Effects of finger millet innovations on productivity in Kenya

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Abstract: Finger millet is an underutilized cereal crop grown in some parts of semi-arid lands in Kenya. Its productivity could be critical in diversifying household nutrition and incomes among resource-constrained farmers in these marginalized areas. The purpose of the current study was to analyze the effect of innovations on the productivity of the crop. More knowledge could help underutilized cereal crops’ practitioners to develop and disseminate better-targeted innovations. A Translog production frontier was found adequate in investigating the effects of innovations on finger millet productivity for a sample of 384 finger millet farmers in Elgeyo-Marakwet County, Kenya. The empirical results indicated that the application of improved finger millet variety and practicing conservation tillage positively affected productivity through the reduction of technical inefficiency. Finger millet yield was more responsive to the number of labour in person-days in comparison to other frontier inputs. The study also found that small farms had higher yields than large farms. The mean technical efficiency of finger millet farmers was about 67%. Income from off-farm activities and membership to the group had positives and significant effects on technical efficiencies. The age of the household head and contacts with extension officers significantly increases the inefficiencies.

ABOUT THE AUTHOR
The study is an extract from the first author PhD thesis “Role of Agricultural Innovations on Productivity and Commercialization of Underutilized Cereals: Case of Finger Millet in Kenya.” The aim of the study was to investigate the use and level of use of agricultural innovations and the associated factors as well as their role in enhancing underutilized cereal crops’ yield and commercialization in Kenya. The second and third authors are Associate Professors at the Department of Agricultural Economics and Agribusiness Management, Egerton University and key supervisors to the research work. The fourth author is an Associate Professor of Agronomy, Egerton University and a third supervisor to the research work.

PUBLIC INTEREST STATEMENT
Increasing productivity of underutilized cereal crops like finger millet is imperative in the diversification of household food security and incomes of resource-constrained farmers, especially those living in marginalized areas. This article examined the effect of innovations (improved finger millet seed variety, conservation tillage, integrated pest, and weed management and membership to finger millet group marketing) on finger millet productivity. Findings showed that encouraging farmers to use improved finger millet seed varieties and practice minimum field operations have a positive effect on finger millet productivity by reducing technical inefficiency. The study further revealed that if young cohorts embrace finger millet production and if farmers participate in off-farm income activities could reduce technical inefficiency in this subsector. However, extension officers may need to review the content of the information they are disseminating to farmers to address issues pertinent to finger millet productivity since their current frequent contact with finger millet farmers increases technical inefficiency.
1. Introduction

Following the advent of the green revolution, the use of agricultural innovations has driven the transformation of cereal production especially in the global north and some emerging nations of Asia (Toenniessen et al., 2008). Application of improved varieties, fertilizers, pesticides, and irrigation raised the productivity of major cereal crops (maize, rice, and wheat) (Evenson & Gollin, 2003). However, these practices were not successful everywhere. At the same time, they contributed to environmental issues, health and social problems, monoculture, and the growth of unsustainable farming systems (Dawson et al., 2016). For some years, the approach has resulted in diminishing productivity of the staple cereal crops aggravated by effects emanating from climate change (Pingali, 2012). As a result, diversification has been viewed as an alternative paradigm for increasing sustainable agricultural productivity to meet the escalating demands of the growing population and changing dietary preferences. In this context, the resurgence of underutilized crops and the adoption of environmentally sustainable practices have gained more attention, especially in developing regions like Sub-Saharan Africa (Mabhaudhi et al., 2016).

Underutilized cereals received less attention by the research community and other practitioners at the advent of major staple crops such as maize, rice and wheat which as argued by Padulosi et al. (2013), resulted in low productivity and limited area under cultivation for these crops. For instance, the yield of finger millet has been very low for many years (Tadele & Assefo, 2012). The low productivity of these crops is due to numerous challenges including though not limited to unproductive seed varieties as well as environmental factors such as pests, diseases, and weeds (Naylor et al., 2004; Pingali, 2012). Nevertheless, these crops are a vital source of sustenance in most of the marginalized areas. In comparison to other cereals, finger millet particularly performs better in adverse agro-ecological and marginal soil conditions (Onyango, 2016). Nutritionally, the crop contains high contents of calcium, dietary fibre, and phenolic compounds (Grovermann et al., 2018). It is also rich in a variety of vitamins, antioxidants and amino acids, more so than maize, wheat, and rice (Singh & Raghuvanshi, 2012). Moreover, finger millet can be stored for more than 5 years without damage by pest and disease (Thilakaratna & Raizada, 2015).

Boosting the productivity of finger millet, therefore, holds great potential to reduce poverty and hunger, the number one and two targets of the Sustainable Development Goals (SDGs) of the United Nations (Dawson et al., 2019). This is imperative, especially in sub-Saharan Africa, where the biggest part of the region is arid and semi-arid lands and more vulnerable to climate change (Kimani et al., 2015). The scenario is further exacerbated through the reality that, widely consumed and traded cereal crops such as maize, wheat, and rice are rain-fed, and their productivity has been declining because of the consequences of climate change (Cairns et al., 2013; Schlenker & Lobell, 2010). For these reasons, most of the countries in Sub-Saharan Africa are among the nations with a significant gap in cereal production and intake (Van Ittersum et al., 2016). In Kenya, semi-arid and arid areas cover the most substantial proportion of the total landmass (over 80%) and home to about 38% of the population (Huho et al., 2010). These areas are characterized by low agricultural productivity, poverty, and food insecurity resulting from frequent crop failure due to the tendency of farmers growing non-adaptable crop species and varieties (Onyango, 2016), as well as unreliable rainfall, high temperatures, and poor soil fertility (Bationo et al., 2011).

