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Exploring the nexus between health status, technical efficiency, and welfare of small-scale cereal farmers in Tanzania: A stochastic frontier analysis

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A R T I C L E I N F O

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A B S T R A C T

Cereal production is important component of Tanzania's agricultural sector, as it provides food security and income for a significant portion of the population. However, low levels of technical efficiency and the negative impact of ill-health on cereal productivity have posed significant obstacles to the welfare of small-scale farmers in the country. This study estimates the technical efficiency of cereal producers in Tanzania, investigates the relationship between farmer health and cereal productivity, and establishes a link between technical efficiency and the welfare of smallholder farmers. Using data from the Tanzania Agriculture Sample Census survey 2019/20, the stochastic frontier production function was used to estimate technical efficiencies, while Tobit and instrumental variables models analyzed the impact of health on cereal production efficiency and the effects of efficiency on the welfare of cereal's small-scale farmers respectively. The findings indicate that the overall technical efficiency of cereal producers in Tanzania is 44.44%, with pure technical efficiency standing at 56.50%. In addition, poor health reduces the likelihood of cereal productivity efficiency by 0.297 ($p < 0.01$). In addition, efficiency was found to significantly improve household welfare, as it increases food security (0.35327, $p < 0.01$), household income (0.2914, $p < 0.01$), and nutrition status by reducing malnutrition (−0.36607, $p < 0.01$). The study recommends that rural agriculture development programs include health components to increase productivity, sustainability, and ultimately the standard of living of rural communities.

1. Introduction

Cereal production plays a vital role in ensuring food security and reducing poverty in Tanzania, particularly in rural regions where the majority of households rely on agriculture as their main source of livelihood [1–4]. Despite its significance, the cereal sector faces considerable challenges, including low levels of technical efficiency and the adverse effects of poor health on productivity [2,5]. These challenges not only impact the livelihoods of smallholder farmers but also have broader implications for the country's overall economic growth. Therefore, understanding the determinants of cereal productivity and how health and agriculture intersect with technical efficacy is crucial in identifying pathways for sustainable and inclusive growth.

Recent statistics reveal that Tanzania's cereal production has been characterized by suboptimal levels of technical efficiency. According to the National Bureau of Statistics, Tanzania's average maize yield in 2020 stood at 1.9 tonnes per hectare, significantly lower than the average yield of 5.5 tonnes per hectare observed in other African nations [6,7]. This pattern of low efficiency extends beyond maize and also affects rice and sorghum production. Additionally, poor health among farmers has emerged as a substantial hindrance to agricultural productivity, especially in rural areas with limited healthcare access [8,9]. Studies have demonstrated that farmers' compromised health not only reduces their physical capacity for work but also impairs their decision-making abilities, resulting in decreased yields and technical efficiency. Consequently, gaining a deeper understanding of the interplay between health, agriculture, and technical efficiency is imperative for addressing these challenges and promoting sustainable and inclusive cereal production in Tanzania.

Enhancing agricultural productivity and food security holds paramount importance for Sub-Saharan Africa's development, including Tanzania [10–12], with technical efficiency serving as a pivotal factor in achieving these objectives. Recognizing this significance, the Tanzanian government has implemented various initiatives aimed at enhancing the

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productivity and technical efficiency of cereal and other crop productions [13]. Nevertheless, a significant portion of small-scale cereal farmers in Tanzania still grapple with achieving high levels of productivity. For instance, maize productivity remains notably low, with just 4.9 million hectares dedicated to maize cultivation [14,15]. This deficiency in cereal productivity can be attributed, in part, to limited access and utilization of improved agricultural inputs and tools, restricted availability of extension services, and inadequate agronomic practices. Ascertaining the drivers and obstacles of technical efficiency among small-scale farmers is pivotal for bolstering cereal crop yields.

Across Sub-Saharan Africa, including Tanzania, numerous studies have scrutinized the technical efficiency of cereal crops such as maize, wheat, sorghum, yam, and potato [16–18]. However, these studies have largely overlooked the influence of farmers' health on the technical efficiency of cereal crop farmers. Therefore, the body of literature has little information on the relationship between farmers health and productivity, given that even existing study [2] have analyze productivity in terms of total production unlike the current study which uses technical efficiency to analyze productivity across small-scale cereal farmers. Moreover, to add knowledge on the same, this study estimates effects of the technical efficiency on the small-scale cereal producers' welfare in order to understand whether such technical efficiency has any significant impact on the livelihood of the farmers' community. Moreover, given the nature and relatively similar characteristics of the smallholder farmers across developing countries particularly Africa, the current study has use Tanzania as the case study to lens the bigger picture of entire African and developing countries farming system.

2. Theoretical framework

The study draws insights from production theory developed by Philip Wicksteed 1894 as explained by Henningsen and Czekaj [19]. The theory explains the maximum output depends on a vector of input used. The relationship can be expressed mathematically as:

$$y = f(x) \tag{1}$$

where y = a single non-negative output quantity, x is a vector of non-negative input quantities. The theory suggests that the observations below the production function indicate technical inefficiency [19,20]. The production function in the context of technical inefficiency can be written as;

$$lny = \ln f(x) - u, u \geq 0 \tag{2}$$

where $-u \leq 0$ are non-positive residuals

In general, output quantity is a function of input quantities, ceteris paribus. Also, a producer is assumed to be rational, always aiming at maximizing the output given the set of input quantities.

