Determinants of Productivity and Efficiency of *Teff* Production in Southwestern Ethiopia

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Abstract

Background: Cereal productivity and production efficiency, including that of teff, which is one of Ethiopia's main food crops, are well below the global average. The problem constrains the country's concerted efforts to attain food and nutrition security. Therefore, raising the productivity and production efficiency of the crop is a prerequisite to meet household and national food security in the country.

Objective: A study was conducted to measure the productivity and production efficiency of teff, and identify factors that determine them in southwestern Ethiopia.

Materials and Methods: A cross-sectional data were collected from 323 teff producers during the 2018/19 production season using a semi-structured questionnaire from three randomly selected districts. A stochastic Cobb Douglas stochastic production function was used to estimate the frontier production and efficiency levels. Ordinary Least Square (OLS) was used to determine factors that influence technical, allocative, and economic inefficiencies.

Results: The results of the stochastic Cobb-Douglas production function showed that the use of seed, fertilizer, and labor significantly influenced productivity of teff. The estimated mean values of technical, allocative and economic efficiencies were 69%, 60% and 56%, respectively. The Ordinary Least Square results revealed that levels of education, age, fertility of the soil and frequency of extension contact had a significant negative effect on technical inefficiency. Similarly, levels of education, participation in off/non-farm activities and soil fertility had a negative effect on both allocative and economic inefficiencies.

Conclusion: It is concluded that teff producing farmers in the study area have disparities in their technical, allocative, and economic efficiencies, implying that there is room to increase teff productivity by reducing production inefficiencies. The government's policies and strategies should, therefore, be directed towards the expansion of education, strengthening the existing extension services, establishing and/or strengthening the existing off/non-farm activities and improving land management practices.

Keywords: Cobb-Douglas production function; Ordinary Least Square; Teff

1. Introduction

Smallholder agriculture dominates a large proportion of the population in developing countries such as Ethiopia, and poor people reside in rural areas. In the Ethiopian economy, the agricultural sector is the most important sector that is given the highest priority in the country's overall economic policy. Agriculture serves as a source of income and employment. It accounts for over 35.8% of national GDP and almost 90% of exports and 72.7% of employment (CIA, 2018). The output, productivity and efficiency status of the sector is; however, well below the world average. For example, in cereal production, which is the largest in the sector, the global average cereal yield is 3.574 t ha^{-1}, while Ethiopia's average cereal yield is 2.538 t ha^{-1} (World Bank, 2020). Due to inefficient management of inputs, limited use of modern agricultural technologies, traditional farming techniques, poor complementary services such as extension, credit, marketing, and infrastructure, poor and biased agricultural policies in developing countries (FAO and WFP, 2012; ATA, 2016).

Cereals, Ethiopia's main food crops, account for 95% of agricultural production and 87.48% of grain production in terms of area covered and production volume (CSA, 2018). Of these, *teff* (*Eragrostis tef*) is an annual warm-season cereal crop belonging to the Poaceae grass family that is endemic to Ethiopia and has been widely grown for centuries (Yifru Teklu and Hailu Tefera, 2005). It is the most significant economic crop grown in Ethiopia by 43% of smallholder farmers,

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covering nearly 32% of the total annual acreage and 21% of the total output of grain (Birrara, 2017). Moreover, *teff* is the second largest cash crop next to coffee, producing roughly USD 500 million a year for local farmers in Ethiopia (Bart Minten *et al*., 2013). Nutritionally, 100 g *teff* grains contain 357 kcal, close to those of wheat and rice (Cheng *et al*., 2017). Since the crop has a high protein and amino acid contents and is gluten-free and low in the glycemic index, which makes it suitable for people with type two diabetes, it has stimulated nutritionists and food scientists' global research interest (Provost and Jobson, 2014; FAO, 2015).

According to the report of the Central Statistical Agency, *teff* ranked the first covering about 29.46% of the total land allocated for cereal crops in the Oromia region during the 2018/2019 cropping year. During the production year, the total area covered by *teff* was 1.43 million hectares with a production of 2.56 million tones and an average yield of 1.79 t ha^{-1} from 2.57 million holders (CSA, 2019). For 2016/17, the total production of *teff* in the Jimma zone was 0.26 million tons produced by 0.55 million private peasant holders on a total of 0.18 million hectare *teff* cultivation. The average yield was reported as 1.51 t ha^{-1} (CSA, 2017).

In Ethiopia, the cereal crops sector in general and production of *teff* in particular are facing serious challenges. Lack of efficient production system, climatic factors, shortage of improved varieties and production inputs, lack proper management practices, poor management of soil fertility as well as weed and pest management are the most common problems (Asmiro Abeje *et al.,* 2019; Ademe Mihiretu and Lijalem Abebaw, 2020). In addition, due to frequent moisture stress at flowering and grain filling stages, the erratic and uneven distribution of rainfall becomes a risk of producing late-maturing local *teff* varieties, resulting in either lower yield or total crop failure (Setotaw Ferede, 2011). Study by Crymes (2015) revealed that 25–30% of *teff* yield is lost before and after harvesting. In the country, the average productivity of *teff* is 1.75 t ha^{-1} at the level of smallholder farmers, which is very low (CSA, 2019). However, the yield of *teff* can be increased to 2.6 t ha^{-1} by researching and applying improved agricultural technologies (Ademe Mihiretu and Lijalem Abebaw, 2020).