It is against this backdrop that triggers efforts to revitalize finger millet in Kenya and other countries in the Sub-Saharan region. Organizations such as International Research Crops Institute for the Arid and Semi-Arid Tropics (ICRISAT) established programs that develop and disseminate innovations for the traditional crops, including finger millets (Goron & Raizada, 2015). The promotion and adoption of improved innovations on these crops are, therefore, witnessed in
most parts of the unfavorable environments of Kenya. The focus is to enhance finger millet productivity, which could be an essential route to reduce poverty and food insecurity (Pingali, 2012). However, while several studies evaluate the effects of innovation on the productivity of major cereal crops (Kassie et al., 2018; Mignouna et al., 2012; Ogada & Nyangena, 2015), studies addressing the same on underutilized cereal crops like finger millet are still scarce. A better understanding of the effects of innovation on finger millet productivity and other underutilized cereal crops is necessary to design promising strategies in order to stimulate growth in the sub-sector. This study, therefore, investigated the effect of these innovations on productivity. Agricultural innovation is an agricultural idea, practice, or knowledge that is new to a farmer or the user, irrespective of whether it is new to other farmers or the country or the world. However, agricultural innovation is a broad term, which encompasses technical, organizational, or institutional innovations (Makini et al., 2016; Triomphe et al., 2013). This study mainly focuses on technical innovations and more specifically on improved finger millet varieties, conservation tillage and integrated pest and disease management as well as organizational innovations (collective action).

2. Productivity and technical efficiency

Productivity measure for crop production is often cited as crop output per land area and commonly referred to as crop yield. However, crop yield is an indication of improved use of inputs or a more efficient combination of inputs. The former refers to production technology, and the latter refers to the production frontier (Grosskopf, 2003). Production frontier can be achieved by either minimizing the resources required for producing a given level of output given their respective prices and technology (allocative efficiency) or maximizing a given level of output from a given level of resources (Technical efficiency). This study focuses on technical efficiency to depict the effect of finger millet innovations on productivity.

There are two approaches to the estimation of technical efficiency; that is the parametric stochastic frontier analysis approach (SFA) proposed by Aigner et al. (1977) and Meeusen and van Den Broeck (1977) and the non-parametric Data Envelop Analysis (DEA) approach proposed by Charnes et al. (1978). The SFA approach, which uses the econometric estimation methods, is generally used in the estimation of the production function formulated parametrically. In contrast, the mathematical programming methods are used in the evaluation of production functions stated in a non-parametric form (Yang, 2014). Evidence abounds in literature that the use of SFA and DEA to measure technical efficiency depends on the objective of the research, the firm, and the available data. The DEA approach is independent of functional form characterizing the underlying technology and therefore avoids misspecification problems. However, the method is deterministic and thus, assumes the deviations from the frontier as consequent of inefficiency effects. As a result, the technical efficiency scores obtained from DEA are lower compared to those received from SFA (Coelli et al., 2005).

The SFA approach incorporates a composite error term representing the stochastic component, which captures the stochastic effect and other shocks outside the control of the farmer, including measurement errors and other statistical noise typical of empirical relationships, and the inefficiency component (Aigner et al., 1977; Meeusen & van Den Broeck, 1977). Also, it allows hypothesis testing and construction of confidence intervals (Wadud & White, 2000). However, this approach assumes a functional form for the frontier technology and the distribution of technical inefficiency term of the composite error term. This study adopts the stochastic frontier function model since agricultural finger millet production exhibits random shocks. Therefore, there is a need to separate the influence of stochastic factors (for example, unfavorable weather conditions, unpredictable pests, and diseases) from the effects of other inefficiency variables (age, education, extension services, access to credit, improved varieties among others) by assuming that the deviation from the production frontier could not be excluded under the control of the farmers.
3. Methodology

3.1. Sampling procedure and data collection
The study purposely selected Elgeyo-Marakwet County in Kenya because of various initiatives by ICRISAT-Feed the future Accelerated Value Chain Development (AVCD) program, Kenya Agricultural Value Chain Enterprises (KAVEs) and Agriculture Sector Development Programme (ASDP), and other partners (Egerton University and Kenya Agriculture and Livestock Research Organization (KALRO)) in the County targeting the improvement of livelihoods using traditional, underutilized crops and owing to its socio-economic conditions since 57% of people live below the poverty line (CIDP, 2013–2017). The selected County Development Plan (2013), also supports the intensification of innovations on drought-tolerant crops like groundnuts, sorghum, and millets in each sub-county (County Development Plan, 2013).

The county is divided into three agro-ecological zones: highlands in the west, Escarpment in the central parts, and the valley floor. The Valley floor is flat and dry with sandy soils, ideal for staple and drought-resistant crops; livestock grazes freely in open areas. In the highlands (Upper Valley), homesteads are located on relatively flat to moderately sloped land with sandy and clay soils; horticulture is currently practiced in this region. The escarpment zone is very steep, but staple or drought-resistant crops are cultivated. This study was carried out on the valley floor and Escarpment Zones of the County.

For this work, we draw from a survey with 384 finger millet smallholder farmers based on multi-stage sampling. The first stage was a purposive selection of the County owing to its Integrated Development Plans (CIDP), which aimed to intensify innovations on drought-tolerant crops like groundnuts, sorghum, and millets in each sub-county (County Development Plan, 2013). Two sub-counties were randomly selected. Two wards from each sub-County were also randomly selected. The determination of the sample size followed proportionate to size sampling methodology as specified by Anderson et al. (2007). Sets of structured and semi-structured questionnaires, organized into five sections, were used to collect data. The first section was dedicated to obtaining information on the socio-economic and demographic characteristics of the survey respondent like age, education, gender, and the number of members in the household as well as household assets. The study devoted the second and third sections to understanding the farm attributes and the production and marketing of crops. The fourth section was mainly to obtain information on the institutional and organizational characteristics of the farmer, followed by the last section committed to identifying various innovations used by finger millet farmers. Data were analyzed using STATA version 15.0 software from StataCorp LLC, Texas, USA. Both descriptive and inferential statistics describe the statistical apparatus to analyze the data.