For all observations, no inefficiencies, i.e., $u = 0$ occur when γ is equal to 0 (no inefficiency, only noise). The null hypothesis and alternative hypothesis for testing the presence or absence of inefficiency can respectively be written as; $H0 : \gamma = 0$ and $Ha : \gamma \neq 0$ [19]. The value of technical efficiency is between 0 and 1. The cereal farmer is technically efficient if its value (TE) = 1 and technically inefficient if TE < 1 which is associated with several socio-economic variables including the health status of a farmer [21].

2.1. Empirical studies technical efficiency effects

Numerous studies have extensively examined the technical efficiency of cereal crops, employing a variety of methodologies such as the Cobb-Douglas stochastic frontier model or the Translog stochastic frontier model. For instance, Mwalupaso [22] delved into the agricultural information and technical efficiency of maize farming in Zambia using the conventional stochastic Cobb-Douglas production frontier (SPF) and the propensity score matching-stochastic production frontier (PSM-SPF) model. Their findings showcased mean technical efficiency (TE) values of 0.76 and 0.63 for users and non-users of mobile phones, respectively.

Sapkota and Joshi [23], situated in the mid-hills of Nepal, harnessed the stochastic frontier production model and the Tobit model to analyze TE and its determinants. Their findings revealed an average TE of 0.71, shaped by factors including the age and schooling years of household heads, experience in maize seed production, livestock ownership, the proportion of maize seed area, seed source, and access to extension services.

Applying a one-step stochastic frontier normal/truncated-normal model, Belete [24] discovered that the mean technical efficiency level for maize-producing farmers stood at 69.03 %. Notably, variables such as the gender of the household head, age, row planting, credit accessibility, active labor force count, farm income, land size owned, access to improved seed and seed type used, and livestock count exhibited significant correlations with technical efficiency in Northern Ghana, as elucidated by the propensity score matching approach. The study underscored the favorable and substantial impact of credit accessibility on farmers' technical efficiency.

Conversely, Khan [25] harnessed a stochastic frontier model to reveal the affirmative and significant associations between tractor hours, labor input, fertilizer usage, and maize yield, with an average technical efficiency of 0.68. Their analysis additionally highlighted that education and farming experience had a negative influence on farmers' inefficiency using the technical inefficiency effect model. Despite the extensive exploration of these factors, these studies have predominantly overlooked the technical efficiency effects of farmers' health in cereal production.

A noteworthy exception is the study by Kitole [2], which centered on the impact of farmers' health on technical efficiency and agricultural productivity among smallholder maize farmers in Tanzania. However, this study did not quantitatively estimate the effect of farmers' health on productivity or technical efficiency through rigorous methods. This study addresses this gap by employing a comprehensive estimation approach. Moreover, this study introduces further analysis of the implications of technical efficiency on the welfare of smallholder farmers, enriching the understanding of the dynamic interplay between these pivotal concepts.

3. Methods and data

3.1. Research design and data

The present study adopts a cross-sectional research design, utilizing data sourced from Tanzania's National Agriculture Sample Census survey of 2019/20. The selection of this dataset stems from its comprehensive nature, encompassing an array of variables crucial to the investigation at hand, particularly pertaining to sociodemographic attributes of smallholder farmers, as well as institutional and household characteristics [26]. The study's sample, comprising 28,548 households, was derived from the larger pool of 33,808 households present in both Tanzania's mainland and Zanzibar.

This study specifically focuses on cereals, encompassing merely three crops as indicated in the National Agriculture census of 2019/20: paddy, maize, and sorghum [27]. This deliberate concentration underscores the study's intent to meticulously scrutinize the intricacies within this select subset of agricultural production.

3.2. Econometric model specification

3.2.1. Cobb-Douglas stochastic production frontier model

The examination of technical efficiency (TE) was carried out using stochastic production frontier models, following the frameworks proposed by Aigner [28], and the Tobit model [29]. The application of the Cobb-Douglas stochastic production frontier, which takes into account the inefficiency term μ following a positive half-normal distribution for the TE analysis, can be expressed as:

$$ln\ y_i = \beta_0 + \sum_i \beta_i\ ln\ x_i + v_i - u_i, u_i \geq 0 \tag{3}$$

$$u \sim N(0, \sigma_u^2) \tag{4}$$

where y_i is the quantity of cereal output, x_i is a vector of quantities of inputs, β a vector of the parameters to be estimated; subscript i indicates the i^{th} farmer, u_i is error term accounting for technical inefficiency, $u_i \geq 0$ must be non-positive (zero or negative residuals) $u_i \geq 0$ (e.g. Ref. [30]). The statistical noise term v_i follows a normal distribution with zero mean and constant variance σ_v^2 while inefficiency term u_i a positive truncated normal distribution (($\mu \neq 0$) with constant scale parameter σ_u^2 and all vs and all us are independent:

$$v \sim N(0, \sigma_v^2) \tag{5}$$

$$u \sim N^+(\mu, \sigma_u^2) \tag{6}$$

Following Alam [31] and Ehiakpor [32], the error term (u_i) is a non-negative error term associated with farmer-specific factors within his control, leading to the i^{th} farmer not reaching the deterministic frontier level. It is assumed to be distributed as a truncation of the normal distribution, with mean (u_i) and variance ($N(0,\sigma_u^2)$), such that the inefficiency error term can be explained by exogenous variables, as follows:

$$u_i = \alpha_i Z_i + w_i \tag{7}$$

where $= \alpha_i$ vector of explanatory variables and $\alpha_i =$ vector of unknown parameters to be estimated, where u_i denotes inefficiency, α_i and Z_i denote the vector of parameters and farmers' characteristics respectively, and w_i denotes the error term.

