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ORIGINAL PAPER

Analysis of resource use efficiency for white cumin production among smallholder farmers empirical evidence from Northwestern Ethiopia: a stochastic frontier approach

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Abstract

Cumin is a flowering plant and the second Ethiopian export spice crop next to ginger. The area coverage, as well as the production of white cumin, is increasing year to year. However, there is a growing gap between white cumin demand and supply in Ethiopia due to its low production and productivity of white cumin. Therefore, this study was aimed to investigate factors affecting the technical inefficiency of white cumin production among smallholder producers in Northwestern Ethiopia. A Semi-structured questionnaire was used to collect the primary data from 228 white cumin producers, who were selected by using a systematic random sampling technique. Moreover, a combination of data analysis methods such as descriptive statistics and the stochastic Cobb–Douglas production frontier model was used to analyze the collected data. The empirical result of the study showed that the mean technical efficiency of white cumin production was 81%. This implies that white cumin producers can boost white cumin output by 19% using the existing level of inputs and technology. The maximum likelihood estimates of the stochastic production model revealed that land, Nitrogen-Phosphate and Sulphate, and urea were statistically and positively affected the production level of white cumin. The positive effect indicates that the lack of these inputs would hamper the production of white cumin. Moreover, the maximum likelihood estimate of the stochastic frontier model coupled with the inefficiency parameters indicated that the age of household head, tropical livestock unit, land fragmentation, and membership of cooperatives were found to be statistically and negatively influence the level of technical inefficiency of white cumin producers, whereas family size, distance to the main road and credit access were found to be statistically and positively influence the level of technical inefficiency of white cumin producers. Hence, the study suggested that the government should strengthen farm cooperatives and construct roads near the residence of producers to improve their efficiency level. Moreover, the district experts should arrange an experience-sharing (which is a proxy variable for age) program to improve the efficiency

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level of less efficient producers by adopting the best practice of relatively efficient producers.

Keywords Cobb–Douglas production · Stochastic frontier model · Technical efficiency · White cumin

Abbreviations

ADEA	Association for the Development of Education for Africa
BoFED	Bureau of Finance and Economic Development
CC	Contingency coefficient
CGAO	Central Gondar zone Agriculture Office
EEA	Ethiopian Economic Asssociation
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
MoA	Ministry of Agriculture
LR	Log-likelihood Ratio
NPC	National Planning Commission
SSCC	Spice Sector Strategy Coordinating Committee
TE	Technical Efficiency
VIF	Variance inflation factor

1 Introduction

Agriculture plays an important role in economic growth, enhancing food security, poverty reduction, and rural development of Ethiopia. About 73% of the population is living in rural areas, creating their income from agriculture and relying on a limited resource- land (ADEA, 2014), and 95% of the country's agricultural output is produced by smallholder producers (Chipeta et al., 2015). The sector contributes 38.5% of GDP (NPC, 2015), provides about 83% of employment opportunities and supplies 70% of raw materials for a country agro-industry (EEA, 2012); and contributes about 70% of export earnings (FAO, 2015). This shows that agriculture is still being the main source of livelihood for most households and it needs great attention for improvement and transformation of the country's economy. Despite its importance for the country's economy, the sector is highly relying on a subsistence farming system. Moreover, the productivity of the agricultural sector is incredibly low and lagged behind the increment rate leading to food insecurity.

Likewise, in Amhara National Regional State, agriculture remains the base of the economy. It is practiced by more than 85% of the population residing in rural areas. The sector is also the major source of food, raw materials for local industries, and export earnings. The contribution of agriculture to the regional GDP was 55.4% (Alemayehu et al., 2015). The fact that the region is endowed with diverse agro-ecologies, fertile soil, and plenty of water potential, has a huge potential for the production of a variety of agricultural products including spice crops both for export purposes and domestic consumption.

In Ethiopia, the history of spices is ancient and it serve as basic food items for most Ethiopian people. Ethiopia is the homeland for many spices, for example, Korarima, long pepper, black cumin, white cumin, Bishop's weed, and coriander. The average land covered by spices is approximately 222,700 ha and the production is 244,000 tons/annum (Fikadu-Lebeta et al., 2019). Spice can be a dried seed, fruit, root, bark, or vegetative substance utilized in nutritionally insignificant quantities as a food additive for flavored, and generally as a preservative by killing or preventing the growth of harmful bacteria. Many of those substances are also used for other purposes, such as medicine, religious rituals, cosmetics, perfumery, or eating vegetables. For example, cumin is important for promoting digestion, improving food-borne infections, and improving blood sugar control and cholesterol (Attokaran, 2017).

Cumin (Cuminum Cyminum) is a flowering plant in the family Apiaceae, native from the east Mediterranean countries to South Asia. In the world, around 300,000 tons of cumin are produced per year (NEWUT, 2017). Cumin is the second Ethiopian cash crop exported next to ginger (SSCC, 2010). In Ethiopia, the three main cumin-producing regional states are South Nation Nationalities and People of Ethiopia, Amhara, and Oromia regional states (MoA, 2016). Ministry of Agriculture MoA (2016) reported that the nationally coverage of cumin is 1000 hectares in 2016, and about 3000-kilo grams were harvested per hectare. The area coverage, as well as the production of cumin, is increasing from year to year. But the increment is not as expected. Cumin is an important cash crop in the Central Gondar zone. According to CGAO (2019), the total area covered by cumin was 4485 hectares with the estimated production of 83,775 quintals, of which the total area covered by white cumin was 2416 hectares with the estimated production of 67,499 quintals during the 2018/2019 production season. However, the production of cumin is low in the Central Gondar zone as compared to India (total area covered by cumin was 781,000 hectares with an estimated production of 4,999,800 quintals during 2017/18 production season) (Rahman et al., 2020), unless effort should be made to increase the production and productivity of cumin. Among the challenges that white cumin producers are facing; lack of improved seed, not applying the recommended fertilizer rate, poor knowledge on post-harvest handling, and absence of improved agronomic practice.

There is a growing gap between cumin demand and supply in Ethiopia, because of the low productivity of the agriculture sector. The serious reliance on traditional farming techniques and poor harmonizing services such as extension, credit, marketing, and infrastructure are the major factors that greatly hinder the development of agriculture in Ethiopia (MoA, 2013). Accelerating the adoption of improved agricultural technologies by smallholder producers is believed to result in a higher output. However, the required substantial gains could not only be achieved by the adoption of improved agricultural technologies but also efficient utilization of the existing resource is essential. The production inefficiency of smallholder producers in Ethiopia has been one of the key factors limiting agricultural productivity, especially cumin production (MoA, 2016).

Therefore, to improve white cumin production and productivity, it is essential to take on technical efficiency at the farm level under the existing resource to enhance the contribution of the white cumin sector to the national economy. Moreover, identifying the level of efficiency and the factors that influence efficiency is of supreme importance on the level of resource use efficiency in white cumin production. Such information is essential for formulating appropriate policies and improving the level of technical efficiency.