3.2. Analytical framework
The study adopted a stochastic frontier production model to analyze the effects of agricultural innovations (improved finger millet seed variety, conservation tillage, IPW, and membership to group marketing) on productivity. Dummy variables of agricultural innovations were included as exogenous variables in the technical inefficiency model. In addition, factors such as the size of land allocated to finger millet production, age of the farmer, gender, education, number of contacts with extension officer, income from non-farm activities, credit access, and technical training were incorporated to explain the underlying causes of deviation from the frontier (Table 1).

The finger millet yield was used as the outcome variable in the stochastic production function and defined as in Aigner et al. (1977)

$$Y_i = f(x_i, \beta) + \epsilon_i$$

(1)
Where $y_i$ indicates finger millet productivity represented by the crop yield of the farmer $i$; $x_i$ is a vector of inputs including land, labor, and quantity of seeds planted per hectare, fertilizers and manure. While $\beta$ is a vector of unknown coefficients to be estimated.

The error term $e_i$ is composed of two components

$$e_i = v_i - u_i$$

Where, $v_i$ is a two-sided idiosyncratic error term assumed to be $iid\mathcal{N}(0, \sigma_v^2)$, independent of $u_i$, accounting for random events beyond the control of the finger millet farmer such as adverse conditions.

### Table 1. Definition and measurement of variables used in the stochastic frontier model of productivity

| Variables          | Description of variables                                                                 | Expected sign |
|--------------------|-----------------------------------------------------------------------------------------|---------------|
| Ln(yield) Dependent variable | Finger millet yield in Kg/ha                                                           |               |
| Inputs             |                                                                                         |               |
| Ln (Seed)          | Natural logarithms of finger millets seeds planted in Kg/ha                            | ±             |
| Ln (Labour)        | Natural logarithms of labour used in person-days per hectare                           | +             |
| Ln (Plot size)     | Natural logarithms of the size of land allocated to finger millet production in hectares| -             |
| Fertilizers        | Fertilizers used in the production of finger millet in Kg/ha                           | +             |
| Manure             | Manure used in finger millet production in litres/ha                                   | ±             |
| Inefficiency variables         |                                                                                         |               |
| Improved variety   | Household used improved finger millet variety ($1 = \text{yes} \ 0 = \text{no}$)       | +             |
| Conservation Tillage | Household practiced conservation tillage on finger millet ($1 = \text{yes} \ 0 = \text{no}$) | +             |
| IPW                | Household practiced IPW on finger millet ($1 = \text{yes} \ 0 = \text{no}$)            | +             |
| Group marketing    | Household head membership to finger millet marketing group ($1 = \text{yes} \ 0 = \text{no}$) | +             |
| Age                | Age of the household head in years                                                     | -/+           |
| Gender             | Gender of the household head ($1 = \text{male} \ 0 = \text{female}$)                  | +             |
| Education          | Years of schooling of household head                                                    | +             |
| Household Size     | Number of people in households (persons)                                                | ±             |
| Non/off-farm income| Income earned outside the farm ($1 = \text{yes} \ 0 = \text{no}$)                      | ±             |
| Distance to the market | Distance to the nearest market in walking minutes                                      | -             |
| Household received credit | Household head credit ($1 = \text{yes} \ 0 = \text{no}$)                              | +             |
| No of contacts with extension | Number of contacts with extension officer                                               | +             |
| Technical training | Household head received training ($1 = \text{yes} \ 0 = \text{no}$)                   | +             |
weather conditions, pest, diseases etc. \( u_i \) is a non-negative technical inefficiency component representing the factors that are under the control of the farmer. Component \( u_i \) is independent and identically distributed as a half-normal distribution that is \( \text{iid} N(0, \sigma_u^2) \) (Zannou et al., 2018). \( u_i \) is further specified as a function of a vector of explanatory variables \( (z_i) \) and a factor of unknown coefficients (\( \delta \)):

\[
\begin{align*}
    u_i &= z_i \delta + w_i
\end{align*}
\]

(2)

where \( w_i \) is a random variable defined by half-normal distribution with zero mean and variance \( \sigma_w^2 \). This assumption is consistent with \( u_i \) being a non-negative independently distributed \( N(z_i \delta, \sigma_u^2) \). \( z_i \) is an ith explanatory variable associated with the technical inefficiency effects and \( \delta \) is a vector of unknown parameters to be estimated.

In Equation (1) the inefficiency component \( (u_i) \) is the log difference between the frontier yield and the actual yield \( Y_i = \ln Y_{i}^f - \ln Y_i \). Therefore, \( (u_i \times 100\%) \) is the percentage by which actual finger millet output can be increased using the same inputs if the production is fully efficient (Kumbhakar et al., 2015). Technical efficiency (TE) of an individual finger millet farmer is the ratio of the observed output \( Y_i \) to the corresponding frontier output \( Y_{i}^f \) both in the original units. The production efficiency of the finger millet farmers is as presented:

\[
TE = \frac{Y_i}{Y_{i}^f} = \frac{Y_i}{f(x_i; \beta) \exp(v_i)} = \exp(-u_i)
\]

(3)

The study adopted a one-stage maximum likelihood approach proposed by Kumbhakar and Lovell (2000), to estimate unknown parameters, with the frontier parameters and technical inefficiencies simultaneously. The likelihood function is expressed in terms of variance parameters (Battese & Coelli, 1995) as follows:

\[
\sigma^2 = \sigma_u^2 + \sigma_w^2
\]