3.2.2. Tobit model for analyzing the effects of farmers' health on technical efficiency

According to Tobin [29], the general form of the Tobit model can be specified as follows:

$$y_i^* = \beta' x_i + \varepsilon_i \tag{8}$$

where y_i^* is a latent variable that is unobserved for values less than 0 and greater than 1, representing the technical efficiency score; $x_{i\ i}$ is a vector of independent variables which include factors affecting the extent of technical efficiency; β' is a vector of unknown parameters to be estimated; ε_i is a disturbance term assumed to be normally distributed with zero mean and constant variance σ^2 and $i = 1, 2, 3 \ldots n$ (n is the number of observations).

With the observed dependent variables which are the technical efficiency score (y_i), the Tobit model may further be specified as:

$$y_i = \begin{cases} 0\ y_i^* \leq 0 \\ y^* \quad if\ \ y_i^* < 1 \leq 0 \end{cases} \tag{9}$$

However, the estimates of the Tobit model are based on the maximum likelihood estimation (ML) by maximizing the Tobit likelihood function [33]. The maximum likelihood estimation may be specified as:

$$lnL = ln\left(\prod_{y_i>0} f(y_i) \prod_{y_i>0} F(0)\right) = \sum_{y_i>0} lnf(y_i) + \sum_{y_i=0} lnF(0) \tag{10}$$

Since y_i^* is assumed to be normally distributed as error terms are assumed to be normally distributed, $f(.)$, $F(.)$ and hence the log-likelihood functions can be written in the form of the density function and cumulative density function of the standard normal distribution as $\varnothing(.)$ and $\Phi(.)$ and the log-likelihood function is rewritten as:

$$lnL = \sum_{y_i>0} -\ ln\ \sigma\left(\frac{y_i - x_i\beta}{\sigma}\right) + \sum_{y_i>0} ln\left(1 - \varphi\left(\frac{x_i\beta}{\sigma}\right)\right) \tag{11}$$

Unlike the case of ordinary least square (OLS) coefficients, it is difficult to interpret the estimated coefficients of the Tobit as a marginal effect because there are three main conditional expectations of interest in the Tobit model. These are: 1) the conditional expectation of the underlying latent variable (y_i^*); 2) the conditional expectation of the observed dependent variable (y); and the conditional expectations of the uncensored observed dependent variable ($y > 0$). Following Greene [34] and McDonald and Moffitt [35], the marginal effects of these conditional expectations are given, respectively, as:

$$\frac{\partial E\left(\frac{y_i^*}{x}\right)}{\partial x} = \beta \tag{12}$$

$$\frac{\partial E\left(\frac{y_i^*}{x}\right)}{\partial x} = \beta\varphi\left(\frac{x\beta}{\sigma}\right) \tag{13}$$

$$\frac{\partial Pr\frac{(y>0)}{x}}{\partial x} = \varphi\left(\frac{x\beta}{\sigma}\right)\frac{\beta}{\sigma} \tag{14}$$

3.2.3. Effects of cereal technical efficiency on smallholder farmers' welfare

On the other hand, the instrumental variable models (i.e., Instrumental Variable Probit (IV Probit) and Two Stage Least Square (2 S LS)) were used to model the effects of cereal technical efficiency on smallholder farmers' welfare. Thus, in this study, the welfare was captured by three indicators namely food security, income and household nutrition status as presented in Table 1 of variables and measurement.

Thus, for the food security and nutrition status, the general IV Probit equation used for estimation was modelled as;

$$Y = X\beta + Z\gamma + \varepsilon_i \tag{15}$$

Whereas a binary response variable presented by Y indicates household nutrition status and food security, X entails the cereal technical efficiency which is also an endogenous variable, and other important control variables used in the study. The instrumental variable is denoted by Z while γ and β are estimated coefficients, and the error term is presented by ε.

Moreover, the 2SLS was used to estimate the income equation whereas in the first stage, the endogenous variable was considered as outcome variable. In this equation X is cereal technical efficiency (endogenous variable), φ is the estimated coefficient, while Z and μ are instrumental variables and error terms respectively as shown in eq (16),

$$X = Z\varphi + \mu_i \tag{16}$$

The second stage involves the inclusion of the predicted values of the endogenous variable from eq (16) (first stage). Thus, the variables involved in the second equation include the income (Y) which is the outcome variable, the predicted values of the endogenous variable (X) and the coefficients that will be estimated (β) as shown in eq 17

$$Y = X\beta + \varepsilon_i \tag{17}$$

Consequently, within the scope of this study, the distance between the homestead and the closest water source was adopted as an instrumental variable. This choice aimed to mitigate potential issues of endogeneity while performing estimations for eqn 15–17. The decision to employ this instrumental variable was influenced by the outcomes of the Wald exogeneity test, which indicated that the instrumental variable does not exhibit exogeneity. As presented in Table 7, the null hypothesis concerning exogeneity was rejected in favor of acknowledging endogeneity.

