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Article

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DEVELOPMENT ECONOMICS | RESEARCH ARTICLE

Technical efficiency of garlic production under rain fed agriculture in Northwest Ethiopia: Stochastic frontier approach

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Abstract: The article focuses on evaluating the technical efficiency of garlic production in northwest Ethiopia. The average yield in the region was lower than its potential, indicating a need to improve farming practices. Data were collected from 359 garlic producers using random sampling. The Cobb-Douglas stochastic frontier production function was used to estimate technical efficiency, which was found to be 73%. This means that about 27% of potential garlic output was lost due to inefficiency. Factors such as land size, seed, fertilizer, insecticide, and oxen days were found to have a positive and significant impact on garlic production. On the other hand, factors like age, extension contact, distance, renting land, garlic disease shock, access to finance, and access to information were linked to technical inefficiency. The study suggests that investing in high-quality seeds, improved farming inputs, and access to information can enhance garlic output by leveraging its high efficiency level.

Subjects: Agriculture & Environmental Sciences; Botany; Economics; Finance

Keywords: garlic; Cobb-Douglas; technical efficiency; productivity

1. Introduction

Garlic has been cultivated for over 7000 years and is the world's favourite and most adaptable bulb crop, used for both culinary and medicinal uses (Malik et al., 2017). Garlic's aroma makes it famous in daily cooking all around the world; therefore, it is recognised as the "queen of the kitchen". Garlic is widely used as a spice in many ways among producers, marketers, and consumers in all curries, fried meals, flavouring dishes, pickles, and sauces (Tadesse & Dejene, 2018). Its medical usefulness in fighting sickness has been widely appreciated, particularly for digestive system diseases, blood cholesterol, sterility, cough, antibiotic agents, and so on. Besides, garlic is used as a traditional medicine to treat any painful ailment that occurs within the body and has long been used as a vegetable and spice to flavour a range of Ethiopian indigenous foods.

Economically, the growing demand for garlic for medical uses, flavours, and cooking gives many farmers the potential to improve domestic production and marketing in Ethiopia (CSA, 2021). In Ethiopia, garlic is the most extensively farmed crop, and it is an essential cash crop for smallholder farmers since its unit price is substantially greater than most other vegetables produced (Emana et al., 2015). In the meher season of 2020–2021 (CSA, 2021), Ethiopia produces 1.14mn quintals of garlic, which are largely distributed in various market channels beyond household consumption. As

a cash crop in many regions of the country, boosting its productivity per unit area and output would allow farmers to earn good returns. In terms of productivity, Ethiopian garlic farmers got a yield of 89.98 quintals per hectare in the 2019 meher season (CSA, 2019). Meher is the main crop season in Ethiopia. It encompasses crops harvested between September and February. While crops harvested between March and August are considered part of the Belg season. This study focused on meher season production since the product is grown using rainfall as the only supply of water and the farmer suffers risk and uncertainty in farm decision-making.

In Ethiopia, a lot of efforts are being made to improve the productivity levels of vegetable crops, including garlic, through the introduction and dissemination of agricultural technologies such as fertiliser, improved seed, fungicides, insecticides, and herbicides (Abrha et al., 2015; Tadesse & Dejene, 2018). This can be evidenced by the rapid increase in the use of these inputs among vegetable farm households in the north-western parts of Ethiopia, where garlic farming thrives. Northwestern Ethiopia, such as Goncha district, is notable for garlic farming (Chekol & Mazengia, 2022). This technology has at least curbed the deterioration of the productivity of land that could have otherwise declined due to land degradation. During the summer (August—December) cropping season, most farmers grow garlic for consumption and commercial purposes with rain-fed agriculture. During the excellent season, a single acre in the country yields an average of 16 tonnes per harvest.

By increasing the productivity of the garlic crop, domestic output of garlic may increase. Productivity may be increased through the use of new technology, increased efficiency, or both. However, because new seed technology adoption in Ethiopia is quite low, improving efficiency is a suitable alternative for increasing agricultural production in the short run (Hussain et al., 2014; Mina et al., 2021). Employing the technical efficiency measures, farmers may produce the highest potential yield from an existing set of inputs and available technology. An effective economic development plan is dependent on increasing agricultural productivity and production growth. Increased productivity improves the return to producers as well as workers, allowing for greater consumption of products and services per person (Mariyono et al. 2020).

Despite the tremendous potential of root crops and programmes implemented to improve the agricultural sector, its productivity could not be improved (Diriba, 2016; Mengesha et al., 2016; Negash et al., 2018). In the case of root crops, the cultivation of garlic crops has a number of challenges in Northwest regions, and the country's overall output and productivity fluctuate for several reasons. For instance, the productivity of garlic declined from 91.81 q/ha to 89.98 q/ha from 2018 to 2019 (CSA, 2019). There are many factors contributing to this yield decline. First, lack of agricultural technology (i.e., limited access in terms of quality and quantity to improved seeds, fertilisers, and pesticides) and high prices of these technologies. Second, lack of knowledge on the efficient utilisation of limited resources and poor application of agricultural technology (Tadesse & Dejene, 2018). Third, land degradation and poor and biased agricultural policies In Northwest Ethiopia, smallholder farmers' use incorrect agronomic methods, lack effective disease and insect pest management practises, and lack improved seed types. Garlic crops are high-risk and vulnerable to severe garlic diseases such as garlic rust, downy mildew, and basal rot, which limit productivity and output (Garmame Galgaye, 2022). All of these problems have contributed to agricultural production, which has been at the subsistence level in Ethiopia for many decades.

Because garlic is one of the potential vegetable crops for consumption and sale, increasing output while preserving acceptable qualities is crucial. To survive, each garlic grower must strive for maximum output and quality, increasing farming households' technological efficiency in garlic growing. Garlic production is heavily reliant on farmers' technical efficiency, which is influenced by socioeconomic characteristics and farm attributes. However, no literature has been found in Northwest Ethiopia that investigates the determinants of the technical efficiency of garlic farming, despite its high potential areas for garlic farming and rapid increase in garlic demand for consumption. To the best of our knowledge, no empirical study in the literature on garlic production

has examined the determinants of technical efficiency for producers. This begs the study question: What is the technical efficiency of garlic production in the district of Northwest Ethiopia? What variables affect efficiency, and how much input is necessary to produce at the technically efficient point? Therefore, the objective of this study is to determine how garlic growers might produce extremely near or on the production potential frontier by making effective use of variable inputs. Specifically, the study investigates how the characteristics of garlic producers and their resource endowment, production techniques, and institutional service delivery affect the technical efficiency of garlic production in Northwest Ethiopia.

Thus, the study of technical efficiency has good opportunities for various stakeholders involved in garlic farming to learn how to use the optimal mix of productive resources. Firstly, the mean technical efficiency of sample farmers in the study area shows to what extent garlic production can be increased if the level of efficiency is improved given the different levels of input use. Conversely, to what extent can inputs be minimised if the level of efficiency is improved at the existing level of output? This helps to evaluate the impact of previous development programmes on increasing the efficiency level of the farmers in the production of garlic. Secondly, the efficiency level of each farmer is measured. This can show the differences in efficiency levels among farmers in the study area in the production of garlic. Thirdly, based on the efficiency level of each farmer, the determinants of inefficiency are identified. Identification of the determinants of inefficiency is important for various planning and policy purposes. This is essential given that the mass of Ethiopian agriculture is rain-dependent; in fact, any technique that increases the productivity of inputs for garlic growing will result in actual revenue improvements for the rural people. Such an empirical study will certainly be useful in designing different policies that target the improvement of farmers' profits and mitigate the problem of productivity the region is facing. Finally, the findings of this study will be helpful for other researchers as a source of literature.

The remaining section of the paper is organised as follows: Section two reviews the theoretical and empirical literature on the technical efficiency of production, the profile of garlic production in Ethiopia, and the conceptual frameworks of the study. Section three provides details about the methodology of the study, followed by the fourth section, which is about results and discussion. Finally, the fifth section explores conclusions, limitations, and further research.

2. Literature review

2.1. Concept and measurement of technical efficiency

Productivity and efficiency are two distinct indicators used to assess the success of a business (Coelli et al., 2005). The ratio of output(s) to input(s) is used to determine productivity. Productivity measurements include total factor productivity, which is a productivity statistic that includes all elements of production (Coelli et al., 2005). Whereas efficiency is a relative concept that is measured by comparing the actual output to input ratio with the optimal output to input ratio, which is represented by the production frontier. The specification of a production function is required for efficiency measures. The production function represents the highest output achievable with a given set of inputs. It describes production performance and measures productivity. The production frontier represents the maximum amount of product that may be obtained from each input. As a result, it reflects the current state of agricultural production technology (Coelli et al., 2005).