(4)

and

\[
\gamma = \frac{\sigma_u^2}{\sigma^2}
\]

(5)

We specified the stochastic frontier production function using the translog production functional form. Based on Equation (1) the translog stochastic frontier model initially developed by Aigner et al. (1977), can be specified as follows:

\[
\ln Y_i = \sum_{k=1}^{6} \beta_k \ln X_{ik} + \frac{1}{2} \sum_{k=1}^{6} \sum_{l=1}^{6} \beta_{kl} \ln X_{ik} \ln X_{il} + v_i - u_i
\]

(6)

Where \( \ln \) represents the natural logarithm, \( Y_i \) denotes finger millet yield of the \( i^{th} \) finger millet farmer \( X_{ik} \) represents input used by the farmer these include (labour, quantity of seeds per hectare, plot size, fertilizers, and manure). \( \beta \) is a vector of parameters to be estimated. \( v_i - u_i \) is the composed error term where, \( u_i \geq 0 \).

All input and output variables were transformed to their corresponding log values. Given Equation (6), and the distributional assumption on the inefficiency component \( u_i \) of the composed error term, the Battese and Coelli (1995), inefficiency model could be specified as:

\[
\begin{align*}
    u_i &= \delta_o + \sum_{i=1}^{12} \delta_i Z_i + w_i
\end{align*}
\]

(7)

where \( u_i \) is the inefficiency, \( Z \) is the vector of exogenous variables including gender, age, education of the household head, household size, dummies of finger millet innovations, access to extension services, off/non-farm, access to credit, access to technical training and other factors that are
likely to affect efficiency. \( \delta \)'s are the parameters to be estimated, and \( w_i \) is the error term of the inefficiency model. To measure the effects of innovations on finger millet yield, dummy variables of innovations were simply included as part of \( \delta \)s as exogenous variables. However, dummy variables may be endogenous because there may be unobserved factors that affect both the use of these innovations and the yield. If not addressed, this endogeneity could lead to endogeneity bias and consequently, result in inconsistent parameter estimates of effects of finger millet innovations on productivity. The use of other inputs may also be endogenous but since the interests of the study is to analyze the effects of finger millet innovations adopted by farmers on productivity, the study, therefore, focused on endogeneity in the finger innovations.

The current study follows the recent work of M. U. Karakaplan and Kutlu (2017), to account for endogeneity in the stochastic frontier model. The study estimated an endogenous stochastic frontier model and compared the results with an exogenous stochastic frontier model. Durbin and Wu-Hausman test was conducted to check for endogeneity among the innovations. The theory behind the DWH test is to check whether the variation across these estimators is significantly different from zero, given the data from the available sample.

To check for the validity of the stochastic frontier model, the following hypothesis was tested to ensure that the model adequately represents the data.

Hypothesis 1: \( H_0: \beta_1 = \beta_2 = \ldots = \beta_n = 0 \) the null hypothesis that identifies an appropriate functional form between the Cobb-Douglas and the translog production function. The hypothesis tested that the second-order coefficients and interaction terms of frontier variables in Equation (6) are equal to zero. The Cobb-Douglas production frontier is a special case of the translog frontier in which the coefficients of the second-order terms are zero that is, \( \beta_1 = \beta_2 = \ldots = \beta_n = 0 \).

Hypothesis 2: \( H_0: \gamma = 0 \) in the Equation (5) the null hypothesis that the inefficiencies are not stochastic and that the technical inefficiency effects are not present in the model at every level, so the joint effect of these variables on technical inefficiency is statistically insignificant. If this null hypothesis is not rejected, the Stochastic frontier model could be reduced to the OLS specification. In this case, if there is an output difference among farmers given equal inputs, this difference is purely due to the difference in random shocks that are outside the control of the farmer.

Hypothesis 3: \( H_0: \delta_1 = \delta_2 = \ldots = \delta_n = 0 \) in Equation (5) the null hypothesis specifies that the influence of identified inefficiency factors, namely, farmer, farm-specific and institutional characteristics and finger millet innovations is zero.

The translog function form estimated coefficients, in Equation (6) do not have straightforward interpretation. This is attributed to the fact that output elasticity is a function of the first and second-order coefficients regarding input use. In this context, the output elasticity with respect to \( k^{th} \) input used, evaluated at the mean, were computed except for fertilizer and manure.

\[
\frac{\partial \text{ln}E(Y)}{\partial \text{ln}(x_k)} = \beta_k + 2\beta_{kk}x_{ki} + \sum_j \beta_j x_{kj}
\]

(8)

The calculation of the semi-elasticity of fertilizer and manure dummy is different since the regression from a log-linear model that contains a logarithmic dependent variable and a qualitative dummy variable for the use of manure and fertilizer. The estimation of elasticity for fertilizer and manure dummies followed the suggestion by Halvorsen and Palmquist (1980). The antilog of the estimated dummy coefficient was considered, and a value of one deducted from it.

\[
\varepsilon_f = 100 \left\{ \exp \left( \beta_f \right) - 1 \right\}
\]

(9)
4. Results and discussion

4.1. Descriptive statistics
In the study area, the agricultural innovations used by finger millet farmers were improved varieties, conservation tillage, integrated pest management, and group marketing. Among all the innovations, integrated pest and weed management was the most used innovation. In this regard, IPW methods included the hand-pulling of weeds and burning before flowering (51%), the use of traps and baits (42%), early planting (15%), the use of other plants (cowpea, pigeon pea, and groundnuts) to trap and destroy pests and control some weeds (27%), and crop rotation (31%). Most of these practices were used in combinations of two or a maximum of three. Finger millet marketing group recorded the lowest used innovation among finger millet farmers in the study area (Table 2).