The elucidation of the other variables utilized in this study have been

Table 1
Variables and their measurements.

Variables (X_i)	Unit (Description)
Sex	Dummy (1 = female, 0 otherwise)
Age	Age of the smallholder farmers in years
Years of schooling	Total number of years of schooling
Household size	Total number of family members
Land (LAC)	Total land available for cereal cultivation (land in acres)
Costs of cereal seeds (COCS)	Total amount of money spent on buying cereal seeds
Cost of traction power (COTP)	Total amount of money spent on machinery and power in farms
Cost of fertilizer (COF)	Total amount of money spent buying fertilizers
Labor (LB)	Total number of active workers in cereal farms
Access to extension services	Dummy (1 = access to extension, 0 = Otherwise)
Access to irrigation services	Dummy (1 = access to irrigation, 0 = Otherwise)
Nutrition status	Dummy (1 = malnourished, 0 = non-malnourished)
Household income	Amount of income earned through cereal cultivation
Food security	Dummy (1 = food secured, 0 = food insecure)
Health status	Dummy (1 = ill health, 0 = Otherwise)

Table 2
Descriptive statistics.

Characteristics	Categories	Frequency	Percentage
Residence	Rural residents	19,427	68.05 %
	Urban residents	9121	31.95 %
Sex	Male	18,713	65.55 %
	Female	9835	34.45 %
Level of education	No Formal Education	12,004	42.05 %
	Primary Education	11,234	39.35 %
	Secondary Education	4065	14.24 %
	Higher Education	1245	4.36 %
Marital status	Married	14,651	51.32 %
	Not Married (Otherwise)	13,897	48.68 %
Off-farm activities	Participate	16,078	56.32 %
	Not participate	12,470	43.68 %

detailed and elaborated upon in Table 1

4. Results

4.1. Descriptive results

A comprehensive overview of the socioeconomic characteristics of the smallholder farmers is provided through the descriptive statistics presented in both Table 2 and Table 3. The findings reveal that a significant portion of cereal producers are situated in rural areas (68.05 %), with a smaller proportion residing in urban areas (31.95 %). Interestingly, the urban residency percentage among cereal producers slightly exceeds the national average distribution of households, which stands at 44 % for urban areas and 66 % for rural areas [27].

Conversely, the findings highlight that a considerable majority of smallholder farmers are male, accounting for 65.55 %, underscoring the prevailing male dominance within the agricultural sector. Furthermore, despite the overarching gender sensitivity, a substantial proportion of participants lack formal education (42.05 %), contrasting with the 14.24 % who have received secondary education and the mere 4.36 % who have attained higher educational levels.

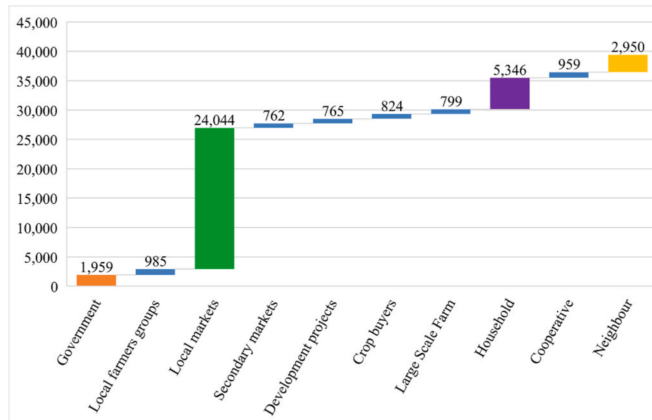

Fig. 1. Source of agriculture inputs.

Moreover, it is noteworthy that over half of the smallholder farmers are actively involved in multiple income-generating activities, often referred to as off-farm activities. This stands in contrast to the 43.68 % who exclusively engage in agricultural activities. These observations deviate from the figures in the National sample for the agriculture census of 2019/20, which indicate that over 50 % are exclusively involved in agricultural activities [27].

The findings presented in Table 3 underscore that a mere 21.42 % of cereal producers in Tanzania opt to utilize agricultural inputs during the cultivation process, while the prevailing majority of 78.58 % refrain from utilizing any agricultural inputs, predominantly relying on seasonal rainfall for cultivation. Additionally, the findings reveal that only 37.86 % of cereal producers in Tanzania have access to extension services, whereas a significant majority (62.14 %) lack such access. These

Table 3
Agriculture practice-related characteristics of cereal producers.

Characteristics	Categories	Frequency	Percentage
Agriculture inputs usage	Use agriculture inputs	6115	21.42 %
	Never use agricultural inputs	22,433	78.58 %
Extension service	Reached by the extension officer	10,807	37.86 %
	Never reached by the extension officer	17,741	62.14 %
Cooperative and Farmers' groups	Member of cooperative only	888	3.11 %
	Members of the farmers group only	360	1.26 %
	Members of both	82	0.29 %
	Not members of any	27,218	89.3 %

results are aligned with the National Agriculture Sample Census report, which indicates that a mere 7 % of Tanzanian farmers have access to extension services [27].

Furthermore, the revelations in Table 3 shed light on the fact that a minimal 3.11 % of cereal producers are solely members of cooperative societies, with an additional 1.26 % being exclusively affiliated with farmers' groups. Conversely, those who maintain dual memberships in both cooperative societies and local farmers' groups constitute 0.29 %. It is important to note that the majority, accounting for 89.3 %, are not affiliated with either of these two farming entities. These findings suggest that the majority of farmers continue to operate their farming activities independently, displaying limited motivation to join any farming organizations. This challenge is widespread across numerous African countries and can often be attributed to inadequate administrative and managerial capabilities of farming institutions, especially cooperative societies [36].