Due to population growth, urbanization, rising income level of citizens as well as its numerous health benefits and specific nutritional content, the demand for *teff* is rising constantly in the country and globally. Therefore, the supply of the *teff* grain has fallen short of the demand. As a result, the price of *teff* is continually increasing (Barretto *et al*., 2021). In order to enhance the *teff* production efficiency of farmers, the current resource allocation levels should be known since low productivity has resulted from the inability of farmers to make full use of available technology, thereby contributing to production inefficiencies (Kumar *et al*., 2018). Although several empirical studies have been conducted to measure the production efficiency of *teff* and other crops in Ethiopia (Moges Dessale, 2019; Agerie Nega *et al*., 2019; Anbes Tesfaye, 2020; Zinabu Tesfaw *et al*., 2021), none of them measured allocative and economic efficiency, but only technical efficiency. No other similar studies have been carried out on the productivity and production efficiency of *teff* in the study area. However, studies by Abate Bekele *et al.* (2019) and Mizan Tesfay *et al.* (2017) showed there is a substantial variability in productivity of *teff* among farmers. For example, *teff* productivity at the national level is 1.88 t ha^{-1}, (CSA, 2021) with the highest productivity of 1.93 t ha^{-1} recorded in the Oromia and Amhara regions, while the lowest productivity of 1.52 t ha^{-1} was recorded in the Benshangul Gumuz region of Ethiopia.

In recent years, the concepts of productivity and efficiency have received a great deal of attention in many countries in a way to measures overall production performance. However, there is a slight difference between them. Generally, productivity growth can be achieved through either technological advancement or efficiency improvement. Efficiency measurement allows for the quantification and comparison of each farmer's performance, as well as the identification of factors that contribute to inefficiencies and performance differences. Identification of factors affecting inefficiency can help stakeholders to improve productivity by identifying controllable and uncontrollable factors that need to be considered when designing interventions to increasing production (Bravo-Urea and Pithier, 1997).

In this regard, improving total production and productivity is not a choice for most developing countries, but rather a priority and the first consideration in their policies. Theoretically, there are two potential options for increasing overall production and productivity. The first option is through improved use of inputs and/or technology enhancement at some input stages. The other option is to develop producers' efficiency. Efficiency measurement studies are important for countries like Ethiopia, where resources are limited and inventing or implementing better technologies is low (Dorosh and Rashid, 2013; Solomon Bizuayehu, 2014). Efficiency estimation would therefore provide information on whether to continue the existing technology by improving the efficiency of less efficient farmers or to encourage adoption of improved technologies to increase the productivity of *teff*. Hence, this study was intended to answer the following three key research questions: (1) What is the productivity of *teff*? (2) Are farmers technically, allocatively, and economically efficient in the production of *teff*? and (3) What are the factors influencing the producers' technical, allocative and economic efficiency levels in the study area? Therefore, the objectives of the study were to measure the productivity and technical, allocative and economic efficiencies of *teff* production, and to identify sources of the crop's production inefficiencies in southwest Ethiopia.

2. Methods and Materials

2.1. Description of the Study Area

The study was carried out in Jimma Zone, southwestern Ethiopia, which is located at the distance of 335 km away from Addis Ababa. The Zone generally lies between 900 and 3334 meters above sea level and is situated between 7°15'N and 8°45'S latitude and 36° 00'E and 37°40'E longitude. The study was characterized by mean annual rainfall range of 1,200 mm to 2,500 mm (JZARDO, 2008). The study site is one of Ethiopia's major cereal production areas; and t*eff* is the second important crop grown next to maize in the Zone in terms of area coverage and volume of production (CSA, 2021).