Measuring the efficiency level of producers benefits economies by determining the extent to which it is possible to boost productivity by improving the neglected source of growth (efficiency) with the existing resource base and available technology. There have been various empirical studies conducted to measure technical efficiency in Ethiopia (Beshir, 2016, Abate et al., 2019, Haile, 2015). Nonetheless, the findings of those studies may not apply to the case of white cumin production within the Central Gondar zone due to the diverse agro-ecological zone, differences in the know-how of the producers, differences in the output produced, and variations in technology and means of production. To the best of the authors' knowledge, no studies were undertaken on the technical efficiency of white cumin-producing producers within the study area. Moreover, it is imperative to update the information based on the current productivity of white cumin producers. However, the productivity of the agricultural system in the study area is very low. The poor production and productivity of crops resulted in food insecurity. Therefore, this study was measured the technical efficiency and identified factors affecting the technical efficiency of smallholder producers on white cumin production.

2 Research method

2.1 Description of the study area

The study was conducted in the Central Gondar zone, Amhara National Regional State, the federal democratic republic of Ethiopia. It is located in the northwestern part of Ethiopia. The zonal capital city is Gondar and geographically Gondar is located at $12^{0}35'60.00N$ latitude and $37^{0}28'0.01E$ longitudes with an average elevation of 2133 m above sea level. Gondar is the capital of Ethiopia until the mid-nineteenth century (Abate et al., 2019). Gondar is located at 725 km from Addis Ababa (the capital city of Ethiopia), 175 km from Bahir Dar (the capital city of Amhara National Regional State), and 120 km from the Simien Mountains at an elevation of 2133 m above sea level. Until the seventeenth century, Ethiopia had no capital, as the empire's rules moved about their territory living in tents in mobile royal camps while the food was provided by producers around the camp. The history of Gondar city begins in 1636, Emperor Fasilides ended the tradition by decreeing Gondar to be Ethiopia's capital and started building a walled enclosure around his castle became the palace compound for half a dozen of various palaces 3 churches and support buildings built two centuries by his successors. The most famous Gondar castles of Ethiopia are located in this 7 ha walled compound, the residence of Ethiopia's government from the seventeenth to the first half of the nineteenth centuries, now being part of the Gondar UNESCO World Heritage Site (Internet, Accessed December 24, 2019). The zone is divided into 13 districts and its boundaries are adjoin with North Gondar zone in the North, Awi zone and West Gojam zone in the South, Waghimra zone in the East, South Gondar zone in the Southeast and West Gondar zone in the West. The zone has a total population of 2,048,975 of which 1,034,412 (50.48%) are men (BoFED, 2009). The zone is dominated by the agriculture sector, which practices a mixed farming system. Agriculture in the study area is mainly rain feed and crop production is constrained by low soil moisture because of erratic and unreliable rainfall especially during the spring season. The type of crops that are commonly grown in the study area is teff, maize, wheat, sorghum, black cumin, **white cumin**, red pepper, barley, chickpea, onion, and oats. The study was conducted in three districts (Takusa, east, and west Demba) which are the major potential white cumin producers in the Central Gondar zone (Fig. 1).

2.2 Sampling technique and sample size determination

A combination of various sampling procedures was employed to select the samples to successfully meet the objectives of the study. The sample size was largely determined by the financial and time constraints. However, an effort was made to improve the reliability of the samples by taking care of each level of the data collection process. The sample frame of the study was the list of households in the selected kebeles, which are found in the study area. The population of interest comprised of white cumin growing producers, at least the producers that grew white cumin in the 2018/2019 production season. A multi-stage sampling technique was employed to draw the appropriate sample of smallholder white cumin producers. In

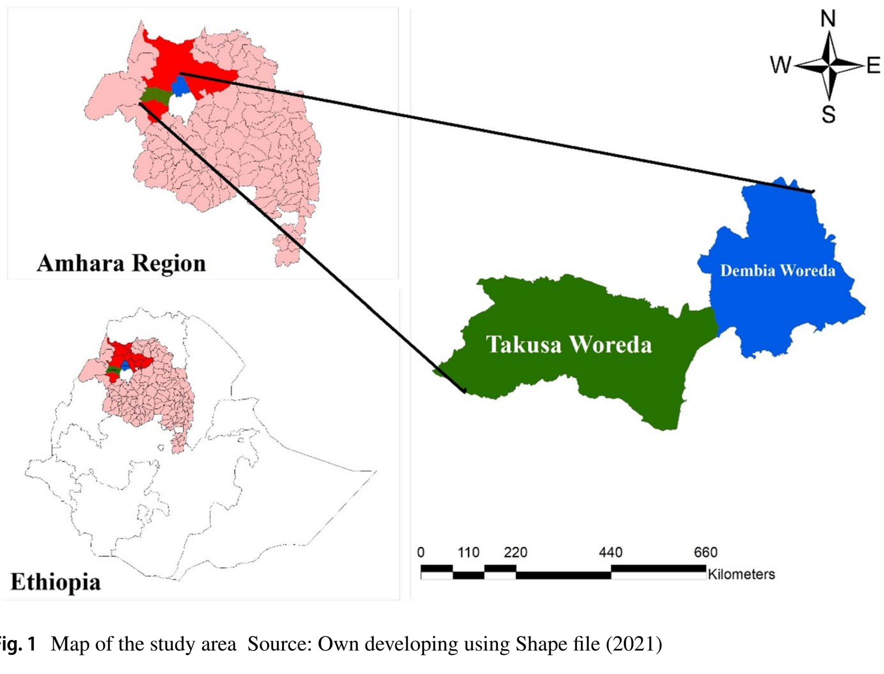

Fig. 1 Map of the study area Source: Own developing using Shape file (2021)

the first stage, East Dembia, West Dembia, and Takusa districts were selected purposively in consultation with Central Gondar zone Agriculture office experts due to the high production potential and best smallholder farming experience of white cumin production. In the second stage, 3 kebeles were selected from each district by using a simple random sampling procedure. In other words, 9 kebeles were selected from these districts by using a simple random sampling procedure. In the third stage, using the population list of white cumin producers from sample kebeles, the intended sample size was determined proportionally to the population size of white cumin producers. Hence, using systematic random sampling technique, 228 white cumin producers were selected using a formula developed by Cochran (1977):

$$n = \left[\frac{Z^2 pq}{e^2}\right] = \frac{1.96^2(0.5 * 0.5)}{0.065^2} = 228 \quad (1)$$

where; n = Sample size; Z = confidence level (Z = 1.96); p = 0.5, q = 1−p and e = 0.065 (error term).

2.3 Data source and collection method

Both primary and secondary data sources were collected to meet the objectives of the study. A structure and semi-structured questionnaires were prepared, pre-tested, and refined to collect the primary data. Nine experienced enumerators were recruited and trained to collect data from 228 smallholder white cumin producers during the 2018/2019 production season. Moreover, focus group discussion, observation, and key informant interviews were employed both by researchers and enumerators. Secondary data were collected from studies conducted by scholars and information documented at different levels of districts agriculture office, central Gondar zone agriculture office, Ministry of agriculture and central statistical agency.