The findings depicted in Fig. 1 illuminate that a majority of cereal producers in Tanzania do not rely on the government or public institutions for procuring agricultural inputs. Specifically, the results indicate that a significant 84.22 % (24,044 out of 28,548) of cereal producers source their agricultural inputs from local markets. Following this, households emerge as the second prominent source, constituting 18.72 % (5346 out of 28,548), followed by borrowing from neighbors, accounting for approximately 10.33 % (2950 out of 28,548). In contrast, the reliance on the government for the provision of agricultural inputs stands at a mere 6.86 %. Studies provide insight into the situation, clarifying that the relatively low government expenditure on agriculture has led to inefficiencies within the sector, placing a substantial burden on farming communities. This dynamic persists despite the sector's considerable contribution to the economies of numerous developing countries [37].

The insights gleaned from Fig. 2(A) indicate that an increase in the land allocated for cereal cultivation corresponds to a modest rise in production, compared to the effect of increasing the quantity of fertilizers. These results infer that the utilization of fertilizers possesses the potential to exert positive impacts on production enhancement. Concurrently, Fig. 2(B) elucidates those higher levels of seed planting correlate with heightened output expectations, while reduced seed quantities yield proportionately diminished harvests.

Moving on to Fig. 2(C), the findings imply that cereal producers in Tanzania exhibit a trend of utilizing lower labor costs in production. This can be attributed to families constituting the principal source of the labor force. Notably, these findings mirror those of numerous studies conducted in developing countries [38,39], collectively underscoring that households experience reduced farming expenses due to their relatively larger family sizes.

The insights gleaned from Fig. 3 underscore that elevated cereal outputs correspond to an escalation in fertilizer usage, seed quantity, and off-farm income. This trend is substantiated by the pronounced concentration of parallel coordinates at higher levels as output levels increase. Conversely, as depicted in Fig. 4, a positive relationship emerges between the augmentation of off-farm income and cereal outputs. This pattern suggests that farmers are inclined to allocate their supplementary income towards acquiring additional agricultural inputs, consequently contributing to an amplified cereal production output.

The data presented in Table 4 reveals that the mean age of cereal producers amounts to 49.6013 years, with the age range spanning from a minimum of 19 years to a maximum of 101 years. Notably, the average age of cereal producers in this study surpasses that reported in the National Household Budget Survey of 2017/18, which was documented at 47.6 years [5,7,11,27].

Furthermore, the smallest household observed consisted of 3 members, whereas the largest household encompassed 28 individuals. Additionally, the calculated average household size among all cereal producers stands at 6.095, surpassing the national average of 4.6 years documented in the National Household Budget Survey of 2017/18 [40].

The population pyramid of cereal producers depicted in Fig. 5 highlights a notable characteristic: the base of the pyramid is relatively narrow, indicating a lower birth rate. This observation underscores a demographic pattern where births have been occurring at a reduced rate. Furthermore, the insights garnered from Fig. 5 project a shift in the shape of the population pyramids over time. The current triangular form is anticipated to evolve into a more barrel-like shape, an alteration attributed to the nation's ongoing economic advancement.

Furthermore, the findings illustrated in Fig. 6 accentuate that the region of Mbeya (indicated by the green shading) emerges as the foremost area in Tanzania when it comes to the utilization of agricultural inputs. It is pursued by Shinyanga, Tabora, Kilimanjaro, and Ruvuma (represented by the purple shading) in terms of their input usage intensity. In contrast, the regions with the lowest adoption rates of

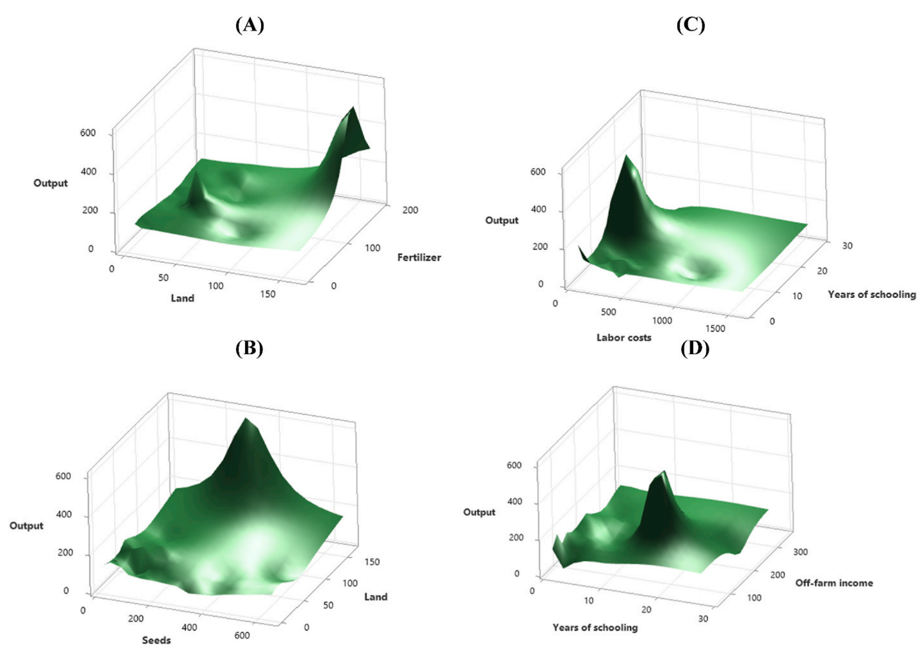

Fig. 2. Surface plots of Output vs. Land vs. Fertilizer vs. Labor costs vs. Seeds vs. Off-farm income.