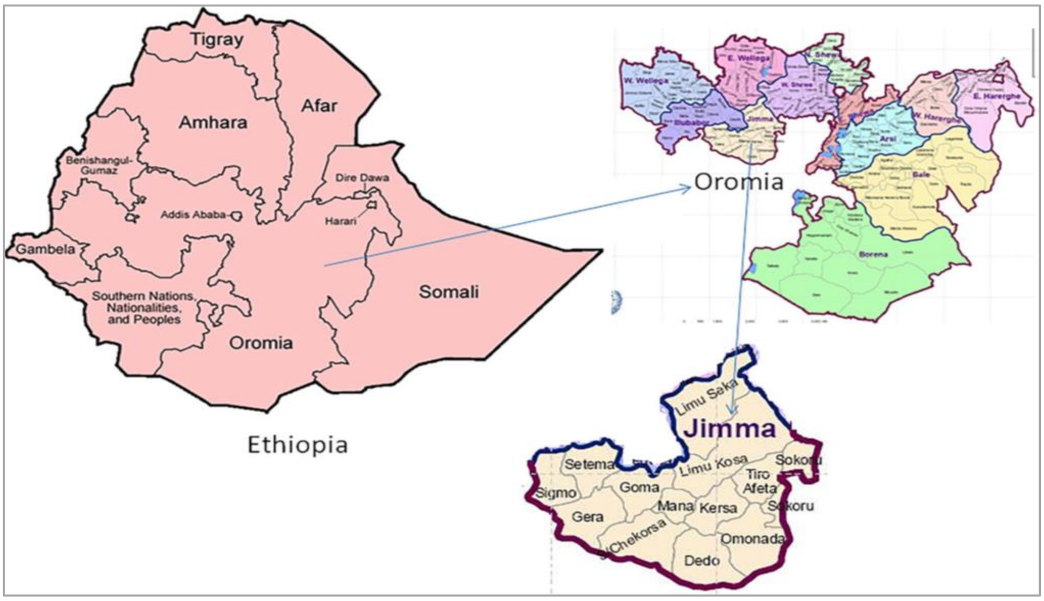

Figure 1. Map of the study area.

2.2. Data Type, Source, and Methods of Data Collection

For this study, both primary and secondary data were used. The primary data were gathered from farmers through an interview with the help of the pre-tested semi-structured questionnaire for 2018/2019 cropping season. The questionnaire used was intended to address questions relating to socio-economic variables, the quantity of inputs, and outputs along with their respective prices, and other factors that may affect producers' efficiency. The data were collected from March 2020 to May 2020 through trained enumerators and researchers. Secondary data were collected from published and organizational sources. To complement the formal method, focus group discussions and key informant interviews were conducted with farmers, development agents, concerned agricultural experts and administration officers.

2.3. Sampling Technique and Sample Size

Purposive and two-stage sampling techniques were employed in order to select sample households. In the first stage, out of the 22 Jimma Zone districts, three districts, namely, Omo Nada, Saka Chokorsa and Kersa, were randomly selected based on the extent of production of *teff*. Secondly, in collaboration with districts agricultural and development office experts, a list of *teff* producing farmers was prepared in the 2018/19 production year in the selected *kebele* (= *the smallest administrative unit in the country*). Finally, a total of 323 sample farmers were randomly selected. Since all districts in the Zone produce *teff* in varying amounts and on varying land sizes, the sample size was determined using Cochran's (1977) formula:

$$n = \frac{Z^2pq}{e^2} \quad (1)$$

Where, n is the sample size; Z is the confidence level (Z = 1.96); p is the proportion of population containing major interest (p = 0.7 and q = 1 − p); and e is allowable error (e = 0.05).

2.4. Methods of Data Analysis and Specification of Analytical Models

Both descriptive statistics and econometric models were used to analyze the data. Descriptive statistics such as means, frequencies, and percentages were used to examine the socio-economic, institutional, and demographic characteristics of the sampled *teff*-producing farmers.

2.4.1. Analytical framework

The production function, which postulates a well-defined relationship between production and factor inputs, is the cornerstone of the theory. Productivity can be improved/increased in two ways. First, by technological change using improved production practices such as ploughs, fertilizers, pesticides, improved seeds, etc., pushing up the production frontier; and second, if the farmer has additional skills to use existing production techniques, productivity will increase (Gezahegn Ayele *et al.,* 2006). Productivity is the value of output to that of input employed in agricultural production, while the relative performance of transforming inputs into outputs is considered efficiency (Coelli *et al*., 2005). Generally, a production function is defined by the following equation:

$$Y = f(x_1,\ x_2\ , x_3 \ldots \ldots, x_n) \quad (2)$$

Where, Y is output and x_i; i = 1, 2…; and n is the levels of inputs that determine the level of output. But there are other non-observable variable inputs and practice that may affect the level of production. These random effects are represented by v_i. Adding the term v_i to equation (2) modifies it to probabilistic expression (Palanisami *et al.* 2002):

$$Y = f(x_1,\ x_2\ , x_3 \ldots \ldots, x_n) + v_i \quad (3)$$

In addition, farmers may be inefficient in production, reducing his/her potential output in addition to random shocks (v_i). The stochastic frontier analysis of production presumes that this inefficiency is specified as follows:

$$Y = f(x_1,\ x_2\ , x_3 \ldots \ldots, x_n) + v_i - \mu_i \quad (4)$$

Where, μ_i the non-negative random inefficiency variables.

2.4.2. Specification of econometric model

Farrell's paper (1957) led to the development of various approaches to productivity and efficiency analysis (Abdul-Salam and Phimister, 2017). Stochastic Frontier Analysis (SFA) and Data Envelope Analysis (DEA) are the two popular techniques used in literature. According to Toma *et al.* (2017), highly correlated results are achieved by both methods. The stochastic frontier technique proposed by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977), later updated by Jandrow *et al.* (1982) has the potential to misspecify functional form, leading to biased inefficiency estimates, which is considered to be a weakness compared to the non-parametric DEA approaches. The DEA technique first introduced by Farell (1957) and further improved by Charnes *et al.* (1978), employs a non-parametric approach to efficiency estimation. The main criticism of this approach is that it ignores the effects of stochastic error and ascribes all deviation from the frontier to inefficiency (Kopp and Smith 1980; Thiam *et al.,* 2001; Murillo-Zamorano, 2004). In addition, the inability to use the term disturbance makes it impossible to conduct statistical studies.