The descriptive statistics of inefficiency variables indicated that on average, a household head had approximately 8 years of formal education; age of the sample household head was found to be 42 years. As shown in Table 3, out of the 384 households interviewed, above 86% were headed by males, while females headed the remaining 13%. The average area cultivated for finger millet production during the 2015/2016 cropping season was 0.6 acres, which accounts for about 30% of the average total cultivated land size and 40% under cereal crops, respectively. The results of the current study indicated that the finger millet farmers interacted with extension officers approximately twice during the cropping period. As displayed in Table 3 about 28% of finger millet farmers had received technical training on finger millet from the research and learning institution on the technical aspects of various innovations.

4.2. Empirical results and discussion
Table 6 presents maximum likelihood estimates of the Translog production stochastic frontier and inefficiency model. The study conducted a generalized Log-likelihood ratio (LR) to test the null-hypothesis that the second-order and interaction variables in the translog functional form are zero.

| Innovations                        | Frequency n = 384 | Percentage of adopters |
|------------------------------------|------------------|------------------------|
| Improved variety                   | 157              | 40.89                  |
| Conservation tillage              | 199              | 51.84                  |
| Group marketing                    | 108              | 28.13                  |
| Integrated pest and weed management | 245              | 63.80                  |

| Variable               | Mean | Std  |
|------------------------|------|------|
| Education              | 8.80 | 3.85 |
| Age                    | 42.38| 12.16|
| Gender                 | 0.86 | 0.34 |
| Household Size         | 5.53 | 2.11 |
| Plot size              | 0.60 | 0.64 |
| Distance to the market | 40.34| 33.79|
| Household received credit | 0.13 | 0.35 |
| No of contacts with extension | 1.7  | 1.12 |
| Technical training     | 0.27 | 0.44 |
The LR test statistic (48.14) higher than the chi-square critical value (15.09) rejected the null-hypothesis at one percent level of significance. The test, therefore, confirms that the translog form is a better presentation of the production function than the Cobb-Douglas form.

The second null hypothesis tested the absence of technical inefficiencies in the model. The study rejected the null-hypothesis owing to a higher computed LR test statistic (38.29) relative to the critical value of (16.63) at 1% significance level. Rejection of null-hypothesis indicates the presence of technical inefficiencies in finger millet production. This further suggests that the traditional average (OLS) production function that assumes technically efficiency among finger millet farmers is not accurate in describing the sampled data. The third hypothesis tested that the independent variables in the inefficiency model are equal to zero. The study employed an LR test to compare the value of the stochastic frontier model with and without explanatory variables in inefficiency effect model. The computed LR test statistic is 52.54 greater than the critical value of 32.0. Following the calculated LR test statistic, the study rejected the null hypothesis at a one percent level of significance. Therefore, the explanatory variables associated with the inefficiency effect model are jointly different from zero.

4.2.1. Effects of frontier inputs on yield
All the frontier inputs included in the model significantly influenced the finger millet yield. The application of the Equation (8) indicates that the coefficients of labour and the quantity of seeds per hectare had positive signs, whereas, farm size coefficient had a negative sign (Table 5). Moreover, the three frontier inputs were statistically significant at one and 10% level. The estimated production elasticity suggests that labour is a more responsive input, followed by seed and farm size. It means that an increase in labour in terms of person-days would affect significantly farm productivity. Specifically holding all other inputs constant, a 1% increase in labour would result in a 1.285% increase in finger millet yield. The high elasticity of labour is not surprising and consistent as hypothesized since finger millet production is labour intensive and finger millet farmers are resource-constraint, and most of them live in marginal areas hence rely on manual labour for finger millet operations. The availability of labor, therefore, would help to maximize finger millet yield.

The quantity of seeds per hectare used was elastic and positively influenced the finger millet yield at a 1% significance level. When all other factors were held constant, the results show that a 1% increase in the quantity of seeds used per hectare increased finger millet yield by 1.228% (Table 4). The finding was surprising since increased seed rate is expected to influence yields negatively due to competition for limited resources resulting from high densities per unit area. The explanation of the current study could be that the increased seed rate per unit area reduces the risk of poor germination and other externalities that affect recommended population density. The findings of the current study further attest that quantity of seeds per hectare applied was the second elastic input compared to other inputs used. The implication is that apart from labor, the seed was the primary limiting factor of production that constrained smallholder farmers from maximizing the output. The reason could be that resources limit most of the smallholder farmers in the marginal areas, hence apply seeds below-recommended rates. Although increasing seed

| Table 4. Output Elasticity |
|---------------------------|
| Variable  | Output Elasticity |
| Labour    | 1.285              |
| Seed      | 1.228              |
| Farm size | −0.503             |
| Returns to Scale | 2.012            |
| Fertilizers | 1.099             |
| Manure    | 0.674              |
rate per unit area may result in increased finger millet yield; however, seed variety used is also essential in determining finger millet yields. Use of improved seed variety could result in high returns with the minimum recommended seed rate.

The area of land allocated to finger millet production was inelastic, significant, and negative at the 10% level. The study indicates that a 1% increase in farm size assigned to finger millet production decreased the yield by 0.503%. The implication is that small farms obtained more yields than large farms. These findings are consistent with our expectation in that finger millet production is labour-intensive and, consequently, small farms use available labor optimally for timely planting, proper weeding, harvesting, and threshing hence high yields. Increase in the area allocated to finger millet production decreases the effects of available labor and other resources resulting in low finger millet yields. These findings agree with the results of Chen et al. (2011) study, which suggested that small farms are more productive than large farms. The study results are contrary to Alene and Manyong (2006), who found a positive and significant influence of farm size on technical efficiency of cowpea production.