2.1.1. Technical efficiency

Concentrates on maximising output from a given set of inputs; it is a prerequisite for economic efficiency. Technical efficiency can be improved by increasing knowledge, competence, training, and access to current information. The optimum combination or allocation of inputs and outputs is described as allocative efficiency. Farmers must be technically and allocatively efficient in order to be economically efficient, according to Coelli et al. (2005).

Thus, technical efficiency can be judged in two ways: input-oriented and output-oriented.

2.1.2. First, Input Oriented (IO) approach

IO investigates the ability to employ fewer inputs while maintaining a constant amount of output. Figure 1(a) depicts a firm's IO efficiency measurement. For example, suppose the farmer uses two inputs, x1 and x2, to create a single output, y, and we assume that a 1% change in input consumption results in a 1% change in output, resulting in a constant return to scale. On the horizontal and vertical axes, the two inputs x1 and x2 are indicated. For an efficient farmer, the isoquant (i.e., the combination of inputs that results in the same level of output) is denoted by SS'. All points on the isoquant represent technically efficient production. A farmer who produces on an isoquant scale is said to be technically efficient.

Figure 1(a) indicates that the farmer who generates output y* at point P is efficient, whereas the farmer who produces output level Y at point Q is inefficient. The farmer's technical efficiency (TE) is the ratio of the distance 0Q to the distance 0P. Therefore, technical efficiency is provided by:

$$\mathrm{TE} = \frac{OQ}{OP} \tag{1}$$

However, technical inefficiency (TI) score of a farmer is given by

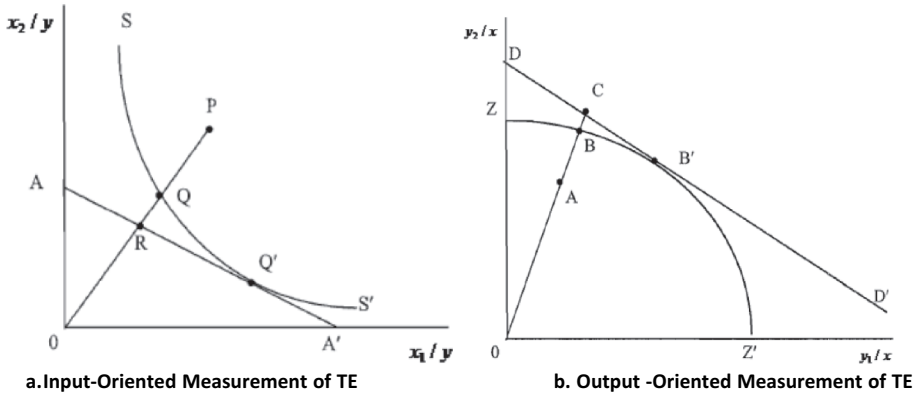
$$\mathrm{TI} = 1 - TE = 1 - \frac{OQ}{OP} \tag{2}$$

The distance QP represents the farmer's observed TI. TI is the amount of input that can be reduced without reducing the amount of output produced. The value of TE ranges from 0 to 1. When a farmer is technically efficient, the value of TE is 1, and when there is input waste, the value is between 0 and 1. For example, as the value of TE increases from 0.2 to 0.8, technical inefficiency decreases. The TE value of 75%, or 0.75, indicates that the farm can boost production by 25% while reducing waste without increasing input utilisation.

2.1.3. Second, Output Oriented (OO) approach

OO examines a farmer's ability to maximise output while minimising input utilisation. Figure 1(b) depicts the OO measurement of TE for a farmer who produces two outputs (y1 and y2) utilising input x. ZZ's production possibility curve (PPC) depicts potential combinations of the two outputs produced with a given level of input x. A farmer who produces on the curve is referred to as "technically efficient". In contrast, a farmer producing inside or below the PPC, such as at point A, is "'technically inefficient'".

To use graphs and equations to describe a farmer's TE, we draw a line 0C from the origin to point C. This line crosses the PPC at point B. A farmer m working at position A uses the same input level



a.Input-Oriented Measurement of TE

b. Output -Oriented Measurement of TE

Figure 1. The input-and-output oriented measurement of technical efficiency.

Source: (Coelli et al., 2005) and Kumbhakar and Lovell (2003).

as an efficient farmer k working at point B. The technical efficiency of farmer m is the ratio of distances 0A to 0B.

$$TE = \frac{OA}{OB} \tag{3}$$

The distance AB shows the size of the technical inefficiency of the farmer m. while farmer k TI is the size of outputs that may be increased without changing the utilisation of input xi.

2.2. Profile of garlic production in Ethiopia

Some root crops, like onions and garlic, are indispensable to improving the taste and scent of the food we eat. These and other economic factors prompt the peasant holders to grow root crops such as garlic, as shown in the survey results. In this section, a comparison of the estimates of 2019 post-harvest garlic crop yield with 2018 in Ethiopia was made, which is believed to give the best bird's-eye view. The analysis is based on whether or not the estimated increase in the volume of production over the two years is due to an increase in cropped area, enhanced crop yield, or a combination of both. More importantly, enhanced crop yield has taken up the lion's share, so one can generally indicate the direction, the rate of change, and the level of steps the agriculture sector is taking up on the ladder of transformation to commercialised agriculture from its initial subsistence starting point (CSA, 2018). Of course, it should be noted that, except for the progress made during the last two and a half decades, the agricultural sector in Ethiopia had remained stagnant for centuries with limited progress in a few specific areas (CSA, 2019).

More specifically, since garlic production is location-specific, the agricultural sample survey for the garlic crop is reported only on the high-production-potential regions of the country, namely the Tigray, Amhara, and Oromia regions of Ethiopia (Table 1; Figure 2). The other regions of the country have low potential for garlic and are not reported in the survey. In 2019, the country produced 1.8mn quintals of garlic, harvested from 19kha with a national average yield of 89.98 qt/ha. The top two garlic-producing regions of the country are Oromia and Amhara (Figure 2). In 2019 alone, the Oromia region contributed 53.6% (1mn qt) to the national production, while the Amhara region contributed 30.2% (591.2kqt) (Table 1). Rainfall is the only source of water for garlic production; the 2019 meher season of crop production has shown significant increments both in the estimated cropped area and volume of garlic crop production in the survey regions of Ethiopia, except Amhara Regional State.

Table 1. Estimates of area, production and yield of garlic crops for 2018 and 2019, Meher Season, Ethiopia

Regions	Area in kha		Production in kiloquintals		Yield(Quintals/Hectare)		
	2018	2019	2018	2019	2018	2019	% Change
Tigray	0.54	1.00	39.1	73.0	72.33	2.85	0.72
Amhara	9.03	6.97	752.0	591.2	83.30	84.82	1.82
Oromia	8.75	11.33	870.7	1,049.3	99.46	92.59	−6.91
Others	*	*	120.4	243.8	*	*	*
Ethiopia	**19.42**	**21.75**	**1,782.2**	**1,957.4**	**91.81**	**89.98**	**−2.00**

Source: CSA (Central Statistics Agency) Ethiopia data from (2019; CSA, 2018) (https://www.statsethiopia.gov.et/our-survey-reports/).

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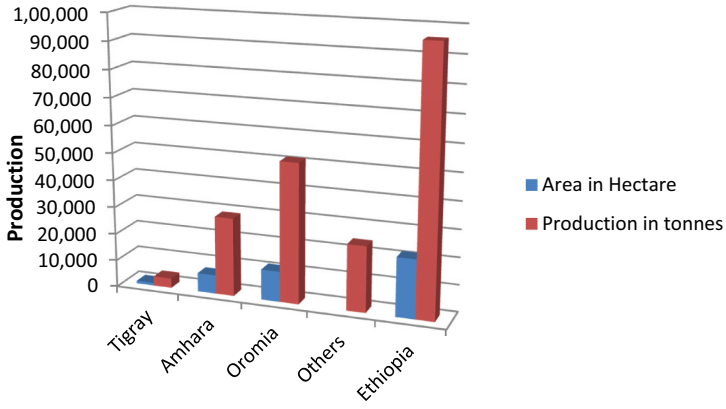

Figure 2. Garlic production and area planted in Ethiopia.

Source: CSA (2019).