In Ethiopia, conventional rain-fed agricultural production dominates because of which the sector is subject to shocks such as weather, climate change, and other uncontrollable factors. In addition, data on farm activity is not adequately recorded because most farmers are uneducated, leading to errors in measurement (Coelli and Battese, 1996). Taking into account these inefficiency characteristics, this study therefore adopted the SFA in estimating the efficiency of *teff* farmers in southwestern Ethiopia since it distinguishes the deviation from the border into the two components of inefficiency and the idiosyncratic error. The symmetric component captures the random effects outside of the control, including statistical noises exogenous to the farmers, particularly those based on cross-sectional household survey data. The general stochastic frontier model in which an additional random error, vi, is added to the non-negative random variable, μ_i, is specified as follows:

$$ln(y) = x_i\beta + v_i - \mu_i\ , \qquad i = 1, 2, \ldots N \quad (5)$$

Various functional forms have been developed to measure the physical relationship between inputs and output. The most common functional forms are Cobb–Douglas and transcendental logarithmic (translog) function, each having their merits and demerits. Both models largely dominate the applications literature in stochastic frontier and econometric inefficiency estimation (Coelli *et al.,* 2005). Following log likelihood test result, Cobb-Douglas functional form was selected in this study (see Equation 11).

2.4.3. Estimation approach

Conventionally, two estimation procedures are used to estimate the inefficiency sources of farmers: one stage estimation procedure and two stage estimation technique. In one-stage estimation, inefficiency effects are specified as an explicit function of certain factors unique to the firm, and all the parameters are calculated in one-step using the maximum likelihood method. The second approach is the two-stage estimation process in which first the stochastic output function is calculated, from which efficiency scores are extracted, then in the second stage the derived efficiency scores are regressed on explanatory variables using ordinary least square (OLS) method or Tobit regression. The Tobit model is best suited when the nature of the dependent variable (efficiency scores) that takes values between 0 and 1 and generates consistent estimates for unknown vector parameters (Maddala, 1999); otherwise, OLS is appropriate. Unfortunately, in the model output, there were no 0 and 1 efficiency scores therefore this study employed two-stage estimation wherein the production function is estimated separately and the inefficiency effects are analyzed using OLS estimation method.

The farm-specific technical efficiency (TE) is defined in terms of observed output (Y_i) to the corresponding frontier output (Y_i) using the available technology is obtained as:

$$\mathrm{TE}_i = \frac{Y_i}{Y_i^*} = \frac{Actual\ yield}{Potential\ yield} = \frac{\exp(x_i\beta - \mu_i)}{exp(x_i\beta)} = \exp(-\mu i) \quad (6)$$

The farm specific economic efficiency (EE) is defined as the ratio of minimum observed total production cost (C*) to actual total production cost (C) is calculated as:

$$\mathrm{EE}_i = \frac{C_i}{C_i^*} \quad (7)$$

According to Farrell (1957), the allocative efficiency (AE) index can be derived from Equations (6) and (7) as follows:

$$\mathrm{AE}_i = \frac{\mathrm{EE}_i}{\mathrm{TE}_i} \quad (8)$$

Following the quantification of the technical, allocative, and economic efficiency measures, a second stage analysis involves a regression of these measures on several hypothesized socio-economic and institutional factors affecting inefficiency of farmers. Since there were no 0 and 1 efficiency scores in the model output, the linear regression model used to examine the effects of farm-specific factors on productive inefficiency is as follows:

$$Ln\left(\frac{\mathrm{E}_i}{1-\mathrm{E}_i}\right) = u_i = \delta X_i + \varepsilon_i \quad (9)$$

Where, Ln denotes the natural logarithm (base, e); E_i or ui is the inefficiency of the i[th] firm and is assumed to be a function of farm specific socio-economic and institutional factors; X_i is a vector of explanatory variables; δ is a vector of parameters to be estimated; and ε_i is identically and independently distributed random errors N(0, σ^2).

According to Green (2003), in SPF hypothesis tests can be made using ML ratio test that are not possible in non-parametric models. A number of tests were performed in this study using the Likelihood Ratio (LR) test given by Equation (10).

$$R = \lambda = -2\ ln\ [L(H0)\ /\ L(H1)] \quad (10)$$

Where, λ is the likelihood ratio (LR); $L(H_0)$ is the log likelihood value of the null-hypothesis; $L(H_1)$ is the log likelihood value of the alternative hypothesis; and ln is the natural logarithms.

The maximum likelihood estimates for the parameters of the stochastic frontier were obtained using the FRONTIER 4.1 (Coelli, 1996) computer program and Stata 13 version, in which the variance parameters are expressed in terms of the parameterization as:

$$\sigma^2 = \delta_v^2 + \delta_u^2 \quad (11)$$

$$\gamma = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2\ )} \quad (12)$$

Where, σ^2 is the total variance of the model and the term represents the ratio of the variance of inefficiency's error term to the total variance of the two error terms defined above. The value of variance parameter ranges between 0 and 1.