The summation of the partial elasticity of production concerning every input for a homogeneous function (all resources varied in a similar proportion) is 2.012. The results represent the returns to scale coefficient, also called the function coefficient or total output elasticity. If the same proportion varies all factors, the function coefficient indicates the percentage by which output increases with a unit increase in the input used. In this case, the production function can be used to estimate the degree of returns-to-scale. Constant returns to scale only hold if the sum of all partial elasticity is equal to one. If this sum is less than one, the function has decreasing returns-to-scale: if more than one, as in this case, an increasing returns-to-scale exists. The estimated returns to scale for finger millet farmers were found to be increasing (2.012). The implication is that finger millet farmers could enlarge their production to expand productivity, given their variable resources adequately.

4.2.2. Semi-elasticity of fertilizer and manure
The study applied Equation (9) to estimate the semi-elasticity of fertilizers and manure. The findings indicated that for the finger millet farmers that used fertilizers, the finger millet yield is higher by 1.099% as compared to their counterparts, other factors held constant. The result showed that finger millet yield is responsive to changes in fertilizer application. This is not surprising since the use of fertilizer tends to increase production. The finding of a positive relationship between fertilizer application and yield supports Abdulai and Huffman (2014), who posit that farms that applied fertilizers obtained high rice yields. Finger millet yield was less responsive to manure application. One percent increase in manure increases the finger millet yield by 0.674. The findings could imply that farmers apply different types of manure, which may have different effects on yield.

4.2.3. Technical inefficiency estimation results
This sub-section evaluates the effects of inefficiency variables on the efficiency of finger millet farmers. In the estimation of technical inefficiency, the dependent variable is the one-sided error term, and thus, positive signs indicate technical efficiency is reducing factors and negative signs technical efficiency-enhancing elements. According to Gorton and Davidova (2004), variables affecting farm efficiency are divided into a farmer, farm-specific and institutional factors. Farmers' characteristics, such as age, education, a household size that represents the capacity of individual's smallholder farmers to act independently on matters about their farm operations. In contrast, institutional and farm-specific factors, such as access to markets, extension, credit, and the size of the farm, may influence or limit a farmer in his or her decisions.

The estimated technical inefficiency model shows that gender, education, family size, household credit, technical training, distance to the market, practicing IPW, and membership to group marketing have no significant effect on finger millet inefficiency (Table 5). While the age of the
finger millet farmer, extra income from non-agricultural activities, number of contacts with extension officers, use of finger millet improved variety and practicing conservation tillage by finger millet farmers demonstrate a significant effect on inefficiency.

The estimated coefficient of age was positive and statistically significant at the 10% level. The implication is that the older finger millet farmers were more inefficient than young farmers. The study indicated that when all factors were held constant, a year increase in the age of the finger millet farmers above the average decreases productivity by 1.4%. In line with this, results of the technical efficiency model reported by Saiyut et al. (2018) identified that the agricultural labour force age 60 years and above increases technical inefficiency, while 15–59 years of age reduces technical inefficiency in Thailand agricultural production. Conversely, several studies reported significant negative relationship between age and technical inefficiency for instance; Dessale (2019), findings suggested that older household head are more technically efficient in wheat production than young counterparts.

Education is expected to reduce technical inefficiency levels, as noted by Phillips and Marble (1986), because education improves access to information, facilitates learning and the adoption of innovations. Other studies support this conclusion, for instance (Külekçi, 2010). However, in our research, education, in terms of the number of years of schooling, had an expected sign but not significant, an indication that the education variable was likely to reduce technical inefficiencies in finger millet production. The results were consistent with the findings of Dawit et al. (2013) which shows that the household members’ highest education was likely to increase efficiency although it was insignificant.

The coefficient of non-farm income was significant and had a negative sign, implying that the farmers who have an extra source of income from non-farm activities tend to be more efficient than those who do not. The significant positive effect may be because income accruing from non-farm activities is used to purchase productivity-enhancing inputs like seed and fertilizers. Similarly, Külekçi (2010), reported that farmers with extra non-farm activities had a significant and positive correlation with efficiency. Along with this same line, Ahmed and Melesse (2018), found that Ethiopian smallholder farmers that had other sources of income from non-farm activities to be more productive than their counterparts.

Contrary to the expectation of the current study, the number of contacts with extension officers had a positive and significant relationship with technical inefficiency. This means that finger millet farmers who had more contact with extension officers were more technically inefficient than their counterparts. The finding was surprising since contacts with extension officers imply more access to farming information and, consequently, farmers are more aware of changes in production techniques and could in this way; minimize inefficiencies on productivity at the farm level. However, the current study findings could imply that the farmers who needed extension services were more technically inefficient in finger millet production than their counterparts. The technical inefficiency among farmers who had more contact with extension officers could also be attributed to other unobservable factors. Abate et al. (2019), work on the technical efficiency of smallholder farmers in red pepper production in Ethiopia found that the frequency of extension contacts had a positive impact on technical inefficiency. However, the result contradicts several other findings; for instance, Mango et al. (2015) indicated that the number of contacts with extension officers for maize farmers played a significant and positive role in determining technical efficiency in Zimbabwe. Alwarritz et al. (2015), reported similar findings.