However, productivity and/or yield levels have declined significantly. As shown in Table 1 below, garlic crop yield declined by 2 Qt/ha for the two consecutive cropping years in Ethiopia (2018 and 2019). The same year indicates a significant decline in yield in the Oromia region by 6 Qt/Ha, while in the Amhara and Tigray regions, the yield shows a positive increment (Table 1). The overall decline in garlic yield confirmed that this crop production is highly susceptible to shocks, particularly unstable rainfall and garlic diseases, low seed utilisation, and poor farmer management (Authority, 2013; Mina et al., 2021). Moreover, the lack of availability and high price of agricultural technology, improper utilisation of the limited resources, and poor agronomic practises contributed to the yield reduction (Garmame Galgaye, 2022; Tadesse & Dejene, 2018). This shows that smallholder garlic farmers are technically inefficient since they are producing below their potential output using the existing technology.

It is suggested that future crop production growth must increasingly come from yield improvements because there is little adequate area available for crop cultivation expansion, particularly in highland Ethiopia. If existing inputs and technologies are not being used efficiently, introducing new technologies will be inefficient (Asefa, 2012). As a result, using current technologies is less costly than developing new ones.

Similarly, Figure 2 depicts Ethiopia's top two largest garlic-producing regions as well as the country's total garlic production. Oromia produces 51,361 metric tons of garlic, followed by Amhara, which produces 28,940 metric tons. Furthermore, Ethiopia produces a total of 95,814 tonnes on a national level. One tonne is equal to ten quintals. As a result, this statistic also demonstrates that the Oromia and Amhara areas of Ethiopia have great potential for garlic production.

2.3. Determinants of technical efficiency of farmers

Farm output producers in developing countries, including Ethiopia, need to maximise their output with the application of various packages of agricultural inputs. From those inputs, land size, oxen-hours, labour, seed, fertiliser, and pesticides were identified as the most decisive factors determining the technical efficiency of outputs. Inputs such as land size (Abate et al., 2019; Abdulai et al., 2017; Koye et al., 2022), seed (Abate et al., 2019; Mina et al., 2021; Wana & Lemessa, 2019), fertiliser (Wassihun et al., 2019), insecticides (Hussain et al., 2014; Mina et al., 2021; Mengesha et al., 2016; Jemal, 2010), and oxen hours (Koye et al., 2022; Mina et al., 2021; Wana & Lemessa, 2019; Wassihun et al., 2019) were identified as the significant determinants of agricultural production. In determining technical inefficiency, variables such as education, farm experience, TLU, family size, training in marketing, age, extension visit, credit access, market information, and plant disease play a significant role (Abate et al., 2019; Abebe & Kegne, 2023; Asfaw & Vasa, 2021; Biney, 2023; Kisusi & Sife, 2015; Kumari & Singh, 2023; Mariyono, 2019; Saiyut et al., 2019; Spielman et al., 2012; Wana & Lemessa, 2019; Worku & Dejene, 2012).

In relation to the specific crop type and county of origin, there is ample proof of the technical efficiency and productivity of vegetable and grain production. For example, Wassihun et al. (2019); Asfaw and Vasa (2021); Abate et al. (2019); Koye et al. (2022); and Wana and Lemessa (2019) explained the technical efficiency and productivity of vegetables such as potato, tomato, and red pepper in various regions of Ethiopia. Related studies are also conducted for other grain crops in Ethiopia by Abdulai et al. (2017), Musa et al. (2015), Hunde and Abera (2019), Wana and Lemessa (2019), and Geta et al. (2013). Other studies, such as Mina et al. (2021) in the Philippines and Hussain et al. (2014) *in Pakistan*, examined the technical efficiency of garlic. Unfortunately, there is little evidence in the literature and no studies in Ethiopia on the technical efficiency of garlic crops.

Although there is considerable potential for garlic production in middle and highland Ethiopia, and many households rely on it for a living, research on the technical efficiency of garlic cultivation is lacking. Furthermore, the impact of sustainable land management practises on garlic production technical efficiency is unresolved. As a result, the purpose of this study is to comprehend how garlic growers might produce extremely close to or on the production potential frontier by utilising variable inputs effectively. Thus, the study of technical efficiency informs farmers on how to use the best combination of productive resources to achieve long-term rural modernization by raising revenue and ensuring nutrition security. This is critical considering that the majority of Ethiopian agriculture is rain-dependent; in fact, any strategy that raises the productivity of inputs for garlic production would result in actual revenue benefits for the rural people, so this study seeks to fill these gaps.

2.4. Conceptual framework

We provided here brief conceptual framework of the study. The conceptual framework shows briefly how socioeconomic characterizes of farmers, institutional factors and national policies are interrelated to improve technical efficiency of farmers. For example, Agriculture transformation plan (ATP) in Ethiopia has been implemented in such a way to influence socioeconomic characteristics of farmers, institutional services to be provided for farmers and land management practices. Moreover, specifically the agricultural sector targets of ATP aims to increase productivity and efficiency of farmers and hence to reduce poverty and food insecurity. The overall objective of ATP is in line with United Nations Sustainable Development Goals. The link between the independent and dependent variables in this study is depicted in Figure 3.

3. Chapter three: methodology of the research

3.1. Description of the study area

This research was conducted in the Goncha Siso Enese District, East Gojjam Zone. It is 343 kilometers from Addis Ababa, Ethiopia's capital city. According to GSEW (2021), the district comprises two cities and 41 rural kebeles, with a total of 39,209 households. The total number of agricultural households was 32,783. The district has an average annual rainfall of 1100–1500 mm, with an irregular distribution of rainfall over time and location. Small-scale agriculture is the district's most important source of income. Goncha district has good potential for veggies, notably garlic. The study area is located in Figure 4.

3.2. Sample design, procedure, and data collection

In this study, first the potential garlic kebeles were identified for selecting sample respondents. Accordingly, from the total of 41 rural kebeles, nine were known with huge potential for garlic production. Since this study was focused on garlic, the sample kebeles were potential garlic kebeles. Then, four high-garlic producer kebeles from the nine of potential garlic kebeles were randomly taken for selecting sample households. The potential kebeles' for garlic production and the accessibility of the locations to visit were factors in the decision for selection. At the next stage, the intended sample size was established according to the population size of garlic producer farmers using a population list from sample kebeles. Lastly, 362 sample households were chosen at random using a simple random sampling approach based on Yamane's formula.

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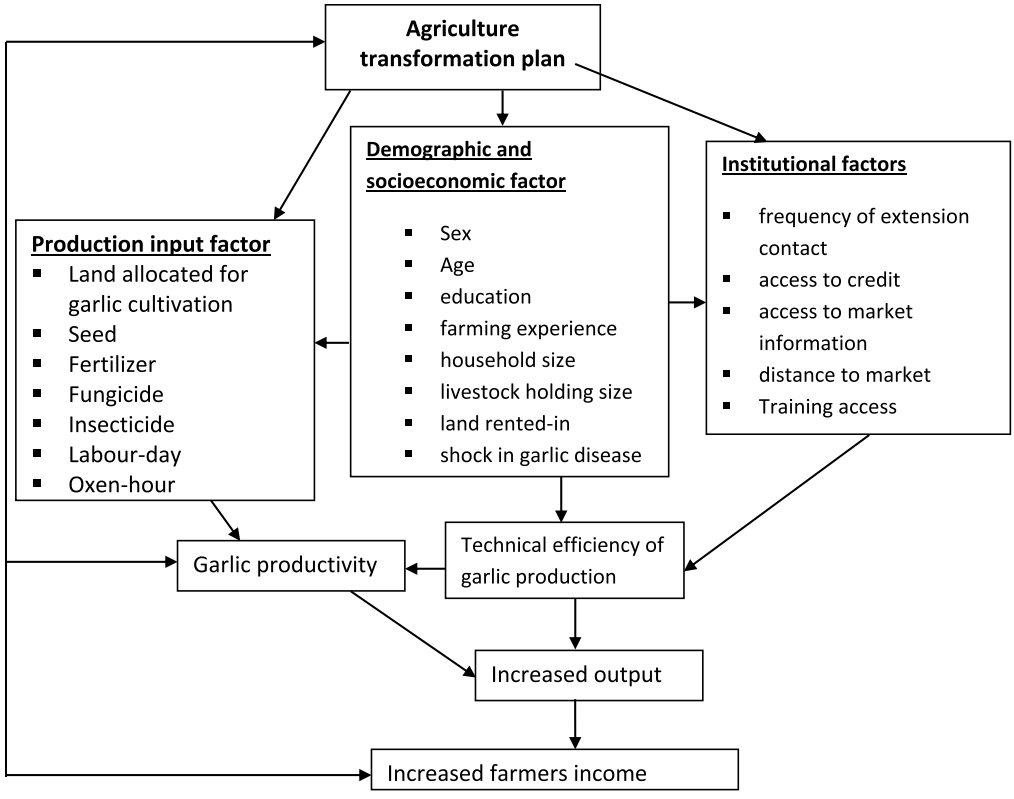

Figure 3. The study's conceptual framework.