2.4.4. Specification of Cobb-Douglas production function

The Cobb-Douglas production function is specified as:

$$Ln(Output) = \beta_0 + \beta_1\, ln(Seed) + \beta_2\, ln(Fertilizer) + \beta_3\, ln(Area) + \beta_4\, ln(Labor) + \beta_5 ln(Oxen) + v_i - ui \quad (13)$$

Where, output is the total output of *teff* produced in kg ha^{-1}; seed is the total quantity of *teff* seed used in kg ha^{-1}; fertilizer is the total amount of Nitrogen, Phosphorous and Sulphur (NPS) and/or urea in kg ha^{-}

[1]; area is the total area covered by *teff* in hectares; labor is family and hired labor measured in man-days; oxen is the amount of draught power used in oxen day; β are unknown production function parameters; v_i is the disturbance error term; and μ_i - is a non-negative random variable, intended to capture technical inefficiency effects in the production.

The cost frontier model is formulated as:

$$Ln(Cost) = \alpha_0 + \alpha_1\, ln(Seed) + \alpha_2\, ln(Fertilizer) + \alpha_3\, ln(Area) + \alpha_4\, ln(Labor) + \alpha_5 ln(Oxen) + v_i - ui \quad (14)$$

Where, cost is the total cost inputs incurred to produce *teff* measured in Ethiopian currency Birr per hectare (ETB ha^{-1}); seed is the cost of *teff* seed measured in ETB ha^{-1}; fertilizer is the total cost of NPS and/or urea measured in ETB ha^{-1}; area is the rental value land measured in Birr; labor is total cost of labor and measured in ETB ha^{-1}; oxen is the cost of oxen power measured in ETB ha^{-1}; α are unknown cost function parameters; and V_i, U_i are as defined earlier.

OLS was used to examine factors that influencing technical, economic, and allocative inefficiency of *teff* producers in the study area. The inefficiency function can be written as:

$$\mu_i = \delta_0 + \delta_1 Sex + \delta_2 Edu + \delta_3 Age + \delta_4 Fert + \delta_5 \text{offam} + \delta_6 Lives + \delta_7 Fams + \delta_8 Farm + \delta_9 Prox + \delta_{10} Credit + \delta_{11} Exten + \varepsilon_i \quad (15)$$

Where, the subscript i indicates the i^{th} household in the sample; μ_i is the technical, economic and allocative inefficiency score; δ_i is a vector of parameter to be estimated; $\boldsymbol{\varepsilon_i}$ is error term; Sex is the sex of households which takes a value of 1 if the household head is male and zero, otherwise; Edu represents the education level of the household farmers measured in continuous years of schooling; Age represents the age of the respondents in number of years; Fert represents the fertility status of the *teff* plot, which would take a value 1 if the land is perceived fertile and 0, otherwise; Offam is participation of sampled households in off/non-farm activities which takes a value of 1 if the household head is involved in off/non-farm activities and 0 otherwise; Lives is the total number of livestock in terms of Tropical Livestock Unit (TLU); Fams represents the number of household size; Farm represents the total land size operated by the farmer during the production year including his owned land, sharecropped lands and rented lands; Prox is the distance of the farm from the house of the household in walking minutes; Credit represents credit utilization for *teff* production, 1 if the household received credit, 0 otherwise; and Exten represents frequency of extension contact, measured by the number of extension visits by extension agents in production season.

3. Results and Discussion

3.1. Demographic and Socioeconomic Characteristics of Households

The average age of farmers was 46.31 years indicating that most of the household heads were within their working age and their schooling level on average was 2.95. Similarly, the majority (about 95.3%) of the respondents were male household heads. The average family size was 5.66, suggesting a large family size, combined with limited land size and traditional production system, creating difficulties for the farmers to sustain their family. The results also revealed that 54.27% of sample households participated in various off/non-farm activities and 61.56% of them got credit from formal and informal sources. In the study area, livestock play a vital role for household income and food security. On average, the livestock holding of the sampled farmers was 7.16 TLU. According to the descriptive result, the average land size was 1.72 hectares. The average distance between the plots under *teff* crop and the farmer's home were 13.67 minutes and the average frequency of extension contacts during the production season in relation with *teff* production was about 3.66 times. Regarding to farmers' perception on soil fertility the result showed that 55.91% of respondents perceived their *teff* farm is fertile (Table 1).

Table 1. Demographic and socioeconomic characteristics of the sample households.