4.2.3.1. Effects of finger millet innovations on finger millet yield. To measure the effects of innovations on finger millet yield, dummy variables of innovations were simply included as part of technical inefficiency variables. The current findings indicated that the adoption of improved finger millet variety positively increases finger millet yields by reducing inefficiency in finger millet
production. The results suggest that a unit increase in the use of finger millet improved seed variety increases productivity by 84.5% (Table 5). The implication is that a choice to adopt finger millet improved variety by farmers could significantly increase finger millet productivity in the study area and other areas with similar agro-ecological characteristics. The results confirm the finding of Handschuch and Wollni (2016), who indicated that the adoption of improved finger millet variety has a positive and significant impact on yields (99.8%). Ahmed et al. (2017), findings indicated that adoption of improved maize varieties leads to significant gains in the well-being of farmers and improves farm productivity.

Table 5. Translog stochastic frontier and inefficiency model

| Variable                          | Coefficient | SE   |
|-----------------------------------|-------------|------|
| Ln yield (Dependent)              |             |
| Constant                          | 2.018***    | 1.354|
| Ln Labor                          | 1.641***    | 0.615|
| Ln Seed                           | 1.451***    | 0.407|
| Ln Plot size                      | −0.727*     | 0.417|
| 0.5*Ln Labor                      | −0.112      | 0.081|
| 0.5*Ln Seed                       | −0.033***   | 0.008|
| 0.5* Ln Plot size                 | −0.100**    | 0.041|
| Ln Labor * Ln Seed                | −0.234**    | 0.099|
| Ln Labor * Ln Plot size           | 0.102       | 0.104|
| Ln Seed * Ln Plot size            | 0.076       | 0.075|
| Fertilizer use                    | 0.161***    | 0.047|
| Manure use                        | 0.112**     | 0.044|
| Inefficiency Effects Model        |             |
| Constant                          | −1.802**    | 0.724|
| Age                               | 0.014*      | 0.007|
| Gender                            | 0.224       | 0.269|
| Education                         | 0.044       | 0.028|
| Household size                    | 0.06        | 0.043|
| Log of no-farm income             | −0.030*     | 0.017|
| Group membership                  | −0.384**    | 0.194|
| Distance to the market            | −0.001      | 0.002|
| Household access to credit        | −0.213      | 0.279|
| Technical training                | 0.05        | 0.210|
| Number of contacts with officer   | 0.295***    | 0.110|
| Sub-County                        | −0.034      | 0.184|
| Improved variety                  | −0.845***   | 0.199|
| Conservation tillage              | −0.664***   | 0.207|
| IPW                               | −0.084      | 0.201|
| Membership to finger millet group marketing | −0.191 | 0.207 |
| Other statistics                  |             |
| Sigma²                            | 0.336       | 0.037|
| Gamma                             | 0.93        | 0.028|
| Lambda                            | 3.637       | 0.057|
| Log-likelihood                    | −143.102    |      |

(Continued)
Practicing conservation tillage to conserve soil and moisture in finger millet production had a negative and statistically significant impact on technical inefficiencies at one percent level of significance. The results could imply that minimizing the number of tillage operations reduces the loss of soil moisture and preserve the soil fertility that may be lost through the wash away of the loose topsoils, and consequently, could result in an increase in yield by 66.4% (Table 5). This provides evidence that soil and water conservation innovation is more critical for neglected cereal crops like finger millet that is primarily grown by farmers facing low and erratic rainfall patterns and marginal land. The results further affirm the potential role of these innovations in raising farm productivity and hence, food security and reducing poverty through higher farm household incomes. The findings agree with Sidar et al. (2017), who found that minimum tillage treatment recorded the highest finger millet yield among tillage treatments.

4.3. Technical efficiency

Based on Equations (2) and (3), farm-specific factors of technical efficiency were estimated. It is evident from the results that the technical efficiency of finger millet farmers in the study area ranges from 16.25% to 95.49%, with a sample mean of 67.39% as presented in Table 6. These results revealed that farmers are constrained by a number of factors such as planting unimproved seed varieties, poor soil and water conservation measures and few young farmers in finger millet production and lack of participation of farmers in off-farm income activities and group activities. The potential for improving the average finger millet technical efficiency is significant and that farmers would increase their yield by reducing technical inefficiency by 30%. This would require the application of improved finger millet seed variety, practicing conservation tillage, and recruiting more young farmers in finger millet production. Finger millet farmers’ participation also in off-farm and group activities would prove essential in reducing technical inefficiency in finger millet production.

4.4. Endogenous stochastic frontier model

In the estimation of the stochastic frontier model in the previous section, finger millet innovations were considered exogenous. However, the decision to adopt finger millet innovations may be

| Variable                  | Coefficient | SE |
|---------------------------|-------------|----|
| Wald Chi2                 | 189.87      |    |
| Prob chi2                 | 0.000       |    |
| Number of Observation     | 384         |    |

***Indicate statistical significance at 1 percent level of significance.

Table 6. Frequency distribution of technical efficiencies

| Technical Efficiency: Range (%) | No. of farmers | Percentage |
|---------------------------------|----------------|------------|
| 0-24                            | 4              | 1.04       |
| 25-49                           | 76             | 19.79      |
| 50-74                           | 137            | 35.68      |
| 75-100                          | 167            | 43.49      |
| Total                           | 384            | 100        |

Mean 67.39
Standard Deviation 17.80
Minimum 16.25
Maximum 95.49

***Indicate statistical significance at 1 percent level of significance.
endogenous since they are likely to correlate with the two-sided error term. This may result in the inconsistent estimation of the effects of finger millet innovations on productivity. Following M. U. Karakaplan and Kutlu (2017), a general maximum likelihood-framework based on instrumental variable approach was employed to handle the endogeneity problem in the stochastic frontier.

Access to information, markets, and resources may have a direct impact on the adoption of innovations. These parameters could directly influence the decision and ability to obtain improved inputs. However, these variables may not have a direct effect on farm productivity, and thus, based on this assumption, several instrumental variables were selected and tested. They included: household credit, distance to the market, number of contacts with extension officer and off/non-farm income and group membership. The technical training and finger millet households’ credit were found to correlate strongly with the decision to adopt but not associated with the inefficiency term. The correlation was statistically significant at one percent level, implying that the covariates were likely to influence finger millet productivity only through their impact on the adoption of finger millet innovations.