Source: own composition based on a review of relevant literature.

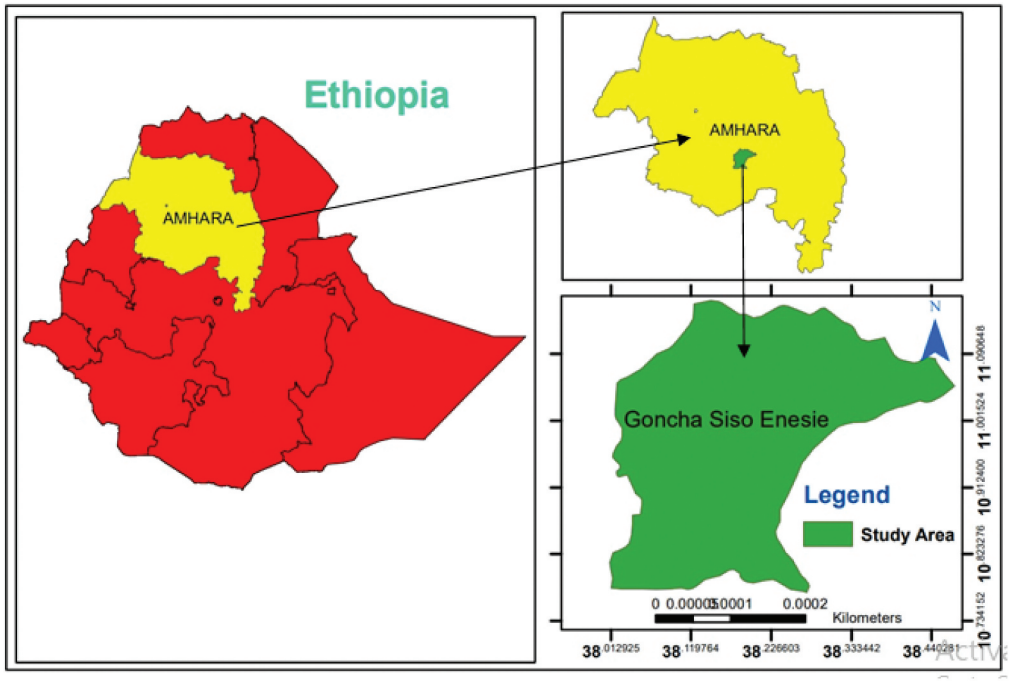

Figure 4. Location map of the study area.

The general formula developed by Yamane (1967) will be employed to determine the sample size of rural households. The study will employ 95% confidence interval and ±5% marginal error. Based on this formula, the sample size was determined as follows:

$$n = \frac{N}{(1 + N(e)^2)} \tag{4}$$

Where, *n* = sample size required, N signifies the total household population under study who are engaged in agriculture, e = the desired level of precision, I.e. margin of error (0.05).

$$\text{Thus, } n = \frac{3,814}{(1 + 3,814(0.05^2)} \ldots, n = \frac{3,814}{(1 + 9.535)}, n = \frac{3,814}{10.535} \tag{5}$$

$$n = 362.03 \sim 362 \tag{6}$$

The distribution of the sample size across the kebeles was based on their relative share of garlic producers to the total sampling frame as shown in Table 2.

The desired sample size from each sample Kebeles was calculated in proportion to the number of garlic grower farmers' households. Finally, after applying the household list of small garlic growers, the calculated size of 362 total samples from all kebeles was randomly picked using the random sampling approach. The data were collected in the Goncha district between December 2021 and February 2022 for the 2021–2022 farming season.

To achieve the study's objectives, both qualitative and quantitative data on an array of garlic producers were gathered from primary sources. For the cross-sectional survey, a team of five trained enumerators delivered semi-structured questions and conducted personal interviews with small-scale garlic growers in the research area. Structured questioners were used to select potential garlic producers at random and collect the relevant data from them. A pretested questioner was used to obtain data on a wide range of socioeconomic aspects of the household, institutional and production input factors, and garlic output level. The questioner also mentions input utilisation and garlic output performance, as well as agricultural production issues.

3.3. Method of data analysis and model specification

In this investigation, descriptive and econometric data analysis methods were used. The descriptive statistics were used to characterise the farming system of the study area, with the mean, maximum, minimum, standard deviation, frequency, and percentage values of variables. An econometric analysis used a stochastic frontier approach to estimate the level of garlic production efficiencies. This is because the stochastic frontier approach is

Table 2. Sample kebeles and garlic producers

No.	Sample Kebeles	Number of garlic producer households	Number of Sample households
1	Goshera	1057	100
2	Gomite	968	92
3	Embawoch	790	75
4	Debreyakob	999	95
Total		**3814**	**362**

Source: GSEW (2022), Agriculture and Rural Development Office.

a substantially better measure of efficiency in the subsistence agricultural system, where farm uncertainties are widespread and are caused by instable weather conditions such as drought, unpredictability of rainfall, and plant disease (Coelli et al., 2005). Moreover, the stochastic frontier technique was employed to estimate technical efficiency because of its capacity to separate inefficiency from deviations caused by variables outside the producers' control. Random shocks, such as garlic rust and garlic disease, drought, and weather, are likely to have an impact on garlic output. Furthermore, measurement errors are likely to be significant. In this instance, where random shocks and measurement mistakes are substantial, a model that takes noise into account is a better choice.

As a result, the stochastic efficiency decomposition approach was better suited to our investigation. The stochastic frontier production function is stated as follows:

$$Y_i = F(X_i;\beta)\exp(v_i - u_i), i = 1, 2, 3 \ldots 365 \tag{7}$$

Where; Y_i represents output of garlic for the ith farmer in Kg/ha, $f(X_i;\beta)$ is a suitable Cobb-Douglas Production function, Xi, is the inputs used in production of garlic in units/ha, βi are the coefficients to be estimated.

Taking the natural logarithm of the already specified Cobb-Douglas production function, the following linear production function can be easily estimated.

$$\begin{aligned} lnY_i = \beta_0 + +\beta_1 \ln land_i + \beta_2 \ln Seed_i + \beta_3 \ln fertilizer_i + \beta_4 \ln insecticide_i + \beta_5 \ln fungicide_i \\ + +\beta_6 \ln labourday_i + \beta_7 lnloxenday_i + v_i - u_i \end{aligned} \tag{8}$$

Where Y_i is the total yield of garlic in quintal/hectare, land is the total land size allocated for garlic in hectares, labor is the total human labor and non-negative, employed-days per hectare in the production process; seed is the total quantity of garlic seed used in kg per hectare; fertilizer is the total amount of chemical fertilizer used in kg per hectare; insecticide is the total amount of garlic farmland sprays in litter per hectare; fungicide is the volume of fungicide in kg per hectare; and oxen days is the number of oxen days used in oxen days. Because of the smallholder farmers and less mechanized farming practices, including tractor use, in the study area, the number of oxen days involved in garlic farming activity is used as a proxy for capital input for plowing and hoeing activities. It was measured being one-oxen day is equivalent to eight working hours (Wana & Lemessa, 2019). β is a vector of production parameters to be estimated, $v_i$is a random variable which is assumed to be $N(0, \delta^2{}_{vi})$and independent of the u_i which is nonnegative random variable assumed to account for technical inefficiency in production.

The model's explanatory variables (such as seed, labor, fertilizer, and insecticide) have been added to estimate the elasticity of the production function and its technical efficiency and inefficiency components. These explanatory variables have the most influence on production costs and were incorporated into the production function.