2.4 Data analysis method

The theory and concept of measurement of efficiency have been linked to the use of production functions. The appropriate technique to measure the efficiency of firms is the parametric frontier approach. The parametric frontier technique can be classified into deterministic and stochastic frontier techniques. The deterministic parametric frontier approach only considers the error term is deviated due to inefficiency whereas the stochastic frontier approach splits the error term into two parts to accommodate factors that are purely random and are out of the control of the firm. The stochastic frontier approach was employed to estimate the level of technical efficiency of producers, because of its ability to distinguish inefficiency from deviations that are caused by factors beyond the control of producers. Crop production is likely to be affected by random shocks such as measurement error, bad weather, drought, bad luck, and pest infestation which are out of the control of the producers. In such circumstances where random shocks exist, a model that accounts for the effect of random noise is more appropriate to choose. Thus, the stochastic efficiency decomposition methodology was more recommended for this study. The stochastic frontier production function could be written as:

$$Y_i = F\left(X_i\beta\right) \exp\left(v_i - u_i\right) \quad \text{i} = 1, 2, 3, \ldots\ldots\ldots\ldots 228 \tag{2}$$

Using a linear representation, the empirical production function with technical inefficiency model to be estimated was written as:

$$\begin{aligned} \ln Y_i = &\beta_0 + \beta_1 \ln lab + \beta_2 \ln land + \beta_3 \ln NPS + \beta_4 \ln Urea \\ &+ \beta_5 seed + \beta_6 \ln oxen + v_i - (\delta_0 + \delta_{1i}\left(Age_i\right) + \delta_{2i}\left(Educ_i\right) \\ &+ \delta_{3i}\left(Famsize_i\right) + \delta_{4i}(Landsize_i) + \delta_{5i}\left(TLU_i\right) + \delta_{6i}\left(Nplot_i\right) \\ &+ \delta_{7i}\left(Soilf_i\right) + \delta_{8i}\left(FExt_i\right) + \delta_{9i}\left(DisDC_i\right) + \delta_{10i}\left(Coop_i\right) \\ &+ \delta_{11i}\left(DisNMkt_i\right) + \delta_{12i}\left(DisMR_I\right) + \delta_{13i}\left(Credit_i\right) \\ &+ \delta_{14i}\left(OFFNON_i\right) + \delta_{15i}(Mkt \inf o) + \varepsilon_i) \end{aligned} \tag{3}$$

where ln denotes the natural logarithm; i represents the i^{th} farmer in the sample; Y_i is white cumin output for the i^{th} farmer; X_i is farm inputs used by the farmer, β is a vector of unknown parameters, v_i is a random variable which is assumed to be $N\left(0, \sigma^2_{v_i}\right)$ and independent of the u_i which is nonnegative random variable assumed to account for technical inefficiency in production.

According to Kopp and Smith cited in Abate et al. (2019), who suggest that functional specification has little impact on the measurement of efficiency, but the stochastic frontier approach needs a prior specification of functional form. The log-likelihood ratio test confirmed that Cobb- Douglas production function is the best functional form of this study (sTable 1). Moreover, a single-stage estimation procedure was used to analyze the determinants of resource use efficiency of white cumin from a stochastic frontier production function. In single-stage estimation, inefficiency effects are defined as an explicit function of certain factors specific to the firm, and all the parameters are estimated in one step using the maximum likelihood procedure. In efficiency analysis, Coelli (1996) suggested that two-stage and single-stage estimation approaches will be used for estimating factors affecting technical efficiency based on SPF. In contrast to single-stage estimation approach, two-stage estimation approach yields a bias and inconsistent estimate; and estimates the standard model and the influences of inefficiency variables on efficiency separately. Those biases are substantial enough that two-stage approach is not recommended against using single-stage approach for identifying factors affecting technical inefficiency.

Table 1 Summary of tests of the assumption of Stochastic Frontier Approach *Source* Model output (2019)

Null hypothesis	Degree of freedom	*LR*	x^2 value	Decision
$H_0 : \gamma = 0$	1	115.66	3.84	Not accepted
$H_0 : \beta_7 = \cdots = \beta_{27} = 0$	21	30.83	32.67	Accepted
$H_0 : \delta_1 = \cdots = \delta_{15}$	15	115.66	23.69	Not accepted

Resource use inefficiency of smallholder white cumin producers depends on demographic, socioeconomic, farm attributes, marketing, and institutional factors. These factors include age, education status, family size in adult equivalent, tropical livestock unit, land size allotted for white cumin, number of plots for white cumin, soil fertility, frequency of extension contact, distance to development center, membership of cooperatives, distance to the nearest market, distance to the main road, credit access, off/non-farm income activity and market information. The expected influences of each of the hypothesized variables that were affected resource use inefficiency are explained below:

Age refers to the age of the household head measured in years. It is a proxy variable for farming experience, in which producers with more years of experience are expected to be less technically inefficient. As the age of the household increases, the producers will be able to use resources efficiently which yields the maximum possible output. On this ground, the age of the household was hypothesized to influence technical inefficiency negatively. A study conducted by Abate et al. (2019), found that as the age of producers increases, the level of red pepper technical efficiency increases. A study done by Belete (2020), also found that as the age of producers increases, the technical efficiency of maize production increases.

Education status it is measured as a dummy variable that takes a value of 1 if the household is literate and 0 otherwise. It is a proxy variable for the managerial ability of a farmer. Hence, it enhances the acquisition and utilization of information on improved agricultural technologies by the farmer to improve crop production. As a result, educated producers are more efficient than their counterparts. On this ground, the education status of the household head was hypothesized to influence technical inefficiency negatively. Education enhances producers' ability to utilize existing technologies and develops flexibility in decision making, which leads to higher level of technical efficiency (Abate et al., 2019*;* Lagiso and Geta, 2019).

Family size the family members of a household head measured in adult equivalent. Under the subsistence farming system, family size constitutes the major labor supply to the farm. The family size members within a given farming household influence the crop production activity. As a result, the family member in a given household is more; the technical efficiency of a farmer in crop production is also more. A study conducted by *Lagiso and Geta (2019) and Shumet (2011),* found that households who have large family size were more technical efficient in red pepper and maize production, respectively, than those who have less family member. On this ground, the family size of a household was hypothesized to influence technical inefficiency negatively.

Livestock holding it is a proxy variable for the wealth status of a household and measures the number of livestock holding of household heads in tropical livestock units. Crop production is highly supplemented and complemented by animal husbandry. The income obtained from livestock serves for investment in crop production (purchase of inputs) that would improve the productivity of the households. A study done by Belete (2020), Wondimu (2014) and Getahun (2014), found that farmer who owning more livestock were more efficient than those who own less livestock. Hence, livestock holding was hypothesized to influence technical inefficiency negatively.

Farm size Land/farm is one of the most important and scarce resources in agricultural production. The size of landholding is hypothesized to have a positive impact on the technical inefficiencies of white cumin production. Small land size is expected to be more efficient than large farms because of its simplicity in management and transaction costs. A study conducted by Sisay et al. (2016) and Belete (2020), found that land size was negatively affecting the technical efficiency of maize production. Hence, a household with a large land size was hypothesized to be more technically inefficient than a household with less land size.

Land Fragmentation This refers to the number of farm plots that a farmer cultivates white cumin during the 2018/2019 production season. This variable is continuous and it was expected to influence the technical inefficiency of white cumin production negatively. A study done by Abate et al. (2019), found that producers with a greater number of red pepper plots were more technical efficient than those who have less red pepper plots.