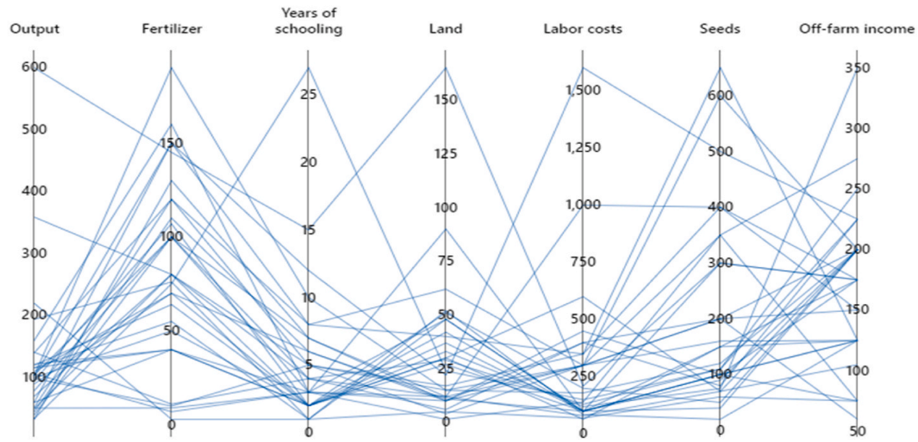

Fig. 3. Parallel Coordinates Plot of Output, Fertilizer, Years of schooling, Land, Labor costs, Seeds, Off-farm income.

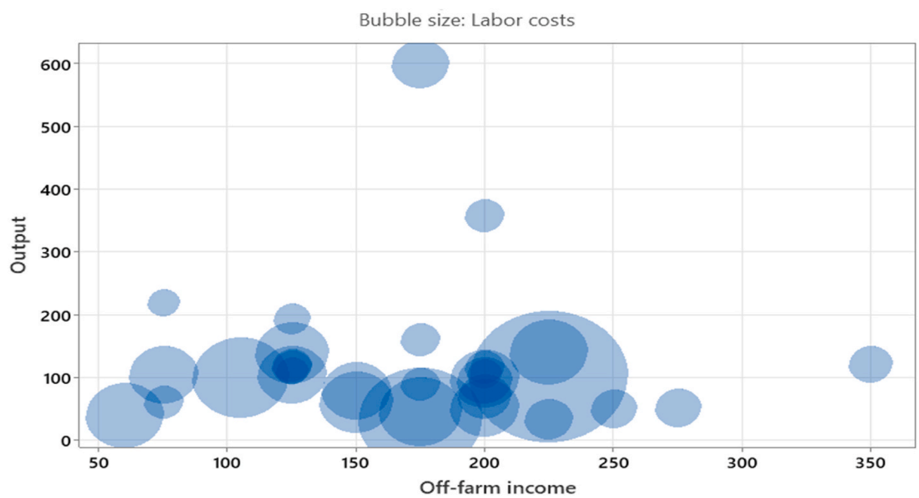

Fig. 4. Bubble Plot of Output vs Off-farm Income.

Table 4
Summary statistics.

Variables	Minimum	Maximum	Mean
Age	19	101	49.60135
Household Size	3	28	6.09562
Health Expenditure	8870	3,485,550	689,500
Agriculture Inputs Expenditure	9500	4,840,430	890,320
Off-farm Income	46,790	3,150,630	679,140

agricultural inputs are Kaskazini Pemba (1 %) and Kusini Pemba (1 %), both situated in the Zanzibar archipelago. These regions are symbolized by the red and yellow shading, respectively.

4.2. *The level of cereal production technical efficiency among smallholder farmers in Tanzania*

The Stochastic Frontier Production Function (SFPF) has been employed to assess the level of technical efficiency (TE) in cereal production among smallholder farmers. This choice is underpinned by the model's capability to concurrently analyze the impact of statistical noise and unobservable factors influencing technical efficiency [28,41]. Additionally, in this study, the Translog model was chosen over the Cobb-Douglas model. This decision was driven by the outcomes of the Likelihood Ratio Test, which indicated the rejection of the Cobb-Douglas model, as detailed in Table 5.

The findings presented in Table 6 introduce the translog stochastic frontier and inefficiency model for cereal production among smallholder farmers in Tanzania. The model's dependent variable is the natural logarithm of cereal production (yield). Notably, the coefficient's significance of γ at the 1 % level signifies the existence of a one-sided error component. This indicates the materiality of technical inefficiency effects, and thus the overall average production function is inadequate to represent the data, with a variance ratio of 56.10 %.

This finding underscores the essential role of cereal production-specific technical inefficiency in elucidating the overall variability of output. This significance surpasses the influence of random disturbances and measurement errors. On a different note, the observed shortfall in output from the frontier output is predominantly influenced by factors within the purview of smallholder farmers engaged in cereal production under study. Hence, the remaining 43.90 % can be attributed to specification bias, measurement errors, and factors beyond the control of smallholder farmers.