Thus, the individual garlic producer's technical efficiency and yield gap may be evaluated using the predicted stochastic production frontiers. The ratio of actual or observed output to the equivalent maximum or potential output given the existing technology was used to calculate production efficiency relative to the production frontier, which is defined as;

$$\mathrm{TE} = \frac{Actual\ output}{Potentail\ output} = \frac{Yia}{Yif*} = \exp(Ui) \tag{9}$$

$$Yif* = \frac{Actual\ output}{Technical\ efficiency} = \frac{Yia}{TE} \tag{10}$$

Where; TE is technical efficiency, Yia is the actual output and Yif* is the frontier/or potential output. In this case, the yield gap (YGi) of the ith farmer in garlic production is the difference between potential yield (Yif*) and actual yield (Yia) and estimated in equation 5 as follows:

$$\text{Therefore, YGi(quantity per hectare)} = Yif* - Yia \tag{11}$$

The TE varies from 0 to 1, or $0 \leq TE \leq 1$. If the TE value approaches 1, the garlic farmer is regarded as the most efficient farmer; if the TE value approaches 0, the farmer is assessed to be technically inefficient (Coelli et al., 2005). Good agricultural practices are followed by a technically efficient farmer. However, it should be emphasized that the TE is assessed only on the performance of the most efficient farmer in the sample.

Similarly, using a one-stage estimation approach, determinant variables of technical inefficiency are regressed on the outputs of a stochastic frontier production function after calculating the efficiency score for each sample household. In single-stage estimation, inefficiency effects are stated as an explicit function of specific independent explanatory variables, and all parameters are estimated in one step using the maximum likelihood (ML) estimation approach. Furthermore, we may test hypotheses about the structure of the production function and the efficiency score of the final output without having to do any further programming.

Smallholder garlic growers' technical inefficiency is influenced by a variety of demographic, socioeconomic, farm attributes, marketing, and institutional variables. These variables include gender, age, education level, family size, and garlic farming experience; land size, livestock size (TLU), extension frequency, soil fertility, credit availability, market knowledge, cooperative participation, and off-farm activities. As a result, the inefficiency model expressed was as follows:

$$\begin{aligned}\mu_i = {} & \delta_0 + \delta_{1i}(M1_i) + \delta_{2i}(M2_i) + \delta_{3i}(M3_i) + \delta_{4i}(M4_i) + \delta_{5i}(\text{M5i}) + \delta_{6i}(\text{M6i}) + \delta_{7i}(M7_i) \\ & + \delta_{8i}(M8_i) + \delta_{9i}(M9_i) + \delta_{10i}(\text{m10}) + \delta_{11i}(M11_i) + \delta_{12i}(M12_i) + \delta_{13i}(M13_i) + Ui\end{aligned} \tag{12}$$

Where μi, is inefficiency score for the ith farm household, δ are parameters to be estimated, and Ui is error term. M1 is the age of the household; M2 is the sex of the household head; M3 is household size; M4 is education level; M5 is the total livestock unit; M6 is land size allocated to garlic; M7 is frequency of extension contact; M8 is access to credit; M9 is distance to the nearest market; M10 is access to information; M11 is rental land; M12 is disease shock; and M13 is farming experience.

3.4. Definitions and measurement of variables used in technical efficiency of garlic

Following the identification of technical inefficiency, the key factors that farmers described differently and caused them to achieve varying degrees of efficiency must be discovered in order to create and advise on critical inefficiency remedies. Stata 14 was used to perform maximum likelihood (ML) estimations of the SPF parameters and the inefficiency impact at the same time. It is also used to obtain the complete descriptive and econometric findings interpreted in the study. To establish the factors to be included in the TE of garlic, a thorough examination of relevant empirical literature was undertaken (Belete, 2020; Geta et al., 2013). As a result, the following variables were hypothesized to affect farmers' technical inefficiency in this study (Table 3).

Table 3. Summary of explanatory variables and working hypothesis

Variables	Measurements	Expected outcome
NB	**Output is in logarithm form**	
Yield of garlic	**Amount of garlic produced (quintal/hectare)**	
Production function		
Land	Land cultivated under garlic production (hectare)	_
Seed	Amount of Seed planted in kg/ hectare	+
Chemical Fertilizers	The amount of UREA and DAP fertilizer in kg per hectare	+
Insecticide	Volume of insecticides used in litter per/hectare	+
Fungicide	Amount of fungicide powder in kg	+
Labor	Total active labor man-days who participated in farming activities per hectare (from Cult-harvesting) (n*d);	+
Capital	The number of a pair of oxen days	+
Technical Inefficiency function		
Age of household head	Continuous (years)	+
Sex of hh head	Dummy (1 for male, 0 otherwise)	+
Household Size	Continuous (no of person)	+
Education (in year of schooling)	Continuous (grade)	+
Livestock holding (TLU)	Continuous (in TLU)	+
Land size in hectare	Continuous(in years)	+
Frequency of extension contact	Continuous (in walking hours)	_
Access to credit	Dummy (1 has got credit, 0 otherwise)	_
Distance to market	Continuous (in hour)	+
Access to market information	Dummy (1=yes, 0 otherwise)	_
Rental land	Dummy, (1=yes, 0 otherwise)	+/-
Garlic disease shock	Dummy, (1=yes, 0 otherwise)	+
Experience in garlic farming		-

Source: authors construction.

4. Results and discussion

4.1. Description of socio-economic variables of sample households

The socioeconomic features of sample households have a significant impact on whether production efficiency is promoted or hindered. After cleaning the data, the overall sample size of farm respondents handled for analysis was 359, as shown in Table 4. The analysis's continuous and dummy variables were both explored (see Table 4). Among the continuous factors, age, for example, impacts the farmers' management experience. During the survey, the average age of the sample farmers was 52.7 years. This suggests that the majority of the sample farmers were in their prime working years. In terms of family size, the average household family size was 4.2, implying that the average family size in the study area was nearly equivalent to the national average family size of roughly 5.2 people per family (Hunde & Abera, 2019). As a result, large family sizes provide a supply of labor for garlic farming operations in developing nations such as the study area. The sample households' average educational level was likewise 2.2. Farmers who improve their information gathering and decision-making skills can produce more with fewer

Table 4. Socioeconomic characteristics of garlic producers

Continuous variables	Mean	St. Deviation	Min	Max
Age	52.7	11.07	34	78
Family size	4.3	1.45	1.4	9.3
Education	2.2	3.08	0	11
Total Livestock Unit (TLU)	3.9	2.30	0	13.8
Land size in hectare	1.1	1.11	0	3.2
Frequency of extension contact	1.9	3.01	0	15
Distance to market	2.1	1.73	0.6	6
Experience in garlic farming	24.7	12.49	3	58
Dummy Variable	**Frequency**			**Percentage**
Sex (1=male)	295			82.2
Access to credit (yes)	120			33.4
Information access (yes)	144			40.1
Rented in land (yes)	204			56.9
Shock (yes)	176			49.0
Observation = 359				

Source: Survey result (2022).

resources. Given the study area's diverse farming economy, livestock plays an important role as a source of revenue. Thus, farmers with larger animal holdings may have less difficulty transporting and purchasing agriculture inputs such as seed, fertilizer, insecticide, and fungicide. Cows, oxen, horses, donkeys, calves, lambs, goats, and hens are among the animals raised by the surveyed farmers. The average livestock size in tropical livestock units (TLU) was 3.9 TLU, ranging from 0 to 13.8 TLU.

In addition, farm households have used the majority of their land for grain cultivation and grazing. The sample households' average farm size was 1.1 ha, which is nearly equivalent to the national average of farmers, which is 1.2 ha (Mussa, 2011). A farmer's maximum land size in Ethiopia is three acres. Despite this, farms larger than 3 hectares exist due to family transfers through inheritance. The average size of the garlic-producing area was 0.1 hectares, with a standard deviation of 0.1. Extension agents also have a significant impact on farmers' production efficiency through the dissemination of agricultural knowledge, including new and better farming practices. As a result, during the 2021/22 production season in the research area, sample farmers were contacted by extension agents an average of 1.9 times, with a minimum of 0 and a maximum of 15 times. Also, the distance to the nearest market was a significant factor in garlic output. According to the study results, the average walking distance from the farmer's residence to the nearest market was 2.04 hours, and the average experience of farmers in garlic cultivation was similarly around 24.7 years.

In terms of the dummy variables, about 82.2% of the sample households were led by males, while the remaining 18% were headed by women. It was discovered that female-headed farmers face bigger challenges in agricultural production and marketing than their male counterparts. Credit access is also projected to help farmers' capacity to employ new farming technology. According to the findings, 33.4% of sample farmers receive financial services, while the remainder do not. Likewise, 41% of the sample household had access to market information regarding the

supply and demand for the garlic crop, and 57% of garlic farmers rented land for agricultural production, while the remaining 43% utilized their land exclusively or rented it out to others. As a result, the rental land market has an impact on the labor supply for garlic cultivation. Finally, 49% of garlic producers have been affected by land diseases such as garlic rust.