Soil fertility status it is measured as a dummy variable that takes a value of 1 if the household head perceives his white cumin plot is fertile and 0 otherwise. It is the quality of soil that enables it to provide nutrients in adequate amounts and proper balance for the growth of a specific crop. Fertile lands are more productive than infertile lands since fertile lands are more responsive to fertilizer inputs. Producers owned more fertile land /having more fertile land/ are more efficient than those who owned /have) less fertile land (Ayele et al., 2019 and Hassen et al., 2010). Hence, it was hypothesized that fertile soil influences the technical inefficiency of white cumin production negatively.

Frequency of extension contact Agricultural extension is recognized as the consciousness of communication of information to help producers form sound opinions and make good decisions. It is a continuous variable measured by the frequency of producers' contact with extension agents per year during the 2018/2019 production season. Producers who have better extension services are expected to be more efficient than others. In other words, provision of intensive extensive extension services about best practices and production enhancing technologies would shift producers from relatively lower to higher level of efficiency (Dessie et al., 2020; Abate et al., 2019; Lagiso and Geta, 2019; and Lindara et al., 2004). Hence, it was hypothesized that the frequency of extension contact influences the technical inefficiency of white cumin production negatively.

Distance to development center Distance to the development center is used as a proxy for assessing the accessibility of extension services to a farmer in white cumin production. Proximity to the development center has the advantage of obtaining technical supports from extension workers related to the utilization of technologies in white cumin production. Hence, distance from the development center was hypothesized to influence the technical inefficiency of white cumin production positively.

Membership of cooperatives membership of cooperatives is used as a proxy for assessing the role of the association in the technical efficiency of white cumin production. Farmer cooperative facilitates information provision related to price, profitability, availabilities of new technology, and the provision of credit services to its members. It is measured as a dummy variable that takes a value of 1 if the household head is a member of cooperatives and 0 otherwise. Agricultural cooperatives are operated in the agriculture sector of the national economy and they are supposed to increases the efficiency of crop production and promote agricultural technologies for efficient utilization of economic resources for crop production (Abebe, 2009). A farmer who is a member of a farmer cooperative is more likely to adopt improved agricultural technologies and hence be efficient in white cumin production than others. On this ground, membership of cooperative was hypothesized to influence technical inefficiency of white cumin production negatively.

Distance to the nearest market It refers to the distance white cumin producer's travel to buy inputs and sell their products in the nearest market. It is used as a proxy variable to access production information, research centers, and agricultural inputs. It is a continuous variable measured in kilometers. Producers whose residence nearer to the district market are less inefficient that those who are far from the district market (Tesfaw et al., 2021). Hence, the proximity of the farmer's house to the market was hypothesized to have a negative influence on the technical inefficiency of white cumin production.

Distance to the main road It is used as a proxy variable for assessing the accessibility of the main road to producers. It is a continuous explanatory variable measured in kilometers. A study done by Tafesse et al. (2020), found that households living far away from the main road were less technical efficient than their counterparts in moringa production. Hence, the proximity of the farmer's house to the main road was hypothesized to have a positive influence on the technical inefficiency of white cumin production.

Credit access It is a dummy variable taking a value of 1 if a farmer received and used credit in white cumin production and 0 otherwise. The availability of credit for a resource-poor household is important to finance agricultural activities. It is an important element in agricultural systems. It affects the ability of a farmer to obtain the necessary inputs at the right time and in suitable quantities. The availability of credit will loosen the constraints of production; facilitating the acquisition of inputs on a timely basis and hence it is supposed to increase the level of efficiency of the producers. It allows producers to satisfy their cash needs induced by the production cycle. Producers who receive credit were assumed to beat liquidity constraints, purchase more production inputs, or a new technological package such as high-yielding seeds since this can be regarded as access to funds (Bekele, 2013; Belete, 2020 and Tafesse et al., 2020). Hence, credit access was hypothesized to have a negative influence on the technical inefficiency of white cumin production.

Off/non-farm income activity It is a dummy variable taking a value of l if a farmer participated in off/non-farm income activity and 0 otherwise. Off/non-farm income activities refer to activities out of their farm and other than farm, respectively. Being involved in off/non-farm activities might have a systematic effect on the production efficiency of producers. This is because producers may allocate more of their time to off/non-farm activities and thus may lag in agricultural activities. The effect on the production of a farmer being involved in off/non-farm activities may be twofold. First, if farmer spends more time on–off/non-farm activities relative to farm activities, this may negatively affect agricultural activities. Second, financial gain generated from off/non-farm activities might be used to acquire purchased inputs and hence positively complement farm activities and will be used as additional money to buy agricultural inputs and also be a supplement for home use (Abebe, 2014, Teklemariam, 2014). Hence, it was hypothesized that a farmer engaged in off/non-farm activities to be less technically inefficient than his counterpart.

Access to market information This is a dummy variable taking the value of 1 if the producer had access to market information and 0 otherwise. The better information producers have the more efficient utilization of inputs which in turn increases the technical efficiency of white cumin production. The general idea is that maintaining a competitive advantage needs a sound business plan which suggests producing optimum white cumin. Hence, it was hypothesized that households who have access to better information are expected to be less technically inefficient than others.

3 Result and discussion

3.1 Estimation of production function

The stochastic production frontier was applied using the maximum likelihood estimation procedure using the Frontier 4.1 computer program (Coelli, 1996). Before proceeding to model estimation, it looks necessary to detect the assumption of the stochastic production frontier model. Therefore, the following hypothesis tests were made for the assumption of the stochastic production frontier model.

First, a test was made for the presence of multicollinearity among continuous and categorical /dummy explanatory variables using variance inflation factor (VIF) and contingency coefficient (CC), respectively. The values of VIF and CC for both types of variables entered into the model were below 10 and 0.75, respectively, which indicates that there is no severe problem of multicollinearity among explanatory variables that were entered into the model.

Second, it is important to test the presence of inefficiency in the white cumin production function for the sample households. This is important to decide whether or not the standard average production function 《OLS》 best fits the data set as compared to the stochastic frontier model 《SFM》. The test was carried out by estimating the stochastic frontier production function and calculating the log-likelihood ratio test assuming that the null hypothesis of no technical inefficiency $\left(H_0 : \gamma = 0\right)$. The log-likelihood test statistics are calculated when the stochastic frontier model is estimated using FRONTIER 4.1. The log-likelihood ratio test is computed to be $LR = -2\left(LH_0 - LH_1\right) = -2(-95.309 - (-37.48)) = 115.66$. This indicates that the inefficiency component of the disturbance term is statistically different from zero because the calculated value exceeds the critical $\chi^2(5\%, 1)$ value of 3.84 at 5% of level of significance (Table 1). Thus, the null hypothesis of inefficiency is rejected which indicated that there is statistically significant inefficiency in the data. Therefore, the stochastic frontier production function was an adequate representation of the data over the traditional average production function.

