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Technical Efficiency of Smallholder Barley Producers in Ethiopia

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ABSTRACT

This study aimed to measure the level of technical efficiency and sources of inefficiency for barley producers in Ethiopia. Primary data was collected from 626 smallholder farmers using a multi-stage sampling technique. The stochastic frontier model was employed to assess the efficiency level, and the result revealed a mean technical efficiency of 79.24 % and an average productivity of 2.2 tons/hectare. This result implies that the productivity of barley producers is 20.76 % behind the potential, and solving all sources of inefficiencies and proper utilization of the production variables will assure the productivity of barley producers to 2.8 tons/hectare. All the production variables, labor, seed, fertilizer, agrochemicals, oxen power, and plot size showed a positive and significant relation to the barley output. Similarly, the squared values and the interaction between production variables were also the most important variables. The inefficiency model also revealed the importance of adopting improved varieties and access to vocational training. Therefore, this study recommends implementing policies and strategies in favor of technology adoption through arranging vocational training to enhance productivity and transform the agricultural sector.

INTRODUCTION

The agriculture sector across the globe has gone through a remarkable transformation over the last six decades. This sector is a lifeline for millions of people in Sub-Saharan countries who rely on it for employment, food security, and income. However, despite its importance, agricultural productivity in these regions has consistently lagged behind the rest of the world. This is due to several factors, including inadequate investments in research and development, limited access to advanced agricultural technologies, insufficient market access for inputs and outputs, and weak extension systems. Addressing these challenges will unlock the sector's full potential, and ensure that farmers in Sub-Saharan Africa can thrive and contribute to the global food supply (Fuglie *et al.*, 2024; Shimeles *et al.*, 2018).

Cereal crops are the backbone of global food security, providing more than half of the world's energy supply and nutrient requirements. Wheat, rice, corn, and barley are the primary cereal crops that millions rely on for their daily food and nutritional needs (Bakshi *et al.*, 2023; Laskowski *et al.*, 2019).

Barley is the most important cereal crop that ranks fourth in terms of acreage and production, following wheat, corn, and rice. Its abundant cultivation and diverse applications make it an indispensable crop globally. It serves as human food, livestock feed, and a key ingredient in various industries worldwide (Tricase *et al.*, 2018). The crop was cultivated on 47.2 million hectares of land, and 154.9 million tons were harvested during 2022. Russia, Germany, France, and Canada are the world's largest barley-producing countries, while Ethiopia, Algeria, and Morocco are the largest barley producers in Africa (FAOSTAT, 2024).

Barley is the most important cereal crop that supports the livelihoods of over 3.6 million smallholder farmers in Ethiopia. It is the 5th crop in terms of total production next to maize, wheat, tef, and sorghum. It is also the 5th crop in terms of acreage following tef, maize, wheat, and sorghum. Barley was cultivated on 799,127.8 hectares, and a total production of 2.1 million tons was harvested during the main season of 2021/2022. Regionally, over 99% of the total production and land allocated to barley production comes from the Oromia, Amhara, and SNNP regions. More than 60% of the annual barley production and 54% of the total land allocated to barley production comes from the Oromia region while 31% of barley production and 36% of the land allocated to barley production comes from the Amhara region (ESS, 2022).

Currently, the national average productivity of barley is only 2.6 tons/hectare, which falls short of the potential of the nationally released barley varieties and the global average productivity. However, the Ethiopian government has been working willfully over the last two decades to improve the production and productivity of some strategic crops. The chief strategy has been the development and utilization of high-yielding and disease-resistant varieties, aimed at enhancing the production and productivity of smallholders (ESS, 2022; Mengistu *et al.*, 2017; Tadesse & Derso, 2019).

Adopting improved agricultural technologies has proven to have a remarkable impact on enhancing production, productivity, income, welfare, and food security. It also contributes much to narrowing the yield gap, reducing poverty, and lowering food prices. These enable the smallholders to produce marketable surpluses, leading to sustainable economic growth and increased access to nutritious foods (Bahta *et al.*, 2018; Biru *et al.*, 2020;

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Gadisa & Addisu, 2022; Houeninvo *et al.*, 2020; Khonje *et al.*, 2015; Makate *et al.*, 2017; Tesfaye *et al.*, 2016; Wake & Habteyesus, 2019; Wordofa *et al.*, 2021).

However, it is imperative to remember that merely adopting improved crop varieties will not guarantee a significant improvement in production and productivity. There are other essential factors to be considered, such as the technical efficiency of the producers, which can significantly impact the overall performance. To achieve optimal yield and maximize production and productivity, it is important to identify all sources of inefficiencies.