In the context of the Stochastic Production Frontier (SPF) model, the coefficient associated with the land allocated for cereal cultivation manifests as positively significant at the 1 % level. This finding suggests that an increment in land allocation corresponds to a cereal productivity increase of 21.6 units across the entirety of smallholder farmers in Tanzania. Similarly, coefficients for other input variables exhibit significance in the SPF model. Specifically, the cost of fertilizer demonstrates significance at 1 %, the cost of traction power at 5 %, and labor at 1 %. These results underscore the importance of these input variables at

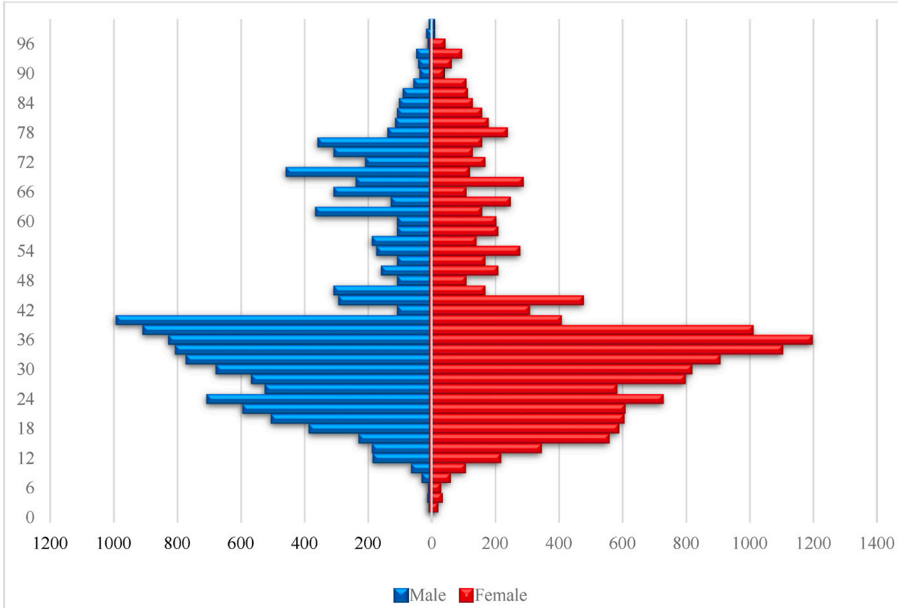

Fig. 5. Population pyramid of cereal producers in Tanzania.

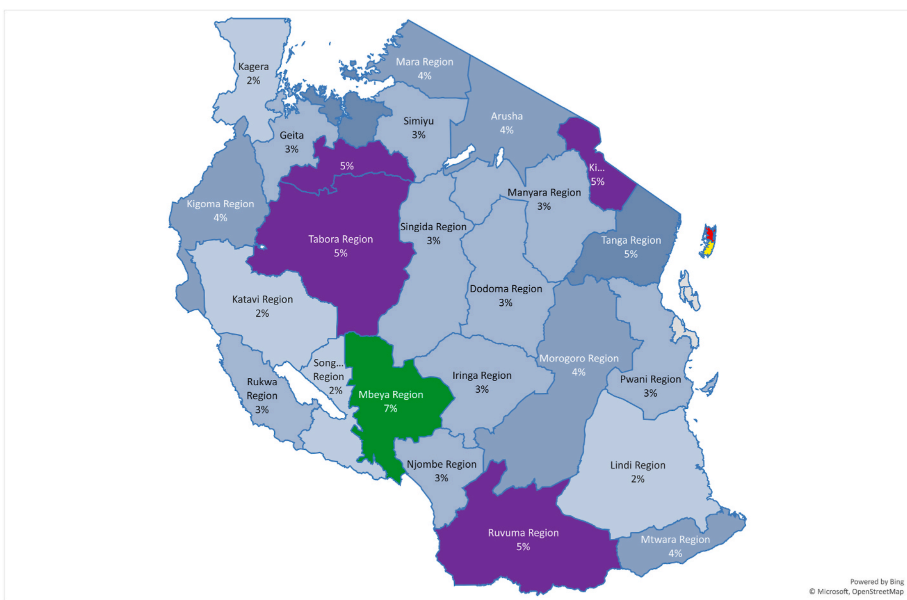

Fig. 6. Share of Agriculture inputs usage by regions.

various levels in cereal productivity.

Furthermore, the results in Table 6 reveal the significance of squared values of the cost of cereal seeds (COCS) and the cost of traction power (COTP) with opposing effects on cereal production. Additionally, the coefficients for interaction terms between production inputs also demonstrate significance. These interactions, including land allocation for cereal production (LAC) and the cost of cereal seeds, LAC and the cost of fertilizer (COF), LAC and the cost of traction power, LAC and labor (LB), the cost of cereal seeds and labor, as well as the cost of traction power and labor, all exhibit meaningful and positive effects on cereal production among smallholder farmers in Tanzania. This suggests that simultaneous proportional utilization of these input variables contributes to an increase in cereal production.