Third, it is necessary to test the selection of the appropriate functional form (Cobb–Douglas versus Translog production function (Table 2)) for the data based on the calculated log-likelihood ratio test value. The calculated log-likelihood ratio

Table 2 Maximum Likelihood (ML) estimate of stochastic production frontier for White cumin Farmers (Transcendental (Translog) Production Function)

Variables	Parameters	Maximum Likelihood estimates	
		Coefficient	Std. Err
Constant	β_0	3.498***	1.308
LnLabor	β_1	−0.104	0.640
LnLand	β_2	−0.290	0.757
LnNPS	β_3	1.183***	0.321
LnUrea	β_4	−1.073***	0.336
LnSeed	β_5	−0.806	0.619
LnOxen	β_6	0.013	0.586
LnLabor*LnLabor	β_7	−0.076	0.133
LnLabor*LnLand	β_8	0.007	0.188
LnLabor*LnNPS	β_9	−0.255***	0.082
LnLabor*LnUrea	β_{10}	0.242***	0.087
LnLabor*LnSeed	β_{11}	0.384**	0.162
LnLabor*LnOxen	β_{12}	0.153	0.159
LnLand* LnLand	β_{13}	0.003	0.083
LnLand* LnNPS	β_{14}	0.079	0.054
LnLand* LnUrea	β_{15}	−0.113	0.591
LnLand* LnSeed	β_{16}	0.264	0.197
LnLand* LnOxen	β_{17}	−0.054	0.152
LnNPS* LnNPS	β_{18}	−0.033	0.023
LnNPS* LnUrea	β_{19}	0.045*	0.025
LnNPS* LnSeed	β_{20}	−0.016	0.081
LnNPS* LnOxen	β_{21}	0.017	0.072
LnUrea* LnUrea	β_{22}	0.007	0.014
LnUrea* LnSeed	β_{23}	−0.019	0.083
LnUrea* LnOxen	β_{24}	0.047	0.073
LnSeed* LnSeed	β_{25}	−0.006	0.034
LnSeed* LnOxen	β_{26}	−0.298*	0.158
LnOxen* LnOxen	β_{27}	0.032	0.039
Sigma-squared (σ^2)		0.053***	0.007
Gamma (γ)		0.999***	8×10^{-5}
Log-likelihood function		−52.895	
Total sample size		228	

***, ** and * show significance at 1, 5 and 10%, respectively

Source: Model output (2019)

is equal to 30.83, and the critical χ^2 at 21 degrees of freedom and 5% level of significance is 32.67 (Table 1). This indicates that the coefficients of interaction terms are statistically not different from zero. Thus, the null hypothesis that all the coefficients of the interaction terms and the square specification of the input variables in the Translog production function specification are equal to zero was accepted.

Therefore, the Cobb- Douglas production functional form was appropriately represented the data and used to estimate the technical efficiency of the sample households in the study area.

Fourth, it is necessary to test the hypothesis which stated that the technical inefficiency effects were not related to the variables specified in the inefficiency effect model. Hence, this hypothesis was rejected at less than 5% level of significance, because the computed LR test statistics was greater than the critical value of Chi-square at 5% probability level (Table 1). Thus, the observed technical inefficiency among white cumin producers in the study area might be attributed to the variables specified in the stochastic frontier model and the variables exercised a significant role in explaining the observed technical inefficiency.

During the production function estimation, a single estimation procedure was applied using the Cobb–Douglas functional form in the Frontier 4.1 computer program. Both the OLS and MLE estimates are obtained (Table 3). In total 21 variables were estimated in the stochastic frontier model including six variables in the Cobb-Douglas production function and fifteen variables were the hypothesized explanatory variables that influence the technical inefficiency.

The stochastic production frontier model result showed that, out of six input variables estimated in the C-D production function, three of them (land, NPS, and urea) were statistically significant. Land allotted for white cumin production had a significant and positive influence on white cumin productivity at a 1% level of significance. This suggests that increasing the land size allotted to white cumin production would increase white cumin productivity. That means, other things being constant, a 1% increase in the land allotted for white cumin will increase the output of white

Table 3 Ordinary least squares (OLS) estimates of the average production function and Maximum Likelihood (ML) estimate of stochastic production frontier for White cumin Farmers

Variables	Parameters	Ordinary Least Square estimates		Maximum Likelihood estimates	
		Coefficient	Std. Err	Coefficient	Std. Err
Constant	β_0	1.606	0.291	2.155	0.295
LnLabor	β_1	0.130	0.075	0.079	0.073
LnLand	β_2	0.393	0.071	0.354***	0.074
LnNPS	β_3	0.094	0.018	0.059***	0.018
LnUrea	β_4	−0.020	0.018	0.030*	0.016
LnSeed	β_5	0.174	0.054	0.038	0.052
LnOxen	β_6	0.141	0.048	0.064	0.044
Sigma-squared (σ^2)		0.139		0.085***	0.011
Gamma (γ)				0.149***	0.039
Log likelihood function		−95.309		−37.480	
Total sample size		228			
Return to Scale				0.443	

*** and * show significance at 1 and 10% respectively

Source: Model output (2019)

cumin by 0.354%. The main reason is that land is the single most important factor of production to increase the output of white cumin in the study area.

Similarly, the application of NPS and urea had a significant and positive influence on white cumin productivity at a 1% and 10% level of significance, respectively. Other things being constant, a 1% increase in NPS and urea application for white cumin will increase the output of white cumin by 0.059 and 0.03%, respectively. This implies that producers who apply a recommended rate of NPS and urea (which means 45 kg/ha nitrogen and 30 kg/ha phosphorus (Tesfaye, 2017)) would receive a higher white cumin yield. Hence, increasing the current level of NPS and urea application will significantly increase the productivity of white cumin production. This result is in line with Geta et al. (2013), who found that increasing the application of chemical fertilizer would increase the productivity of maize. Therefore, a positive sign shows that the lack of these farm inputs would hamper agricultural crop production.

The estimated value of sigma squared $\left(\sigma^2\right)$ for the stochastic frontier model of white cumin output was 0.085 which is statistical significance at a 1% level of significance. This revealed that the goodness of fit of the specified assumption of the distribution of the composite error Abate et al. (2019), Ahmed et al. (2014) and Degefa et al. (2017). The estimated value of gamma (γ) was 0.149 which measures the extent of variability between the observed and frontier output affected by the technical inefficiency. This implies that about 14.9% of the total variation in white cumin output is due to technical inefficiency. Furthermore, the result of the frontier model indicated that the input variables specified in the model had an inelastic effect on the production of white cumin. The analysis of return to scale (which is a measure of resource total productivity) for white cumin production was obtained by the summation of the partial elasticity of all inputs which had a significant effect. Thus, the summation of the partial elasticity was 0.443 which indicates that white cumin production in the study area is operating at a decreasing return to scale. Hence, by increasing all inputs by one percent the output of white cumin will increase by less than one percent. This result is in line with Abate et al. (2019), who found that by increasing all inputs by one percent the output of red pepper would increase by less than one percent.

3.2 Technical efficiency scores and yield gap due to technical inefficiency

The stochastic frontier model result revealed that the technical efficiency scores of white cumin production varied from 40.1 to 99.6% with the mean technical efficiency of 81% (Table 4). This indicates that if sample producers operated at full efficiency level, they would increase their white cumin output by 19% using the existing inputs and level of technology. This indicates that most producers in the study area are using their existing resources inefficiently. Hence, in the short run, there is room (an opportunity) to increase white cumin output by using the existing inputs and performing the practice of technically efficient producers in the study area.