4.2. Description of variables used in production function

The mean, standard deviation, minimum, and maximum levels of continuous variables utilized in the study are presented in Table 5. For example, in the Goncha district, the sample's mean real garlic output is 6.2 quintals per hectare with a standard deviation of 4.9, demonstrating more diversity in garlic production among farmers. In the study area, the minimum and highest amounts of garlic output are 0.5 and 30 quintals per hectare, respectively. This suggests that the study region has a low level of output and potential resource usage inefficiencies. Farm households employ land, seed, fertilizer, insecticides, fungicides, labor, and oxen to produce garlic.

The average garlic production land holding was about 0.1 hectare, with a seed rate of 52.7 kg/ha. The average quantity of land allotted to garlic implies that farmers in the study region operate and manage their enterprises on a small scale. In terms of fertilizer, urea and DAP were used in the study area for garlic growing. Chemical fertilizer was applied at a rate of 40.7 kg/ha on average, with a standard variation of 44.7 kg/ha. Weedicide and fungicide, which are utilized in garlic cultivation, were also significant variables. For garlic-growing operations, the sample farmers used 0.3 litter/ha of insecticides and 0.5 kg/ha of fungicide on excess. Furthermore, sampled farmers used 10.6 man days per hectare of human labor and 1.3 ox days per hectare for garlic production activities.

4.3. Empirical analysis: stochastic frontier analysis

In this study, stochastic frontier regressions for the distributional assumption of Ui as a half-normal and exponential distribution were estimated and reported in table 6 below. The log likelihood ratio test shows whether the null hypothesis (Ho: $\delta 2\, u = 0$) is against H1: $\delta 2\, u > 0$ for both exponential and half-normal distribution assumption estimation. If Ho is the true stochastic frontier model, it is reduced to OLS regression with normal error terms. While in this study for half-normal and exponential distributions, chibar2 at 1 degree of freedom is 170 and 240, respectively, with a probability value greater than chibar2 of 0.000, confirming the rejection of the null hypothesis and the existence of technical inefficiency. Once the researcher has determined the existence of technical inefficiencies in the model, the next step is testing whether the truncated normal or half-normal distribution is chosen using the log-likelihood ratio test.

Table 5. Descriptive statistics for both input and output variables

Variables	Mean	St. Deviation	Min	Max
Quantity in quintal	6.2	4.9	0.5	30
Land size allocated to garlic	0.1	0.1	0.001	0.75
Seed (Kg)	52.7	50.4	0.75	400
Fertilizer (Urea +DAP) in Kg	40.7	44.7	0	250
Insecticide in litter	0.3	0.4	0	2.5
Fungicide in esheg (kg)	0.5	0.5	0	3
Labour man day	10.6	7.6	1.5	52
Oxen day	1.3	0.9	0	6

Source: survey result (2022).

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Table 6. Maximum likelihood estimates of stochastic frontier function under different distributional assumption

Variables	Half-normal distribution			Exponential			Truncated		
	Coeff	SE	p-value	Coef.	SE	P-val	Coef	Std.err	P-val
Lndgarlic	2.343	.458	0.000	2.922	.541	0.000	**2.921**	**.541**	**0.000**
Seedkg	.001	.0005	0.011	.001	.0005	0.011	.001	.0005	0.011
Fertkg	.0008	.0005	0.108	.0008	.0004	0.058	.0008	.0004	0.058
Insecticides	.814	.134	0.000	.959	.095	0.000	.959	.095	0.000
Fungikg	.051	.105	0.627	.023	.093	0.802	.023	.093	0.802
Labrday	.001	.003	0.774	−.002	.003	0.552	−.002	.003	0.533
Oxendays	.093	.031	0.003	.055	.023	0.020	.055	.023	0.020
_cons	1.17	.033	0.000	1.091	.032	0.000	1.091	.032	0.000
Mu	——			——			−544.8	552.43	0.324
/lnsig2v	−5.517	.468	0.000	−4.69	.245	0.000	——		
/lnsig2u	−.888	.085	0.000	−1.90211	.1284	0.000	——		
sigma_v	.0633	.014		.0955631	.01172		——		
sigma_u	.641	.027		.3863316	.02481		——		
sigma2	.415	.034		.1583844	.018561		——		
lambdaλ $=\frac{\delta u}{\delta v}$	10.121	.035		4.042684	.030705		——		
Gamma (γ)$=\frac{\delta^2 u}{\delta^2}$	0.9903			0.9425			0.9999567		
LR test of sigma_u =0	chibar2(01) = 1.7e+02		Prob ≥ chibar2 = 0.000	chibar2 (01) = 2.4e+02		Prob ≥ chibar2 = 0.000	——		
/lnsigma2	——			——			5.35121		
/ilgtgamma	——			——			10.04786		
sigma2	0.4152			0.1583			210.8633		
sigma_u2	0.4112			0.1492			210.8542		
sigma_v2	0.0040			0.0091			.0091254		
Log-likelihood	−126.24534			−93.988			−94.026203		

Source: survey result (2022).

Log-likelihood ratio is computed as $LR = \lambda = -2ln(L(H0)/L(H1)) = 2(loglike(H1) - loglike(H0))$. Where, Ho and H1 represents log-likelihood value of half normal (restricted model) and truncated normal (unrestricted model), respectively. That means the half normal distribution is the restricted forms of truncated normal distribution by assuming that mu = 0. Given this, log-likelihood ratio test is $LR = \lambda = 2(-94.026203 - (-126.24534)) = 64.44$, with a critical value Prob > chi2 = 0.0000. The result shows Ho is rejected conforming that the truncated normal distribution which is a one step model is appropriate for this study.

Gamma, which represents the proportion of production loss due to inefficiency, is 99.99%, 99.03%, and 94.25% for the truncated, half-normal, and exponential distribution models, respectively. The value of gamma for the stochastic production function is near one and considerably distinct from zero, suggesting the presence of production inefficiencies in garlic production. As a result, the null hypothesis asserting that the combined impact of production inefficiency effects is zero is rejected since lambda is greater than one. In this study, a truncated normal distribution model with consistent, stable, and/or efficient results is applied.

4.3.1. Kernel density estimation for truncated-normal distributional assumption

The technical efficiency of production, according to Coelli (1995), may be evaluated if and only if the error term for the inefficiency impact is stochastic and has non-negative truncation with truncated normal distributional assumptions. In this study, we looked at the kernel density distribution function, which is represented in Figure 5, and it verified that the inefficiency component of the error term UI is non-negatively distributed with a truncated normal distribution.

4.3.2. Partial elasticity and returns to scale

The coefficients of inputs utilized in the production process could not be understood directly in the trans-log production function with a truncated normal distribution under the assumption of error terms due to the presence of the variables' second order or cross products. Consider the partial elasticity of each input at the mean level when evaluating variables in the trans-log truncated production function. As a consequence, partial elasticity shows the relative importance of production factors in garlic production or the responsiveness of output to a 1% change in the inputs used. Land size assigned to garlic, seed rate, fertilizer, insecticides, and oxen days are among the production parameters that have a substantial and positive influence on the change in garlic output level as expected (See Table 7). Keeping other variables constant, a 1% increase in garlic land size increases garlic output in the study region by 0.145 percent. The result is consistent with the previous studies of Koye et al. (2022), Abate et al. (2019), and Abdulai et al. (2017).

Furthermore, increasing seed amounts per kg by 1% increases garlic yield by 0.033 percent while all other parameters remain constant. This observation is supported by the previous findings of Wana and Lemessa (2019), Abate et al. (2019), and Mina et al. (2021) who showed that seed has a positive effect for increasing crop production. For fertilizer usage, other variables stay constant; a 1% increase in nitrogen fertilizer applied per hectare results in a 0.015 percent increase in garlic production. The findings are aligned with those of Wassihun et al. (2019).Insecticide coefficients are also important inputs to garlic production, meaning that doubling insecticide (L/ha) would result in a 0.14% increase in garlic yield. The optimal application of various sprays on garlic crops aids in the management of garlic disease and the production of maximum yield (Hussain et al., 2014; Mina et al., 2021; Mengesha et al, 2016; Jemal, 2010). Finally, increasing oxen days in the study area by 1% increases productivity by 0.038 units. An increase in the number of oxen-days in the course of land preparation increases garlic yield. The findings are also compatible with the previous findings of Koye et al. (2022), Wana and Lemessa (2019), Wassihun et al. (2019), and Mina et al. (2021).