Continuous variables	Minimum	Maximum	Mean	St. deviation
Age (years)	29	75	46.31	14.53
Education (years of schooling)	0	12	2.95	2.68
Farm size (ha)	1	6.5	1.72	0.68
Proximity (Minute)	3	45	13.67	4.97
Livestock (TLU)	1	18.1	7.16	2.64
Family size (number)	2	11	5.66	1.58
Extension (frequency)	0	9	5.8	22.66
Dummy variables	Responses		Percentage	
Sex	Male(1)		95.3	
	Female(0)		4.7	
Fertility perception	Fertile(1)		55.91	
	Otherwise(0)		44.09	
Off/non-farm	Yes(1)		54.27	
	No(0)		45.73	
Credit	Used(1)		61.56	
	Not used(0)		38.44	

The average *teff* yield was 1030 kg ha^{-1}, implying that there is a low level of productivity and resource use inefficiency in the study area as compared to the regional and national averages, which are 1930 and 1880 kg ha^{-1}, respectively (CSA, 2021). The average land allocated for *teff* was 0.79 ha with seed rate of 21.5 kg ha^{-1} in average. Regarding fertilizer type, the most commonly and intensively used chemical fertilizer for the production of *teff* crop are NPS and Urea. The result revealed that the sample farmers on average utilized 66.5 kg ha^{-1} of chemical fertilizer. On average, the sample farmers used 28.68 man days per hectare of human labor and 15.24 oxen days per hectare for *teff* production activities (Table 2).

Similar to the production function, cost functions are summarized and presented in Table 2. Among other inputs, cost of oxen took the smallest share and cost of fertilizers took the highest share, out of the total cost of *teff* production.

Table 2. Descriptive statistics of both inputs and output variables.

Variable description	Mean	St. Deviation
Output (kg ha^{-1})	1030	50.86
Seed (kg ha^{-1})	21.5	13.56
Fertilizer (kg ha^{-1})	66.5	29.90
Area(ha)	0.79	0.52
Human labor(MDs ha^{-1})	28.68	11.82
Oxen(OXDs ha^{-1})	15.24	8.29
Cost of production (ETB ha^{-1})	5568.68	1678.4
Cost seed (ETB ha^{-1})	976.5	898.67
Cost fertilizer (ETB ha^{-1})	2118.45	1954.5
Cost of land (ETB)	2856.44	1958.44
Cost human labor (ETB ha^{-1})	995.78	823.15
Cost oxen (ETB ha^{-1})	850.45	775.21

3.2. Hypothesis Tests and Productivity Analysis

Prior to model estimation, all the hypotheses (assumption of stochastic frontier) were tested using generalized likelihood ratio (LR) given in Equation 11. Accordingly, hypothesis tests for selection of correct functional form, the existence of inefficiency and variables that explain the difference in efficiency were conducted. The test was carried out by estimating the stochastic frontier production function and conducting a likelihood ratio test assuming the null hypothesis of no technical inefficiency. The generalized likelihood ratio statistics, $\lambda = 22.44$, was greater than the critical value of 6.63. Hence, null hypothesis is rejected at 1% level of significance showing that the stochastic frontier production function is not an adequate representation of the data.

Likewise, the LR statistical test was estimated for the selection of the appropriate functional form (Cobb–Douglas versus Translog production function). The test result showed that the calculated value of $\lambda = 13.64$ is less than the critical value of 30.58, thus the null hypothesis is not rejected at 1% level of significance implying that Cobb-Douglas functional form best fit the data set. Similarly, to test the null hypothesis that the explanatory variables are not associated with technical inefficiency, λ was calculated using the value of the log likelihood function under the stochastic frontier model (a model without explanatory variables of inefficiency effects) and the full frontier model (a model with variables that are presumed to determine technical, allocative and economic inefficiency of each farmer). The calculated value of $\lambda = 61.64$ is greater than the critical value of 24.72, thus the null hypothesis is rejected at 1% level of significance. Hence, these variables explain the difference in inefficiency among farmers.

Table 3. Generalized likelihood ratio tests of hypothesis for the parameters of the SPF.

Null hypothesis	DF	LH_o	LH_1	Calculated χ^2 (LR) value	Critical value (χ^2,0.01)	Decision
Ho: $\gamma = 0$	1	–3.07	45.16	22.44	6.63	Reject
Ho: $\beta_6 = \beta_7$ - - - $= \beta_{20} = 0$	15	13.17	97.87	13.64	30.58	Not reject
H_0: $u_i = \delta_1 = \delta_2 = \ldots = \delta_{11} = 0$	11	–45.23	67.14	61.64	24.72	Reject

The results of the maximum likelihood estimates (Table 4), showed that variance of the technical inefficiency parameter gamma (γ =0.58) is significantly different from zero at 5%. This implies that 58% of total variation in *teff* yield among sample farmers is due to technical inefficiency. There is, therefore, a room for increasing production of *teff* in the study area by improving the technical efficiency of farmers at the current input and technology level. Among input variables used in Cobb-Douglas stochastic production function seed rate, chemical fertilizers and human labor had significant effect in explaining variation in *teff* yield among sample farmers. The coefficient for seed was negative and significant at 5% level, indicating that 1% increase in seed usage will reduce the teff yield by 0.11%. Because row planting is difficult for *teff* farmers, they may prefer broadcasting, which may cause them to use more seed than is recommended, resulting in lodging. Similarly, the application of chemical fertilizers (NPS and Urea) had significant and positive influence on *teff* yield at 1% level of significance. This could indicate that farmers who apply higher rates of chemical fertilizer receive higher *teff* yield. The use of human labor had a significant and positive effect on *teff* yield at 1% level of significance, suggesting that increasing labor utilization in operations such as land preparation, planting, fertilizer application and weeding would significantly increase *teff* yield because of the current underutilization of human labor.