Knowing the individual producer's technical efficiency and actual output in white cumin production enables us to determine the potential level of white cumin output

Table 4 White cumin yield gap due to technical inefficiency

Variable	Mean	Std. Dev	Min	Max
TE	0.810	0.161	0.401	0.996
Actual Yield	11.375	8.389	2	49
Potential Yield	14.879	14.550	3.039	118.778
Yield Gap	3.504	7.853	0.034	69.778

Source: Own survey result (2019)

that producers produce through efficient use of existing inputs and technology. The potential white cumin output was estimated for sample white cumin producers by dividing the actual individual level of white cumin output by the predicted technical efficiency scores from the stochastic frontier model. After calculating potential white cumin output the yield gap of white cumin was estimated. The yield gap is estimated by the difference between technically full efficient white cumin yield and observed white cumin yield.

It was observed that mean technical inefficiency was 19% which caused a 3.504 quintal per hectare yield gap of white cumin on average with a mean value of the actual output and the potential output of 11.375 and 14.879 quintals per hectare, respectively. This shows that sample households in the study area were producing on average 3.504 quintals per hectare lower white cumin output than their potential yield. In other words, the result indicated that in the short run there is a potential to increase white cumin output on average by 3.504 quintals per hectare at the existing input use and technology through improving the technical efficiency of producers. Figure 2 illustrates that under the existing practices there is room to increase white cumin yield following the best-practiced farms in the study area.

The frequency distribution of TE at which sample households operate is presented in Fig. 3. They vary from one farmer to another in a range from 0.41 to 0.996. Most households had a higher technical efficiency level. That means the distribution of the technical efficiency scores is skewed to the right. Most of the sample producers have TE scores greater than or equal to 50%. More than 36.84% of sampled producers have a TE score above 90%, meaning that there is room to enhance production by 10%. To the other end, there are also groups of sample producers with very low (less than 0.5) levels of efficiency. The frequency distribution of efficiency indexes indicates that there is a high technical efficiency variation among producers. Hence, the presence of technical inefficiencies could be eliminated by implementing the practice of technically efficient white cumin producers in the study area.

3.3 Determinants of technical inefficiency of white cumin producers

The stochastic production frontier model was used to estimate factors affecting the technical inefficiency of white cumin production. In crop production, technical inefficiency is affected by a wide range of household and farm-specific factors. After measuring the level of technical efficiency and having information about the existence of inefficiency, it is essential to identify the source of variation in technical

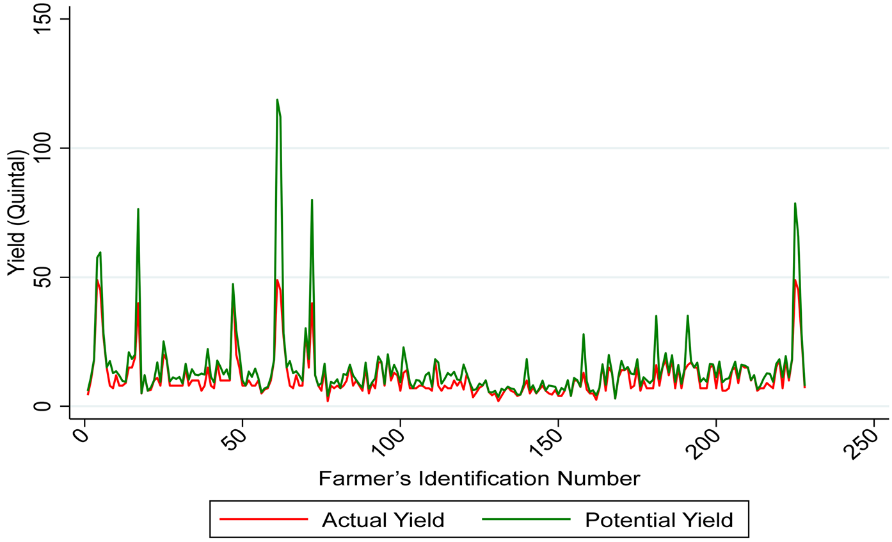

Fig. 2 Comparison of the actual and the potential level of yield

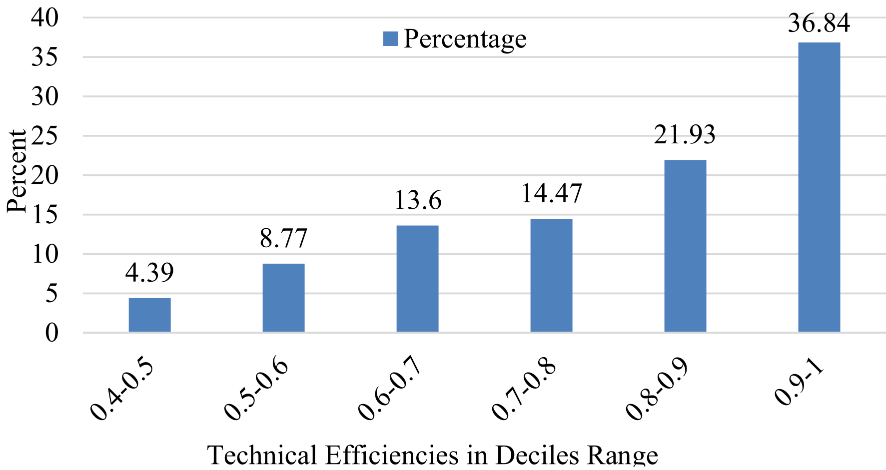

Fig. 3 Frequency distribution of technical efficiency

inefficiency. The maximum likelihood estimates of the stochastic production frontier model showed that among 15 variables used in the analysis age, family size (in adult equivalent), tropical livestock unit, land fragmentation, membership of cooperatives, distance to the main road, and credit access were found to be statistically and significantly affect the level of TE of white cumin producers (Table 5).

Table 5 Maximum likelihood Estimates of factors affecting technical inefficiency

Variables	Coefficient	Std. Err
Constant	1.039***	0.250
Age	− 0.009***	0.003
Education status	− 0.039	0.082
Family size (AE)	0.029*	0.016
Tropical livestock unit	− 0.063***	0.010
Land size allotted for white cumin	− 0.180	0.217
Land Fragmentation	− 0.122**	0.052
Soil fertility	0.299	0.217
Frequency of Extension contact	− 0.021	0.022
Distance to the development center	− 0.002	0.002
Membership of cooperatives	− 0.250***	0.096
Distance to the nearest market	− 0.001	0.001
Distance to the main road	0.002**	0.001
Credit access	0.337***	0.053
Off/non-farm income activity	− 0.052	0.065
Market information	− 0.064	0.082
Log-likelihood function	− 37.480	

***, ** and * show significance at 1, 5 and 10% respectively

Source Model output (2019)

The **age** of the household head (which is a proxy variable for experience) had a statistically significant and negative relationship with technical inefficiency of white cumin production at 1% of the level of significance. The negative sign of the age of household head on technical inefficiency of white cumin production was consistent with the expected hypothesis. The result revealed that as the age of producer's increases, their level of technical efficiency increases. This may be due to producers becoming more experts in different agronomic practices as they become experienced in white cumin production. This study is in line with Abate et al. (2019), Yami et al. (2013), Lemma and Zinabu (2016), Wassie (2014).