As far as we know, no comprehensive studies are exploring the technical efficiency of barley producers at the national level yet. However, this information is crucial and could have significant implications for the policy recommendation. Therefore, this study was designed to assess the technical efficiency of barley producers in Ethiopia using the primary data collected from major barley-producing areas of the country.

MATERIALS AND METHODS

Types of Data, Sources, and Methods of Collection

This research used primary data collected from 626 sample barley producers in Ethiopia, selected using a multi-stage random sampling technique. The three major barley-producing regions, namely Oromia, Amhara, and SNNP, were purposively selected based on their potential in barley production. These regions contribute to over 99% of the national barley production. The sample was selected from 5 zones in Oromia, 1 zone in Amhara, and 1 zone in SNNP, and 18 districts were randomly selected from these zones. A total of 42 kebeles were randomly selected from the districts, and 630 sample households were interviewed, with 4 observations discarded due to incomplete information. Of the complete observations, 35.5% (222) were adopters, and the rest 64.5% (404) were non-adopters. The research also used secondary data collected from published and unpublished sources.

Data analysis Methods

For the data analysis, statistical methods such as descriptive statistics, inferential statistics, and econometric models were executed. The summary of the socio-economic, institutional, and demographic variables was presented using mean, minimum, maximum, and standard deviations. Furthermore, Chi-square and t-tests were performed to determine the existence of significant differences between adopters and non-adopters. Finally, to assess the level of technical efficiency and factors responsible for the technical inefficiency of barley producers, the stochastic frontier model was applied.

Analytical Framework

In the process of crop production, farmers usually try to maximize their profits by increasing their production and reducing their costs. However, not all farmers achieve success in their farming practices, despite their efforts to produce efficiently. This is often due to a deviation from the optimal production, which can occur due to a farmer's inefficiency or unexpected events that are beyond their control. Therefore, a farm household can fall short of the optimal production frontier due to a combination of factors, including the farmer's inefficiency and unforeseen circumstances that may arise.

To model agricultural production and assess technical efficiency, the stochastic frontier model is a highly regarded method. It enables comprehensive modeling of technical efficiency either output-oriented or input-oriented. This makes it an indispensable tool for researchers and practitioners (Wang & Horncastle, 2015). Following (Aigner *et al.*, 1977; Kumbhakar *et al.*, 2015; Meeusen & Broeck, 1977), the functional form of the stochastic frontier model can be expressed as:

$$\ln y_i = \ln y_i^* - u_i,\ u_i \geq 0 \quad (1)$$

Where: y_i^* is the frontier output level, y_i is the observed output level, and $u_i \geq 0$ is the production inefficiency that reducing farm output.

$$\ln y_i^* = f(x_i ; \beta) + v_i \quad (2)$$

Where: f is the functional form to be used, x_i is a vector of input variables, β is a vector of coefficients to be estimated, and v_i is a zero mean random error.

For the sake of simplicity, equation 2 can be expressed as:

$$\ln y_i = f(x_i; \beta) + \varepsilon_i \quad (3)$$

Where: ε_i is the composite error term, while y_i, x_i β, and f are as defined earlier.

$$\varepsilon_i = v_i - u_i \quad (4)$$

From equation 1, the term u_i is the log difference between the maximum output and the actual output that can be expressed as:

$$u_i = \ln y_i^* - \ln y_i \quad (5)$$

From equation 5, u_i x100 represents the percentage increase in the actual output that could be achieved if the farmer was fully efficient, or the percentage of the output that is lost due to the farmer's technical inefficiency.

It is possible to express u_i as the ratio of the actual output to the frontier output by rearranging equation 1.

$$e^{(-u_i)} = y_i / y_i^* = TE_i \quad (6)$$

Efficiency varies across companies and over time (Battese & Coelli, 1992). So, it is logical to ask about what factors are responsible for the variations in efficiency. According to Battese and Coelli, the determinants of inefficiency can be expressed as a linear function of a set of explanatory variables that reflect the characteristics inherent to the company. This model allows the estimation of the efficiency scores, and factors responsible for the inefficiency of the farmers in a single-step estimation (Battese & Coelli, 1995). The single-step estimation helps to overcome the estimation bias that occurs in the widely used two-step approach (Wang & Horncastle, 2015).