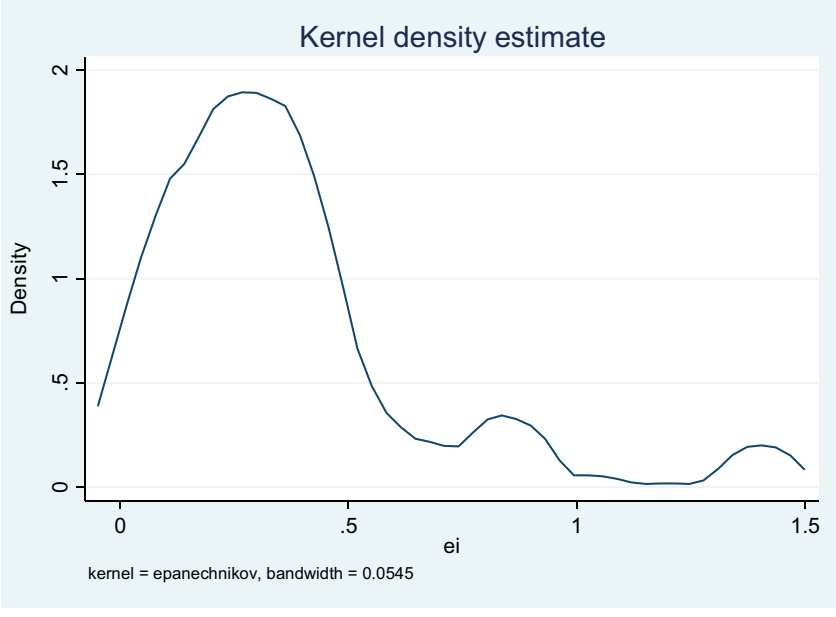

Figure 5. Kernel density estimation of error term, ui under truncated normal distribution.

Table 7. Partial elasticity and returns to scale

Variables	ey/ex	Std. Err.	P>|z|
Land size allocated to garlic	.144	.026	0.000*
Seed (Kg)	.033	.012	0.011**
Fertilizer (Urea+DAP) in Kg	.015	.008	0.057***
Insecticide in litter	.144	.014	0.000*
Fungicide (kg)	.005	.020	0.802
Labour man day	−.012	.020	0.554
Oxen day	.038	.016	0.019**
Returns to scale	0.367		

*,**,and *** are significant level at 1%, 5%, and 10% respectively.

Source: Survey result (2022).

In addition to partial elasticity, it was determined if farm households in the garlic production displayed a growing, stable, or decreasing return to scale. It is discovered that garlic production in the Goncha district has a declining return to scale, which means that the change in output is smaller than a proportional change in all inputs utilized in garlic production.

5. Frequency distribution of technical efficiency of garlic producers

In terms of the frequency distribution of technical efficiency scores, more than half of the garlic producers scored between 0.4 and 0.6 (Table 8). With a mean score of 0.575766, the minimum and maximum technical efficiency scores are 0 and 0.9, respectively. Based on the findings, garlic output may be increased by utilizing the available inputs.

A frequency distribution of the anticipated technical efficiencies is shown in Figure 6 to provide a better understanding of the distribution of the technical efficiencies. According to the frequency of occurrences of the presented technical efficiencies in range, the majority of households have technical efficiencies between 0.4 and 0.6. The sample frequency distribution shows a clustering of technical efficiencies in the 0.4–0.6 efficiency range, which accounts for 57% of the responses. The data also show that there is a significant difference in technical efficiency between the least and most technically efficient farmers in the study area.

6. Analysis of yield gap

According to Table 8, the average garlic output difference between sample farmers due to technical efficiency variance was 4.49 q/ha. This means that the sample farmers lost an average of 12,140.37 birr per hectare, or $2,698.45 birr per quintal. In the research region, the average technical efficiency of garlic production was 73%, with maximum and minimum values of 97% and

Table 8. Frequency distribution of technical efficiency of garlic producers

Efficiency level	Frequency	Percent	Mean	Min	Max
0	20	5.57			
0.1–0.3	61	16.99			
0.4–0.6	206	57.38			
0.7–0.9	72	2.06			
Total	359	1.00			
Technical effi-score	359		.575766	0	0.9

Source: Survey result (2022).

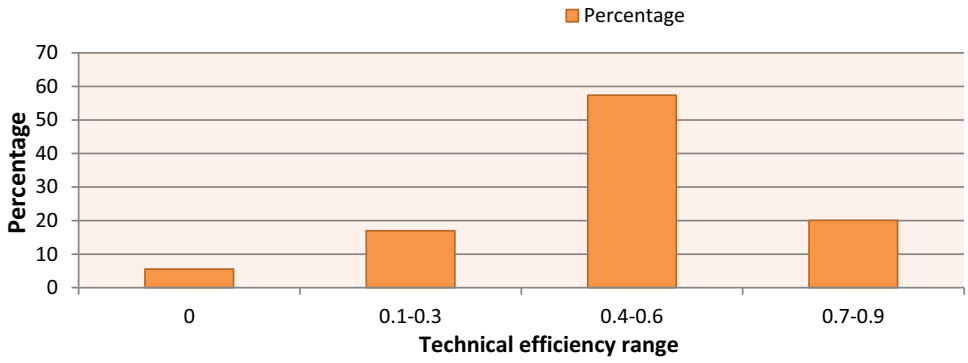

Figure 6. Frequency distribution of technical efficiency scores (source: own survey result, 2022).

4%, respectively (see Table 9). The mean technical efficiency value of 73% means that garlic farmers only attained an output level of 73% at their potential level, and they might gain an extra 27% if technical inefficiencies in production were eliminated. In other words, if resources were used efficiently, the typical farmer could raise current output by 27% while using existing resources and technology.

7. Determinants of technical inefficiency

Table 10 shows the technical inefficiency estimates based on the stochastic frontier. According to the data, the average value of technical efficiency was 73%, showing that there is potential for improvement in production. The typical value of technological inefficiency, on the other hand, was around 38.62%. Table 10 shows the determinant variables of the technological inefficiency model.

7.1. Age

The variance in technical inefficiency among garlic producers has been shown to be explained by age. According to the ML estimation findings, as age increases by one year, garlic inefficiency increases by 0.006 points. Farmers who are older have higher technical inefficiencies than younger farmers. According to Saiyut et al. (2019) and Li and Sicular (2013), the labor force aged 60 and more increases technological inefficiency, but the work force aged 15–69 decreases technical inefficiency. Young farmers are better informed than older farmers, and they employ pertinent information and new agricultural inputs more effectively. Furthermore, physical problems deteriorated as people aged. This might be a source of issues with increasing agricultural production and productivity.

7.2. Extension contact

The frequency of extension contact showed a statistically significant positive effect on technical ineffectiveness (TE). It demonstrates that as the frequency of extension contact increases, so does resource allocation inefficiency. Furthermore, most farmers stated throughout the poll that they lack new skills and information learned from agricultural extension agents. Contacting the extension agent in this situation will simply result in resource underutilization,

Table 9. Yield gap

Variable	Obs	Mean	Std. Dev.	Min	Max
Actual output	359	6.19	4.99	0.5	30
T/Efficiency	359	0.73	0.21	0.04	0.97
Potential output	359	10.69	32.88	2.88	596.57
Yield Gap	359	4.49	30.95	.225	572.57
Money lost (birr/ha)	359	12140.37	92547.74	28.47	1717727

Source: Survey result (2022).

Table 10. Determinants of technical inefficiency

Dependent variable: Technical inefficiency level

Inefficiency Variables	Coef.	Std. Err.	P>|t|
Age	0.01	0.003	.080***
Sex	−0.09	0.06	.146
Household size	−0.01	0.02	.695
Education	0.003	0.01	.705
Total Livestock Unit (TLU)	−0.02	0.01	.189
Land size in hectare	−0.01	0.03	.696
Frequency of extension contact	0.05	0.01	.000*
Access to credit	−0.14	0.05	.008*
Distance to market	0.08	0.02	.000*
Information access	−0.10	0.05	.051***
Rental land	0.14	0.05	.017**
Garlic disease shock	0.18	0.06	.001*
Experience in garlic farming	−0.002	0.002	.456
Constant	−0.07	0.14	.617
	Mean	**SE**	**Min/max**
Technical inefficiency mean (Tineff)	0.38	0.43	.028/3.217
Technical efficiency mean (TE)	0.73	0.21	.040/.972
			Number of obs = 358
			F(13, 344) = 8.27
			Prob > F = .0000

Source: survey result (2022).

creating a positive association with technical inefficiency. The findings are supported by Abate et al. (2019) and Bati et al. (2017). Agricultural extension creates demand among farmers but fails to associate this with the necessary supplies such as improved seeds, fertilizers, and crop pest-and-disease management practices. Despite the log period of agricultural extension program in Ethiopia, significant changes in the provision of advisory services have not been achieved (Spielman et al., 2012). The availability services and the quality of service providers are not more efficient than before.