Family size Family size measured in adult equivalent (which is a proxy variable for family labor force) had a statistically significant and positive relationship with technical inefficiency of white cumin production at 10% level of significance. The result revealed that as the family size of a household increases, the level of white cumin technical inefficiency increases. The reason might be family members in a household are idle during the production of white cumin. However, large family size is a guarantee for the availability of a labor force for farm operation to accomplish on time like plowing, weeding, and harvesting.

Livestock ownership (measured in Tropical Livestock Unit), which is a proxy variable for estimating the wealth status of a farmer, had a statistically significant and negative relationship with technical inefficiency of white cumin production at a 1%

level of significance. The result indicated that the number of livestock owned by a farmer increases, the level of white cumin technical efficiency increases. This indicates that the availability of livestock is essential for a different purpose. For example, producers who have livestock can sell them and buy farming inputs, besides smoothing their income and better feed their families with animal and poultry products such as meat, milk, and egg. Moreover, pack animals are used for timely transportation of farm inputs from market to home and crop output from the threshing point to the home. The availability of livestock is essential during the peak season of white cumin production because threshing is made using animal power in the study area. Hence, livestock ownership has a positive effect on the technical efficiency of white cumin production in the study area. This study is in line with Sisay (2016) and Alemu et al. (2009) who found that livestock owners have a positive and significant effect on the technical efficiency of crops.

Land fragmentation represents the number of plots of land on which the farmer has grown white cumin during the 2018/2019 production season. Fragmentation had a statistically significant and negative relationship with technical inefficiency of white cumin production at a 1% level of significance. The result indicated that a farmer with more white cumin plots is more technically efficient than a farmer with fewer white cumin plots. The reason is maybe as the number of plots operated by the farmer increases; the farmer will be able to distribute labor resources for various activities. Moreover, it would be used as one of the risk minimization strategies of producers. Producers may be benefited from fragmented white cumin plots in that different plots may represent the reduced risk that different plots provide if the plots are located sufficiently distributed, such that producers face totally different degrees of weather-induced variations like floods and mineral content on the various plots. This result is in line with the findings of Abate et al. (2019), and Kitila and Alemu (2014).

Membership of cooperatives is used as a proxy for assessing the role of the association in the efficiency of white cumin production. Membership of cooperatives had a negative and significant effect on technical inefficiency of white cumin production at a 1% level of significance. The result showed that a farmer who is a member of a farmer cooperative is more technically efficient in white cumin production than those who are not a member of farmer cooperatives. This might be farmer cooperatives facilitate information provision related to price, profitability, and availabilities of new technology and the provision of credit services to its members. Producers who are a member of cooperatives are more efficient in white cumin production than those who are not a member, because producers in a cooperative are more progressive and apply new agricultural technologies. This result is in line with (Sisay, 2016), who found that producers who are a member of farmer cooperatives are more technically efficient in maize production than those who were not a member of cooperatives.

Distance to the main road (which is a proxy variable to reach the nearest market on time) had a statistically significant and positive relationship with the technical inefficiency of white cumin production at a 1% level of significance. This indicates that a farmer whose residence is far from the main road is more technically inefficient than those who are near the main road. The reason might be producers relatively far from the main road may have low information and supervision by the district agricultural experts, use less productive inputs because of transportation cost for getting improved inputs, and wastage of time by traveling to the market during peak agronomic practice. This result is in line with Lemma and Zinabu (2016) and Dessie et al. (2020) who found that distance to the district market hurts the technical efficiency of teff production.

Credit access had a positive and significant effect on the technical inefficiency of white cumin production at a 1% significance level. The result indicated that producers who had access to credit is less technically efficient than those who did not have. This is may be due to the reason that producers spend the accessed credit for consumption smoothing instead of purchasing inputs for white cumin production. In other words, producers may use the loan for unintended purposes such as consumption smoothing rather than purchasing agricultural inputs for white cumin production. This result is in line with Abate et al. (2019) who found that producers who have access to credit had a positive effect on the technical inefficiency of red pepper production.

4 Conclusion and recommendation

White cumin is a popular spice not only in Ethiopia but also all over the world. It is a flowering plant that grows by Ethiopian smallholder farmers commonly for commercial purpose. It has a several health benefit which includes improving immunity, aiding digestion, preventing cancer, and treating skin disorders and anemia. Despite such importance, as the researcher's knowledge, no much study has done on the technical efficiency of white cumin production in the study area. Therefore, this study was aimed to investigate technical efficiency and factors affecting the technical efficiency of white cumin production among smallholder producers in northwestern Ethiopia.

The result of the study confirmed that the mean technical efficiency of white cumin producers was 81%. This indicates that there is room to boost the production and productivity of white cumin production by using the existing resources and the current state of technology. The maximum likelihood estimates of the stochastic production frontier model revealed that land allotted to white cumin, NPS, and urea fertilizer had statistically and positively affected the level of white cumin production. This implies that the lack of these farm inputs would hamper the production and productivity of white cumin. Moreover, the maximum likelihood estimates of the stochastic production frontier model confirmed that the age of household head, land fragmentation, livestock ownership, and membership of cooperatives were found to positively and significantly influence the level of technical efficiency of white cumin producers while family size, distance to the main road and credit access were found to be significantly and negatively influence the level of technical efficiency of white cumin producers. Hence, based on the finding of the study, the local government should strengthen farmer cooperatives to reinforce farm to farm knowledge sharing by providing incentives, awareness creation, and providing different facilities such as offices, credit, and stores. Moreover, the government should be strengthening the existing livestock production system by providing better health services, better livestock forage, and adopting high-yielding breeds in the study area. In addition, producers should use their family labor effectively and produce at different plot level to minimize natural hazards for efficient white cumin production. Therefore, the existing level of inefficiency of white cumin is high and this calls for enhancing farmer's resource endowment by providing credit and better attention of policymakers and researchers for tackling the source of these inefficiency differentials to improve the livelihood of white cumin producers.

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Availability of data and materials The authors want to declare that they can submit the data at any time based on publisher's request. The datasets used and/or analyzed during the current study was available from the authors on reasonable request.

Declarations

Conflict of interest All authors have received research grant from University of Gondar to accomplish this research for collecting research data. The authors declare that they have no competing interests.

Ethical approval and consent to participate Ethical clearance letters were collected from University of Gondar research and community service directorate and Central Gondar zone of face to care for both the study participants and the researchers. During survey, of facial letters were written for each kebele / villages/ informed verbal permission was obtained from each client, and confidentiality was maintained by giving codes for each respondent rather than recording their name. Study participants were informed that clients have a full right to discontinue or refuse to participate in the study. Hence, all participants throughout the research, including survey households, enumerators, the supervisors and key informants were fully informed of the objectives of the study. They were approached friendly in free moods until then do this research.