Table 4. Maximum-likelihood estimates of the Cobb-Douglas SPF model.

Variables	Coefficient	SE	t-ratio
Constant	2.59***	0.81	3.19
lnSeed	–0.11**	0.05	–2.20
lnFertilizer	0.22***	0.07	3.14
lnLabor	0.38***	0.09	4.22
lnOxen	0.23	0.19	1.21
lnArea	0.18	0.14	1.28
Sigma-squared (σ^2)	0.43***	0.09	4.77
Gamma (γ)	0.58**	0.25	2.32
Log likelihood Function	–48.67		

Note: *** and *** refer to statistical significance at 5% and 1% probability level, respectively.*

3.3. Efficiency Scores and Their Distribution

The results of the efficiency analysis show that the average technical, allocative and economic efficiencies of sampled households were about 69, 60, and 56%, respectively. This shows that sample households were relatively better at technical efficiencies than allocative and economic efficiencies. However, while they were relatively better, they were still technically inefficient. According to the mean level of technical efficiency, the sample respondents' *teff* yields can be increased by about 31% on average if appropriate measures are taken to improve the level of efficiency of *teff* growers. Similarly, sample farmers' average allocative efficiency was 60%, which shows that farmers are not allocatively efficient in producing *teff*, and therefore a farmer with an average allocative efficiency level would benefit from a cost saving of approximately 40% to reach the level of the most efficient farmer. Likewise, the mean economic efficiency of sample farmers was 56%, indicating that the production process had a significant level of inefficiency. The overall effect of both technical and allocative inefficiencies has resulted in such a level of economic inefficiency. That is, a producer with an average level of economic efficiency should reduce the current average cost of production by 44%, without reducing output levels, in order to reach the potential minimum cost level (Table 5).

Table 5. Estimated technical, allocative and economic efficiency scores.

Types of efficiency	Minimum	Maximum	Mean	St. deviation
TE	0.21	0.98	0.69	0.08
AE	0.15	0.93	0.60	0.11
EE	0.09	0.85	0.56	0.05

Note: *TE = Technical efficiency; AE = Allocative efficiency; and EE = Economic efficiency.*

The frequency of occurrences of the predicted technical, allocative and economic efficiencies in range indicate that the highest number of households have technical, allocative and economic efficiencies score between 60 and 80%. There were also some households whose allocative and economic efficiencies score levels were less than 20%, but there was no technical efficiency score in this range. The result shows existence of high allocative and economic inefficiencies compared to technical inefficiencies (Figure 2).

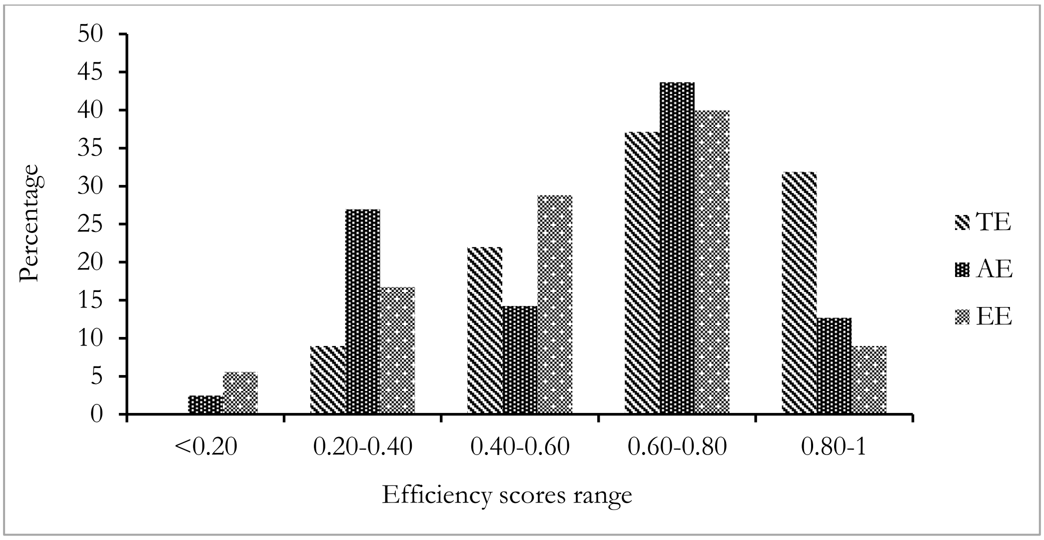

Figure 2. Frequency distribution of technical, allocative and economic efficiencies scores.