The transcendental logarithmic function is the functional form used in this research. It captures the interaction effects of the input variables that play a significant role in the process of maximum likelihood estimation. The functional form of this function can be expressed as follows:

$$lny_i = \beta_0 + \sum_{j=1}^{n} \beta_j lnx_{ij} + \frac{1}{2}\sum_{j=1}^{n}\sum_{i=1}^{n} \beta_{ij}\, lnx_j\, lnx_i + v_i - u_i \quad (7)$$

Where: y_i is the total quantity of output, x_i is the quantity of input used, v_i is the two-sided error term, and u_i is the one-sided error term or the technical inefficiency effects The linear functional form of the variables affecting the technical inefficiency can be expressed as:

$$u_i = \delta_o + \sum_{k=1}^{n} \delta_k z_i + \varepsilon_i \quad (8)$$

Where: δ_k is a vector of parameters (regression coefficient) to be estimated, z_i is a vector of inefficiency variables (institutional, demographic, and socio-economic variables), and ε_i is the random error of the model.

Variables

Based on the reviewed literature, the production variables and the variables anticipated to affect the inefficiency of the farmers that are listed in Table 1 were included in this study.

Table 1: Lists of variables and their anticipated effect on the technical efficiency of barley producers

Var. code	Description and measurements	Expected effect
y_i	Barley output per plot measured in kg	
P_i	Production Variables	
P_1	Plot size allocated for barley measured in hectares	-
P_2	The adult labor force used per plot measured in an hour	+
P_3	Oxen power used for ploughing measured in an hour	+
P_4	Quantity of fertilizer used per plot measured in kg	+
P_5	Quantity of seed used per plot measured in kg	+/-
P_6	Quantity of agrochemicals used per plot measured in kg	+
x_i	Inefficiency Variables	
x_1	Sex of the household head (Female/Male)	+
x_2	Access to off-farm income (No/Yes)	+/-
x_3	Livestock owned measured in tropical livestock unit	+/-
x_4	Access to training on barley production (No/Yes)	+
x_5	Age of the household head measured in years	-
x_6	Family size measured in man-equivalent	+
x_7	Land owned measured in hectares	+
x_8	Plot distance from the residence measured in walking minutes	-
x_9	Market distance measured in minutes of walking	-
x_{10}	Access to credit service (No/Yes)	+
x_{11}	Access to extension services (No/Yes)	+
x_{12}	Education of the household head measured in years of schooling	+
x_{13}	Adoption of improved barley varieties (No/Yes)	+
x_{14}	Experience in barley production measured in years	+

Source: Authors' compiled based on reviewed literature

RESULTS AND DISCUSSIONS

Descriptive Results

Table 2 describes the production, socioeconomic, and institutional variables of the study. The results indicate that barley producers harvest an average yield of 1608 kilograms from 0.7 hectares of land, showing an average productivity of 2.2 tons/hectare. More than 81 % of the respondents had 10 years or more of experience in barley production, with an overall average experience of 18.8 years. The average family size was 6, with the majority of respondents having a family size ranging from 1 to 8. On average, each household sprays over a liter of various agrochemicals on their barley plot, including pesticides, herbicides, and fungicides due to the emergence of different diseases in recent years. The majority of the barley producers (94.9%) have access to extension services, and only 40.7% received specific vocational training on barley production. Access to credit services is also very low (35.3 %).

Table 2: Descriptive results of the production, socioeconomic, and institutional variables

Variable	Mean	Std. Dev.	Min	Max
Barley yield (kg)	1608.439	1721.151	30	14000
Labor used (hr.)	112.486	94.599	16	732

Fertilizer used (kg)	26.93	22.7	1	200
Seed used (kg)	68.92	60.184	10	700
Oxen power (hr.)	32.684	32.861	3	196
Agrochemicals (kg)	1.394	.959	.1	9
Plot size allotted to barley (ha)	.723	.569	.1	6
Livestock owned (TLU)	8.32	3.978	2.6	28.3
Plot distance (minutes)	24.808	41.7	0	400
Market distance (minutes)	56.006	33.602	5	180
Age of the head (yr.)	47.618	12.609	21	87
Experience in barley production	18.773	8.354	3	50
Family size (AE)	6.045	2.239	1	19
Education of the head (yr.)	1.573	.795	0	4
Land owned (ha)	1.483	1.243	0	8
Sex of the head	.914	.281	0	1
Access to off-farm income	.332	.471	0	1
Crop disease occurrences (no/yes)	.942	.233	0	1
Training on barley (no/yes)	.407	.492	0	1
Access to credit services	.353	.478	0	1
Access to extension contacts	.949	.22	0	1
Adoption of improved barley (no/yes)	.355	.479	0	1

Source: Authors' survey result

Econometric Results

The study utilized the stochastic frontier model to assess the technical efficiency of barley producers. The model incorporated key first-order production variables such as labor, fertilizer, seed, plot size, agrochemicals, and oxen power. Additionally, squared values and interactions of these production variables were included. Furthermore, the model accounted for factors anticipated to impact the inefficiency of barley producers, including sex, age, education, livestock holding, experience, off-farm income, plot distance, market access, extension services, credit, improved variety adoption, training, land ownership, family size, and crop diseases.