Consent for publication Not applicable

References

Abebe, G. G.: Off-farm income and technical efficiency of smallholder producers in Ethiopia (2014)

Adea, A. F. T. D. O. E. F. A.: Ethiopia Country Report For The 2014 Ministerial Conference On Youth Employment, Abidjan, Côte d'Ivoire, 21–23 July (2014)

Abate, T.M., Dessie, A.B., Mekie, T.M.: Technical efficiency of smallholder producers in red pepper production in North Gondar zone Amhara regional state Ethiopia. J. Econ. Struct. **8**, 18 (2019)

Abebe, D.: Technical efficiency of onion production under irrigation: the case of Kalu Woreda of South Wollo (Doctoral dissertation, MSc Thesis, Haramaya University, Haramaya, Ethiopia) (2009)

Ahmed, M.H., Lemma, Z., Endrias, G.: Technical efficiency of maize producing producers in Arsi Negelle, Central Rift valley of Ethiopia: Stochastic frontier approach. Poljoprivreda i Sumarstvo **60**, 157 (2014)

Alemayehu, M., Tessafa, F., Bizuayehu, S. & Ayele, B.: Amhara Region Horticulture Development Strategy (2015–2019). Agro-Big, Bahir Dar, Ethiopia. URL: https://www. agrobig. org/documents/7.1 _ Amhara_Region_H orticulture_Development_Strategy_2015–2019. pdf. Accessed on January, 20**,** 2018 (2015)

Alemu, B.A., Nuppenau, E., Boland, H.: Technical efficiency of farming systems across agro-ecological zones in Ethiopia: an application of stochastic frontier analysis. Agri. J. **4**, 202–207 (2009)

Attokaran, M.: Natural food flavors and colorants. John Wiley & Sons (2017)

Ayele, A., Haj, J., Tegegne, B.: Technical efficiency of wheat production by smallholder producers in Soro district of Hadiya Zone, Southern Ethiopia. East African J. Sci. **13**(2), 113–120 (2019)

Bekele, A. R.: Technical efficiency variation for smallholder irrigated maize producers: a case study of tibila surface water irrigation scheme. Mekelle University (2013)

Belete, A.S.: Analysis of technical efficiency in maize production in Guji Zone: stochastic frontier model. Agriculture & Food Security **9**(1), 1–15 (2020)

Beshir, H.: Technical efficiency measurement and their differential in wheat production (2016)

Bofed, B. O. F. A. E. D.: Amhara national regional state population projection based on the 2007 census (2009)

Cgao, C. G. Z. A. O.: Annual report on area coverage and production of major crops during 2018/2019 production season (2019)

Chipeta, M., Emana, B. & Chanyalew, D.: Ethiopia's Agriculture Sector Policy and Investment Framework (2010–2020) External Mid-term Review. Secretariat of the Government of Ethiopia, Development Partners Sector (2015)

Cochran, W. G. 1977. Sampling techniques-3

Coelli, T.J.: A guide to FRONTIER version 4.1: a computer program for stochastic frontier production and cost function estimation (Vol. 7, pp. 1–33). CEPA Working papers (1996)

Degefa, K., Jaleta, M., Legesse, B.: Economic efficiency of smallholder producers in maize production in Bako Tibe district, Ethiopia. Dev. Country Stud. **7**, 80–86 (2017)

Dessie, A.B., Abate, T.M., Adane, B.T., Tesfa, T., Getu, S.: Estimation of technical efficiency of black cumin (Nigella sativa L.) farming in northwest Ethiopia: a stochastic frontier approach. J. Econ. Struct. **9**, 1–14 (2020)

EEA, E. E. A.: Annual Report on Ethiopian Economy. Addis Ababa, Ethiopia (2012)

FAO, F. A. A. O.: Ethiopia Country Highlights on Irrigation Market Brief. UNFAO, Rome, Italy. Prepared under Food and Agricultural Organization of United Nations (UNFAO)/International Finance Corporation (IFC) cooperation (2015)

Fikadu-Lebeta, W., Diriba-Shiferaw, G. & Mulualem-Azene, M.: The Need of Integrated Nutrient Management for Coriander (Coriandrum sativum L.) Production (2019)

Geta, E., Bogale, A., Kassa, B., Elias, E.: Productivity and efficiency analysis of smallholder maize producers in Southern Ethiopia. J. Hum. Ecol. **41**, 67–75 (2013)

Haile, B.T.: Determinants of technical allocative and economic efficiencies among onion producing producers in irrigated agriculture: empirical evidence from Kobo district Amhara region Ethiopia. Afr. J. Agri. Res. **10**, 2180–2189 (2015)

INTERNET Accessed December 24, 2019. Royal Enclosure Gondar, Ethiopia FAMOUS GONDAR CASTLES OF ETHIOPIA, LOCATED IN FASIL GHEBBI, a 7 ha royal enclosure: (https://www.nationalparks-worldwide.com/eaf/ethiopia/gondar/gondar.html).

Kitila, G.M., Alemu, B.A.: Analysis of technical efficiency of small holder maize growing producers of Horo Guduru Wollega zone, Ethiopia: a stochastic frontier approach. Sci, Technol Arts Res. J. **3**, 204–212 (2014)
Lemma, Z., Zinabu, T.: Analysis of technical efficiency of teff producer producers in Raya Kobo District, Amhara National Regional State. Haramaya University, Ethiopia (2016)
MOA, M. O. A.: Report on area coverage and production of major crops, Addis Ababa, Ethiopia (2016)
Moa, M. O. A.: Report on area coverage and production of major crops, Addis Ababa, Ethiopia (2013)
NPC, N. P. C.: Ethiopian second five year (2015/162019/20) Growth and transformation plan, Addis Ababa, Ethiopia (2015)
Newut, T.: Analysis of economic efficiency of cumin (Cuminumcyminum) In North Achefer District, Amhara National Regional State, Ethiopia. St. Mary's University (2017)
Rahman, A., Akbar, D., Bhattarai, S., Thomson, M., Trotter, T. and Timilsina, S.: Market analysis of cumin seed. Online: Central Queensland University. (2020)
SSCC, S. S. S. C. C.: Spice Sub-Sector STRATEGY for ETHIOPIA, ACP Agricultural Commodities Programme. International Trade Centre (ITC), Division of Country Programmes (DCP), Export Strategy (2010)
Sisay, D., Jema, H., Goshu, D., Abdi, K.: Agricultural technology adoption, crop diversification and efficiency of maize-dominated farming System in Jimma Zone. Haramaya University Ethiopia, South-Western Ethiopia (2016)
Sisay, D.: Agricultural technology adoption, crop diversification and efficiency of maize-dominated smallholder farming system in Jimma Zone, Southwestern Ethiopia. *Haramaya University, Ethiopia* (2016)
Teklemariam, T. M.: The impact of international potato center's nutrition project on smallholder producers' income and adoption of improved potato varieties: Tigray region, Northern Ethiopia. Mekelle University (2014)
Tesfaw, Z., Zemedu, L., Tegegn, B.: Technical efficiency of Teff producer producers in Raya Kobo district, Amhara National Regional State Ethiopia. Cogent Food Agri. **7**(1), 1865594 (2021)
The case of smallholder producers in South Wollo. *IJEBF,* 4**,** 1–16.
Wassie, S. B.: *Technical efficiency of major crops in Ethiopia: stochastic frontier model.* (2014)
Wossen, T.: Determination of optimum rates of nitrogen and phosphorus fertilization for white cumin (Trachyspermum ammi (I) sprague) in Takusa Woreda of North Gondar Zone. Int. J. Sci. Res. Publ. **8**, 460–463 (2017)
Yami, M., Solomon, T., Begna, B., Fufa, F., Alemu, T., Alemu, D.: Source of technical inefficiency of smallholder wheat producers in selected waterlogged areas of Ethiopia: a translog production function approach. Afr. J. Agric. Res **8**, 3930–3940 (2013)

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