7.3. Credit

The findings suggest that access to financing has a detrimental impact on garlic producers' technical inefficiency. This means that for every unit of birr received in credit, the inefficiency of garlic production is reduced by 0.139 units. Credit availability transfers the cash restriction outward, allowing farmers to make timely purchases of supplies that they cannot provide themselves. Cash requirements for purchasing inputs on time (seed, fertilizer, fungicide, and pesticide) and a solution for the liquidity trap resulted in farmers being more efficient than their counterparts. The findings are congruent with the previous studies (Abebe & Kegne, 2023; Asfaw & Vasa, 2021; Kumari & Singh, 2023; Musa et al., 2015; Wana & Lemessa, 2019).

7.4. Distance to the market

Distance (proximity to the market) is a favorable and major indicator of garlic production inefficiency. Farmers who live far from marketplaces are more technically inefficient than

those who live near them. This might be owing to farmers' lack of access to input and output markets as well as market information because they are positioned far from the market. If the market was a long distance from homesteads, they would be unable to obtain the most important market information (price, demand and supply of garlic) and they become technically inefficient. Furthermore, a greater distance to market results in a higher transaction cost, which reduces the farmer's advantages. More significantly, being further away from markets inhibits farmers from engaging in market-oriented agriculture. The result is consistent with the findings of Mina et al. (2021); Asfaw and Vasa (2021), Wassihun et al. (2019) and Musa et al. (2015).

7.5. Access to information

Access to information considerably minimizes technological inefficiency. Farmers' access to information boosts their chances of receiving accessible inputs on schedule. Smallholder farmers compete with bigger producers using accessible information, and they enhance their expertise to boost output and productivity as well as market opportunities for their goods (Mariyono et al., 2021). Farmers can do a lot to boost productivity if they have access to and use the necessary information sources (Kisusi & Sife, 2015; Mariyono, 2019). For example, Arinloye et al. (2015) and Mariyono et al. (2021) demonstrate that farmers using mobile phones contact more consumers and are believed to minimize market information asymmetry, notably for input and product pricing. The availability of market and technological knowledge has a considerable impact on the adoption of intensive commercial farming. When farmers have access to market information, vegetable cultivation becomes less risky, and they have more negotiating power over input and output pricing. The availability of vegetable-related technology in the local market, such as hybrid seeds, modern fertilizers, and crop protection inputs, has also greatly contributed to the establishment of commercial vegetable farming operations. Furthermore, the benefits of quick information transmission and real-time access to information (Mwalupaso et al., 2019) boost the possibility for farmers to adopt effective practices and prevent them from making rash judgments. This reaffirms the assertion of Arinloye et al. (2015) and Mariyono (2019) that access to information practices accelerates farmers' technical efficiency.

7.6. Land rent-in

Furthermore, according to the ML estimation result, land rental has a positive and considerable influence on technical inefficiency. This might be due to the ineffectiveness of contractual agreements (Qiu et al., 2021). In rural Ethiopia, rental land markets based on output-sharing agreements are popular. The study backs up the findings of Deininger et al. (2011), who found that renting land through output sharing results in considerably lower levels of efficiency in Ethiopia. Owner-cum-sharecroppers in Ethiopia yield less on sharecropped plots than on owned (or fixed-rental) plots. The following input applications may explain the difference: When compared to operator-cum landlords, the intensity with which family work, manure application, oxen hours for land preparation, and chemical fertilizers are employed is higher on plots farmed by operator-cum tenants (who cultivate their own land). When landlords and renters exchange inputs, efficiency improves. Furthermore, most rental land transactions are carried out with strong social contacts for the sake of family ties, and the land size negotiated in this situation is very small. Because of the difficulties of adding mechanized inputs to small crops, kinship rents resulted in inefficient land use (Holden & Ghebru, 2005). For most small farmers, farm size and production have an inverse connection, whereas big farm sizes have a mild U-shaped association (Sheng et al., 2019).

7.7. Garlic disease shock

Shocks from major garlic diseases such as garlic rust (Worku & Dejene, 2012) and fungus (Mengesha et al, 2016; Jemal, 2010) can result in large crop losses in affected areas. Garlic rust, at its most extreme, causes technical inefficiency by lowering production. Garlic rust starts at the bulb formation stage (Tadesse & Dejene, 2018). As the illness spreads, the leaf

tissue that covers the lesions ruptures, revealing masses of orange, powdery spores that later appear as pustules. Severely diseased leaves are nearly completely covered in pustules, causing widespread yellowing, withering, and premature drying. Garlic rust fungus, on the other hand, later grows on the same leaves, resulting in black pustules. Previous studies back this up. Proper fungicide and weedicide spray plots yield more than unsprayed control plots. Garlic disease impacts technical inefficiency by causing bulb weight losses, bulb diameter reductions, clove number per bulb losses, clove weight losses, and plant height differences (Worku & Dejene, 2012). For example, Worku and Dejene discovered that garlic rust disease caused a 59% loss in Bale, Ethiopia. So that the varying sprays intervals resulted in a variation in overall yield due to the difference in disease severity.

8. Conclusions and recommendations

This study investigates the technological efficiency of garlic farmers in northwest Ethiopia. Results of the Cobb-Douglas production function show that, the estimated mean technical efficiency was 73% and 4.5 quintals of garlic output per hectare were lost. Implying that, garlic producers in the study area are not operating at full technical efficiency and that there is room for garlic producers to increase output at existing levels of input and with the available technologies. The estimated gamma value indicates that 99% of the variation in garlic output is due to the inefficiency factor, and the total production may be enhanced further with more effective use of resources and technology. The maximum likelihood (ML) estimation result also indicated that land size, seed, fertiliser, weedicide, and oxen days were all positive signs and had a significant effect on garlic output, as expected. This depicts that farmers who allocated more land for garlic production and increased the use of seed, fertilisers, weedicides, and oxen days obtained higher garlic yields. With respect to technical inefficiency, factors such as age, extension contact, distance, and garlic disease shock were all shown to be positively linked with technical inefficiency. Whereas access to finance and access to information enhance technical efficiency.

Because garlic plays an important role in enhancing farmers' socioeconomic status, food security, and medicinal use in both rural and urban areas, smallholder farmers must use available inputs as efficiently as possible. Agricultural institutions should do substantial studies on comparative advantage in garlic production efficiency in order to specialise in garlic production. Because there is a considerable mean difference in garlic efficiency and production across the study households, garlic growers should share their experience and specialise to maximise their absolute and comparative advantage. As previously said, there is the possibility of boosting production by enhancing the technological efficiency of garlic producers. As a consequence, agricultural policy initiatives should seek to maximise the use of both stochastic and conventional inputs. Garlic diseases such as garlic rust and fungus, downy mildew, and basal rot have been proven to be the main problems facing garlic producers in the research area. As a result, agricultural extension agents should provide training on how to overcome all of these issues. Corrective actions should be taken to address the supply of chemical pesticides as well as raise farmer understanding about the use of these pesticides.

Since cross-sectional data does not account for other elements such as risk and market imperfections shown by time series data, panel data should be used for future research on garlic production/technical efficiency and to assess how efficiency has changed over time. The findings revealed some important inefficiency in the current garlic production system that might be targeted by policy to boost productivity in the garlic producing economy. Continuous improvements in the technical efficiency of garlic production could assist income development and poverty reduction. As a result, continuous surveillance of technological efficiency in garlic production is required to assess changing agricultural situations and inform policy activities as a cure. This necessitates additional and continuous research.

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Appendix 1. Conversion factor for computation of man – equivalent

Age group (years)	Male	Female
<10	0.6	0.6
11–14	0.9	0.7
15–50	1	0.8
>50	1	0.8

Source: Yenesew et al., (2015).

Appendix 2. Conversion factors used to estimate Tropical Livestock Unit equivalents

Animal Category	TLU
Cow and ox	1.0
Heifer	0.7
Bull	1.0
Weaned calf	0.3
Calf	0.2
Mule	1.1
Horse	1.1
Donkey (adult)	0.7
Donkey (young)	0.3
Sheep and goat (adult)	0.1
Sheep and goat (young)	0.0
Chicken	0.0

Source: Abera et al., (2021).