were more efficient in cowpea production. Farmers with more years of experience tend to become more efficient through 'learning-by-doing' [3]. This corroborates the findings of Ebukiba [72] and Ebukiba [74] who also reported similar results. Farming experience has been reported to be positively and significantly related to technical efficiency [8,75]. One-year unit increase in farming experience diminishes technical inefficiency and rises technical efficiency [74].

The coefficient of information sources/extension services (-0.669) was negative but statistically significant at 5% level, implying that technical efficiency increased among farmers with agriculture information sources/extension contact with the extension agents. It is possible that information sources/extension visits to farmers affect their technical efficiency, because extension contact has significant relationship with cowpea output. Inadequate information/extension contact with extension agents leads to production inefficiency. Farmers that have more information sources/extension contact tend to be more exposed to and informed about improved production methods and technologies which in turn increase their efficiency in farming and hence increase their output level [3]. Increasing contacts with extension officers decreases technical inefficiency, possibly because easy access to extension contact discloses the farmers to modern agricultural practices that guarantee higher yields and productivity. The coefficient of access to digital financial services (1.527) was positive and statistically significant at 5% level, implying that access to digital financial services increased technical inefficiency among farmers. This suggest that the more a farmer accessed digital financial services the less technical efficient he or she was compared to a farmer who did not access digital financial services. This may be because the farmers could have prioritized the digital finances for other purposes rather than cowpea production. Another explanation for this inefficiency could be due to limited mobile telephone services in the study area due to few markets or shopping centres in the farming rural area set up. This study finding are inconsistent with those of Birhanu [76] who reported that mobile telephone ownership was an avenue to accessing digital financial services and significantly determines technical efficiency. The households owning a mobile phone were more efficient than those which did not own.

The coefficient of gender (-0.134), household size (-0.246), group membership (-0.612) and access to credit services (-1.792) were all negative but statistically insignificant at 5% level. This implies the four variables did not affect technical inefficiency in cowpea production. Hence, the findings did not conform to a priori expectation of negative and significant effects on technical inefficiency. Other studies gave varied results like Joseph [68] who found no statistical evidence to indicate gender affects the efficiency of farmers. Oseni [34] reported household size had positive and insignificant effect of technical inefficiency. Getahun [15] reported group membership having positive and significant impact on technical efficiency. Ngango [77] found negative and significant influence of credit access on technical efficiency. Ambetsa [36] and Kamau [78] reported access to credit having a significant and positive effect on technical efficiency.

4. CONCLUSION AND RECOMMENDATIONS

This study analyzed the technical efficiency of cowpea production in Chuka Sub County, Tharaka Nithi County, Kenya. The results of the study revealed that production, socioeconomic and institutional factors affected farmer's level of cowpea production in the study area. The study also revealed that the efficiency index of the farmers was less than one (1) (i.e., <100%) implying that all the farmers were producing below maximum efficiency frontier and were unable to obtain optimal production from their mix of production inputs. The distribution of technical efficiency indices among farmers ranged between 2% to 98% with a mean of 34%. This implied that the cowpea farmers were producing below average. This suggested there is a scope to increase the technical efficiency of the farmers by 66% in the long-run through efficient utilization of existing mix of production inputs and technology. Stochastic frontier analysis revealed that some coefficients of the variables included in the model significantly affected the level of technical efficiency in cowpea production. The relevant production factors that influenced technical efficiency were labour, top-dressing fertilizer, manure, agrochemicals and land size. Socioeconomic and institutional factors were age, education, farming experience, information sources and extension services and access to digital financial services. Based on the findings of this study, Technical efficiency was significantly influenced by labour, top dressing fertilizer, manure, agrochemicals, land, age, education, farming experience, information sources and extension services and access to digital financial services. There is need to formulate policies targeting these variables to help promote cowpea production and productivity. There is need to enhance the efficiency of cowpea farmers through capacity building and improving agricultural information exchanges through extension services and information dissemination of new innovations, agronomic practices, technology, pest and disease management, climate information etc., to boost farm productivity, there is need for the cost of agricultural inputs especially pesticides, herbicides, improve seed and fertilizer to be subsidized by the county governments to promote more production of crops to enhance food security. Further studies can be conducted on the effect of digital information sources in enhancing cowpea production technical efficiency amongst smallholder farmers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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