All of the production variables, their squared values, their interactions, and the inefficiency variables were fitted into the model after heteroscedasticity and multicollinearity tests were completed. The squared value and the interaction of the variables were included assuming linear and quadratic associations that may coexist. The interaction effect of the production variables denotes the complementarities of the production inputs in agricultural production. The negative complement suggests that a joint increase of the variables decreases the production efficiency, while the positive complementarity suggests a joint increase of the variables increases the production efficiency.

Table 3 revealed that all the production variables, labor, fertilizer, seed, plot size, chemical, and oxen hour showed a positive and significant relation to the technical efficiency of barley producers. This result validates the finding reported by (Muleta & Getahun, 2022). Out of the squared values of the production variables, only the square of chemical was insignificant, and the rest were significant. Similarly, the majority of the interaction between the production variables significantly affected technical efficiency.

The variables anticipated to affect the inefficiency of barley producers were also included in the model along with the production variables, their squared values, and their interactions in a single-step estimation, and the result revealed that vocational training on barley production, adoption of improved barley varieties, and plot distance were the variables that affected technical inefficiency of barley producers. Adoption of new technologies was negatively related to the inefficiency, and this is in line with the finding reported by (Wongnaa *et al.*, 2019).

Table 3: Maximum likelihood estimation results

Variables	Coef.	St. Err.	z	P>z	[95%Conf.	Interval]
Frontier						
Ln of labor	0.587***	0.183	3.210	0.001	0.228	0.945
Ln of fertilizer	0.076***	0.025	3.070	0.002	0.027	0.124
Ln of seed	0.464***	0.092	5.060	0.000	0.284	0.643

Ln plot size	0.174**	0.073	2.380	0.017	0.031	0.316
Ln of chemical	0.345***	0.066	5.220	0.000	0.216	0.475
Ln of oxen hour	0.473***	0.069	6.870	0.000	0.338	0.607
Ln of labor square	-0.143*	0.077	-1.860	0.063	-0.293	0.008
Ln of fertilizer square	0.039***	0.010	4.060	0.000	0.020	0.057
Ln of seed square	0.140**	0.066	2.120	0.034	0.010	0.270
Ln of plot size square	0.131***	0.031	4.260	0.000	0.071	0.191
Ln of oxen square	-0.144**	0.056	-2.570	0.010	-0.254	-0.034
Ln of chemical square	-0.029	0.022	-1.290	0.196	-0.072	0.015
Ln of labor X ln fertilizer	-0.076**	0.035	-2.150	0.032	-0.145	-0.007
Ln of labor X ln of seed	-0.113	0.125	-0.900	0.368	-0.358	0.133
Ln of labor X ln plot size	0.005	0.079	0.070	0.948	-0.150	0.160
Ln of labor X ln oxen hour	0.495***	0.100	4.960	0.000	0.299	0.690
Ln of labor X ln chemical	-0.187***	0.068	-2.770	0.006	-0.320	-0.055
Ln of fertilizer X ln seed	-0.014	0.028	-0.510	0.608	-0.068	0.040
Ln of fertilizer X ln plot size	-0.017	0.022	-0.780	0.438	-0.061	0.026
Ln of fertilizer X ln oxen hour	0.064*	0.034	1.900	0.058	-0.002	0.130
Ln of fertilizer X ln chemical	0.022	0.017	1.260	0.209	-0.012	0.056
Ln of seed X ln plot size	0.147**	0.072	2.050	0.040	0.007	0.288
Ln of seed X ln oxen hour	-0.333***	0.100	-3.340	0.001	-0.528	-0.137
Ln of seed X ln chemical	0.028	0.062	0.460	0.644	-0.092	0.149
Ln of plot size X ln oxen hour	-0.171***	0.054	-3.160	0.002	-0.276	-0.065
Ln of plot size X ln chemical	0.076	0.047	1.630	0.103	-0.015	0.168
Ln of oxen hour X ln chemical	0.172***	0.066	2.620	0.009	0.043	0.301
_cons	2.478***	0.419	5.920	0.000	1.657	3.298
Mu						
Sex of the head	5.653	6.213	0.910	0.363	-6.525	17.831
Access to off-farm income	-1.785	2.999	-0.600	0.552	-7.663	4.094
Livestock owned	-0.896	0.546	-1.640	0.101	-1.966	0.175
Training on barley	-12.783**	6.416	-1.990	0.046	-25.358	-0.209
Age of the head	0.075	0.111	0.680	0.499	-0.143	0.293
Family size	-1.074	0.770	-1.390	0.163	-2.583	0.436
Lad owned	-0.610	1.113	-0.550	0.583	-2.792	1.571
Plot distance	0.049 *	0.025	1.930	0.053	-0.001	0.098
Market distance	0.020	0.036	0.560	0.573	-0.050	0.090
Access to credit	-3.077	3.039	-1.010	0.311	-9.033	2.879
Access to extension	-1.795	4.185	-0.430	0.668	-9.998	6.407
Education of the head	-0.838	1.616	-0.520	0.604	-4.006	2.330
Adoption of improved barley	-35.475**	17.439	-2.030	0.042	-69.655	-1.295
Experience in barley	-0.365	0.236	-1.550	0.122	-0.827	0.098
Crop disease occurrences	17.659	13.594	1.300	0.194	-8.984	44.302
_cons	-21.954	17.492	-1.260	0.209	-56.238	12.330
Usigma						
_cons	2.060***	0.435	4.730	0.000	1.207	2.913
Vsigma						
_cons	-2.725***	0.099	-27.580	0.000	-2.919	-2.531
sigma_u	2.801***	0.610	4.600	0.000	1.828	4.291