Durbin and Wu–Hausman test was conducted to check whether the endogeneity problem existed. The results revealed that the calculated test statistics for planting improved finger millet variety was 10.30, integrated pest and weed management 4.65 and 2.83 for conservation tillage hence, and rejected the null hypothesis of no endogeneity for the three innovations at 1%, 5% and 10% level of significance, respectively. The findings revealed that the decision to adopt improved variety, conservation tillage, and IPW were endogenous. The calculated test statistics for the decision to join the finger millet marketing group was not significant. The variable, therefore, was not correlated with the two-sided error terms.

Table 7 results are obtained from the estimation of the endogenous stochastic frontier model, assuming the half-normal distribution of the inefficiency component. Following the endogeneity test, three innovations, namely; improved variety, conservation tillage, and IPW entered into the model as endogenous variables. Whereas the decision to join the finger millet marketing group and other inefficiency and frontier covariates were treated as exogenous variables. The parameter estimates for the two models were quite similar. The results indicate that improved variety and conservation to have a positive effect on efficiency. However, the coefficients of the two innovations are reduced drastically; from 0.847 to 0.467 for improved variety and 0.664 to0.443 for conservation tillage for the exogenous and endogenous models, respectively. Thus, failing to account for endogeneity problem could overestimate the effect of the adoption of improved finger millet variety and conservation tillage on technical efficiency. However, there was no significant

| Variable                   | Endogenous Coef. | SE  |
|----------------------------|------------------|-----|
| Constant                   | 2.088***         | 1.285|
| Ln Labor                   | 1.432**          | 0.624|
| Ln Seed                    | 1.517***         | 0.415|
| Ln Plot size               | -0.716*          | 0.411|
| 0.5*Ln Labor               | -0.085           | 0.084|
| 0.5*Ln Seed                | -0.031***        | 0.008|
| 0.5* Ln Plot size          | 0.102**          | 0.039|
| Ln Labor * Ln Seed         | -0.247***        | 0.101|
| Ln Labor * Ln Plot size    | 0.118            | 0.103|
| Ln Seed * Ln Plot size     | 0.043            | 0.074|

(Continued)
difference between the mean technical efficiency for the exogenous model (67.39) and (69.57) from the endogenous model.

5. Conclusion

The current study analyzes the effects of agricultural innovation adoption on the productivity of underutilized cereals crops. The Translog exogenous and endogenous stochastic frontier production results indicated that improved variety and conservation tillage reduces technical inefficiencies and hence could increase productivity. The variation of the coefficients of improved variety and conservation tillage in the two models exhibited the existence of endogeneity problem; thus, failing to account for it would lead to overestimation of the effect. Labour, seed, fertilizers, and manure frontier covariates had a positive and significant effect on finger millet yield. While increased area under finger millet production significantly reduced the finger millet yield. Labour input had the highest elasticity, followed by seed. The model results also indicated that over three-quarter of the difference between the actual and frontier finger millet output was primarily due to the existence of inefficiency factors in finger millet production. The estimated mean technical efficiency of finger millet farmers was about 67%. Income from non-farm activities as well as membership to group reduces technical inefficiencies. Age of the household head and contacts with extension officers, on the other hand, significantly increases the inefficiencies.

Based on the findings the study recommends coordinated effort by the policymakers to promote the use of improved finger millet seed varieties and productive soil and water conservation measures through the adoption of minimum field operations and other conservation practices, to improve soil fertility and water-holding capacity, increase the yields.

| Variable                          | Endogenous Coeff. | SE  |
|-----------------------------------|-------------------|-----|
| Fertilizer use                    | 0.152***          | 0.043 |
| Manure use                        | 0.098**           | 0.043 |
| **Inefficiency model**            |                   |     |
| Constant                          | −3.744***         | 0.590 |
| Age                               | 0.013*            | 0.007 |
| Gender                            | 0.300             | 0.274 |
| Education                         | 0.040             | 0.027 |
| Household size                    | 0.054             | 0.043 |
| Log of non-farm income            | −0.034*           | 0.018 |
| Group membership                  | −0.014            | 0.191 |
| Number of contacts with the officer | 0.169*           | 0.101 |
| Distance to the market            | −0.001            | 0.003 |
| Sub-county                        | −0.064            | 0.183 |
| Improved variety                  | −0.467***         | 0.246 |
| Conservation tillage              | −0.443*           | 0.259 |
| IPW                               | −0.044            | 0.273 |
| Membership to finger millet group marketing | −0.252     | 0.206 |
| Log-likelihood                    | −712.438          |     |
| Wald ch2                          | 181.08***         |     |
| Mean technical Efficiency         | 69.57             |     |

*, ** and *** indicate statistical significance at 10, 5 and 1 percent level of significance.
6. Definition of terms

**Agricultural innovations**: is an agricultural idea, practice, or knowledge that is new to a farmer or the user, irrespective of whether it is new to other farmers or the country or the world.

**Integrated pest and weed management (IPW)**: is the system of pests and weed management that incorporates cultural, physical, mechanical, and biological practices to manage pest and weeds. This study included; hand pulling of weeds and burning before flowering, the use of traps and baits, early planting, the use of other plants (cowpea, pigeon pea, and groundnuts) to trap and destroy pests and control some weeds, and crop rotation.

**Conservation tillage** is defined as practice that includes no-till and minimum tillage systems. These techniques maintain plant residues on at least 30% of the soil surface after tillage activities.

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