3.4. Determinants of *Teff* Production Inefficiency

Ordinary Least Squares was used to identify variables influencing the levels of inefficiency among the sampled farmers. Socio-economic, demographic, farm characteristics and institutional factors influenced inefficiency of *teff* production (Table 6). Household head education status, which can be a proxy variable for the farmer's managerial ability, had a negative and significant effect on technical and economic inefficiencies at 1% level of significance and allocative inefficiency of *teff* production at 5% significance level, implying that less educated farmers are not technically, allocatively and economically efficient than relatively educated farmers. The result might be that, educated farmers are believed to have better access to agricultural information and a higher tendency to more optimally and efficiently adopt and use improved inputs (such as fertilizers and crop varieties). This result is in line with the findings of Milkessa Asfaw *et al.* (2019).

Age of household head had statistically significant and negative relationship with technical inefficiency of *teff* production at 5% of level of significance. It implies that older farmers were technically more successful than their young counterparts. The reason for this was probably that, owing to cumulative farm experiences, farmers become more skillful as they grow older. The finding is in conformity with the results of Agerie Nega *et al.* (2019) and Tadie Mirie *et al.* (2019). Soil fertility also had a negative and significant effect on technical, allocative, and economic inefficiencies at the 1% significance level. This means that farmers who allocated fertile land for the production of *teff* were more efficient technically, allocatively, and economically than their counterparts (farmers who allocated no fertile land for teff production). This may be linked to those fertile lands that require less commercial application of fertilizer, which leads to cost reductions and reduces farmers' inefficiency. This result is similar with the findings of Tadele Mamo *et al.* (2017) and Milkessa Asfaw *et al.* (2019).

Frequency of extension had a statistically significant and negative relationship with technical inefficiency at 1% significance level, implying lower inefficiency for farmers who are more in contact with the development agent. It is assumed that extension services will help in the dissemination and adoption of new technologies. In addition, these extension services provide farmers with guidance on the use of different resources, such as fertilizer, and provide consultancy services to more effectively manage their scarce resources. This result is also consistent with research done by (Tolesa Tesema *et al.*, 2019) and in contradiction with the study by (Tadie Mirie *et al.*, 2019).

In this study, in relation to allocative and economic inefficiencies, the coefficient of participation in off/non-farm activities has a negative and statistically significant effect at 10% and 1% level of significance, respectively. The reason for this is that the revenue obtained from such activities could be used for the purchase of agricultural inputs, which allows farmers to maximize their output at lower cost of production. This finding is consistent with the results reported by Mulubrehan Kifle *et al.* (2017) and Anbes Tenaye (2020).

Table 6. OLS regression results for determinants of inefficiency of *teff* producers.

Variables	TE		AE		EE	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	1.07***	0.15	0.83**	0.42	2.44***	0.38
Sex	–0.06	0.04	–0.07	0.11	–0.07	0.02
Education	–0.80***	0.12	–0.35**	0.17	–0.07***	0.01
Age	–0.45**	0.20	–0.07	0.04	–0.05	0.03
Off/non-farm	–0.18	0.5	–0.13*	0.07	–0.09***	0.02
Livestock	–0.11	0.09	–0.09	0.12	–0.05	0.04
Family size	–0.14	0.72	–0.14	0.10	–0.14	0.09
Farm size	0.03	0.05	0.02	0.08	–0.04	0.03
Proximity	0.02	0.13	0.01	0.02	0.06	0.08
Fertility	–0.21***	0.02	–0.17***	0.06	–0.10***	0.02
Credit	–0.05	0.33	–0.15	0.12	–0.04	0.05
Extension contacts	–0.17***	0.04	–0.05	0.04	–0.09	0.06
R^2	87.23		92.72		83.17	
Adj. R^2	85.64		89.09		79.90	

Note: *TE = Technical efficiency; AE = Allocative efficiency; and EE = Economic efficiency. *, ** and *** denote statistical significance at 10%, 5% and 1% probability level, respectively.* R^2 *= Coefficient of determination.*

4. Conclusion and Recommendations

The results of the stochastic frontier analysis of this study have demonstrated that the sampled households' average technical, allocative, and economic efficiencies were about 69, 60, and 56%, respectively. The estimated stochastic production frontier model showed that seed, fertilizer and labor were significant determinants of the *teff* productivity. Similarly, the output of ordinary least square regression indicated that household heads' age, education, contact with extension, and soil fertility had a negative and significant effect on technical inefficiency. Education, participation in off/non-farm activities and soil fertility had a negative and significant effect on economic and allocative inefficiencies, and in addition to these, extension contact had a negative and significant effect on allocative inefficiency.

The results imply that *teff* producing farmers in the study area are not operating at full technical, allocative, or economic efficiency levels. Thus, there is considerable room for improving production and productivity of *teff* by improving management practices using existing inputs and technologies. Thus, it is recommended that the local government should arrange field days to exchange the knowledge of more efficient farmers with less efficient farmers. It is also possible to increase the managerial ability of farmers by using the human and infrastructural facilities available, such as extension agents and training centers for farmers. In order to enhance and maintain the fertility of agricultural land, development programs are needed to improve land management practices. In addition to this, future efforts may need to look at mechanisms through which farmers can access better farming methods through extension services. Government and other concerned bodies also need to train farmers on off/non-farm entrepreneurship so that they can generate income, thereby helping to purchase farm inputs.

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