sigma_v	0.256***	0.013	20.250	0.000	0.232	0.282
lambda	10.940***	0.611	17.910	0.000	9.743	12.138
Log-likelihood = -241.7116, No. of obs. = 626, Wald $chi^2(27)$ = 4613.72, and Prob > chi^2 = 0.0000						

Source: Authors' survey result

Estimation of the Technical Efficiency Scores

Table 4 summarizes the estimated technical efficiency score. The mean technical efficiency is 79.24 % with a standard deviation of 16.20 %. The efficiency score ranged from 9.24 % to 99.64 %. This result indicates that barley producers in Ethiopia are producing below the frontier, and the production is 20.76 % short of the potential. This result implies that barley producers in Ethiopia would increase their output by 20.76 % by solving all sources of their technical inefficiencies and efficient utilization of their resources.

Table 4: Summary of the technical efficiency scores

Efficiency score range		Frequency	Percent (%)
< 0.1		002	0.32
0.1 – 0.2		009	1.44
0.2 – 0.3		008	1.28
0.3 – 0.4		016	2.56
0.4 – 0.5		010	1.60
0.5 – 0.6		018	2.88
0.6 – 0.7		032	5.11
0.7 – 0.8		112	17.89
0.8 – 0.9		306	48.88
> 0.9		113	18.05
Total		**626**	**100**
Mean	0.7924	Minimum	0.0924
Std. dev	0.1620	Maximum	0.9964

Source: Authors' survey result

The result in Table 2 indicated that barley producers in Ethiopia are harvesting an average yield of 2.2 tons/hectare. However, the technical efficiency score presented in Table 4 indicates that the average productivity can be increased by 20.76 %. This implies that solving all sources of technical inefficiencies will boost the productivity of barley producers to 2.8 tons/hectare.

CONCLUSIONS

This study analyzed the level of technical efficiency and its determinant factors for barley producers in Ethiopia. The result revealed that barley producers in Ethiopia are inefficient and produce below the potential. The average technical efficiency is 79.23 %, and the average productivity is 2.2 tons/hectare. This result indicates that the productivity of barley producers can reach 2.8 tons/hectare if all sources of inefficiencies are solved.

All the first-order variables, seed, fertilizer, labor, agrochemicals, plot size, and oxen power positively affected the technical efficiency of barley producers. Similarly, except for the chemical sprayed, all squared values of the production variable significantly affected the technical efficiency of barley producers. Moreover, the interactions of the production variables were also included in the model, and more than half significantly affect the production efficiency of barley producers. Finally, among the included inefficiency variables, the adoption of improved barley varieties, vocational training, and plot distance were found to affect the efficiency of barley producers. Households with access to crop-specific training are more likely to be efficient than households with no access. Similarly, households using improved barley varieties are technically more efficient than households recycling the improved seed and using the local varieties. Plot distance is the variable positively related to technical inefficiency. This indicates that the plot's proximity to the farmer's residence increases efficiency.

The findings of this research emphasize the importance of providing vocational training to farmers to maximize the use of improved crop varieties and associated techniques. It also signifies that intensifying the extension system will encourage the adoption of improved varieties that will significantly contribute to enhancing the technical efficiency of smallholder farmers. Therefore, implementing policies and strategies promoting the adoption of improved agricultural technologies is recommended to open the prospects for farmers to become more productive and food secure and accelerate the sector's transformation.

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