4.3. *Determinants of technical efficiency of cereal production*

The effects of exogenous factors on cereal production efficiency have been examined in this study through a one-stage procedure, where both the Stochastic Production Frontier (SPF) and the determinants for efficiency were simultaneously estimated. In the estimation of the inefficiency model, eight variables were found to be statistically significant in influencing the efficiency of cereal production among smallholder farmers in Tanzania (*see* Table 6).

The findings reveal that being a female cereal producer has a positive and significant impact on the inefficiency of cereal productivity compared to male producers. This suggests that males exhibit higher productivity than females. These results align with the studies conducted by Belete [24], and Ayele [50], which argue that despite males having relatively lesser engagement in agricultural production, their

Table 5
Hypothesis tests for model specification and statistical assumptions.

Null Hypothesis	Likelihood Ratio Test (LR)	Critical Value	Degrees of Freedom	Verdict
Testing the null hypothesis that the translog SFPF can be reduced to a Cobb-Douglas SFPF				
$H_0 : \beta_{ij} = 0$	30.56***	19.42	11	Reject H_0
Testing the null hypothesis that the distribution of inefficiency can be reduced from truncated normal to half normal distribution $\mu_i = 0$				
$H_0 : \mu_i = 0$	26.5***	5.62	2	Reject H_0
The null hypothesis that technical inefficiency effects are not in the model ($H_0 : \gamma = 0$)				
$H_0 : \gamma = \delta_1 = \delta_2 = \delta_3 = \delta_n = 0$	171.58***	20.153	13	Reject H_0

***p < 0.01, **p < 0.05, *p < 0.1.

Table 6
Maximum Likelihood estimates on the Stochastic Production Frontier and factors influencing inefficiency of cereal production among smallholder farmers in Tanzania.

Dependent Variable (Cereal production)		Parameters	Estimated Value	t-statistics
Stochastic Production Frontier				
	Constant	β_0	0.382***	2.619
	ln(LAC)	β_1	0.216***	5.115
	ln(COCS)	β_2	0.002	0.097
	ln(COF)	β_3	0.404***	3.602
	ln (COTP)	β_4	0.115**	3.031
	ln(LB)	β_5	0.101***	4.985
	$[\ln(LAC)]^2$	β_{11}	0.006	0.350
	$[\ln(COCS)]^2$	β_{22}	−0.052**	−2.590
	$[\ln(COF)]^2$	β_{33}	0.230	0.142
	$[\ln(COTP)]^2$	β_{44}	0.011**	3.020
	$[\ln(LB)]^2$	β_{55}	0.057	0.031
	ln(LAC) ln(COCS)	β_{12}	0.203**	4.560
	ln(LAC) ln(COF)	β_{13}	0.114**	3.605
	ln(LAC) ln(COTP)	β_{14}	0.154**	4.610
	ln(LAC) ln(LB)	β_{15}	0.327**	4.200
	ln(COCS) ln(COF)	β_{23}	0.260	0.073
	ln(COCS) ln(COTP)	β_{24}	0.062	0.059
	ln(COCS) ln(LB)	β_{25}	0.119**	4.092
	ln(COF) ln (COTP)	β_{34}	0.518	0.007
	ln(COF) ln(LB)	β_{35}	0.620	0.082
	ln(COTP) ln(LB)	β_{45}	0.327**	4.988
Inefficiency Model				
	Age	δ_1	−0.123**	−3.013
	Sex (female)	δ_2	0.267*	2.095
	Years of Schooling	δ_3	−0.402***	−4.793
	Household size	δ_4	0.082**	4.513
	Off − farm income	δ_5	−0.295**	−4.724
	Access to extension	δ_6	−0.125*	3.474
	Access too irrigation	δ_7	−0.302**	−4.007
	Health expenditure	δ_8	0.415**	5.815
	Access to financial services	δ_9	0.186**	3.739
Diagnosis statistics				
Tests	Sigma square	$\delta^2 = \delta_u{}^2 + \delta_v^2$	0.0813***	4.501
	Gamma	$\gamma = \frac{\delta_u{}^2}{\delta^2}$	0.5610***	4.055
	ln(Likelihood)		18.539	
	LR test		24.425	
	Overall Technical Efficiency		0.444	
	Pure Technical Efficiency		0.565	

***p < 0.01, **p < 0.05, *p < 0.1.

involvement contributes significantly to improved productivity through capital and machinery usage.

Furthermore, the role of education in promoting human advancement is reaffirmed by this study's results. The analysis demonstrates that an increase in the level of education among cereal producers corresponds to a significant decrease in inefficiency. This indicates that higher education levels enhance cereal productivity. This concurs with the assertions of studies [23,42,43], which contend that higher education plays a significant role in boosting agricultural productivity, despite the prevalence of lower and average education levels among active participants in the sector within most developing countries.

Despite family members being a primary source of labor in agricultural communities across many African countries, this study uncovers that an enlargement of household size among cereal producers leads to a significant increase in inefficiency in cereal production. This is attributed to the presence of non-working family members whose contribution to household welfare and productivity is limited [5]. Thus, a larger number of non-working members burdens the household's capacity to produce, thereby diminishing production efficiency [44]. However, Kelemu and Negatu [45] argue that larger family sizes are beneficial for households relying on agriculture as their main income source.

Furthermore, the findings in Table 6 indicate that an increase in off-farm income exhibits a negative and significant relationship with inefficiency in cereal production. This suggests that as farmers' income from non-farming activities rises, their ability to invest in agricultural productivity also expands, consequently leading to increased agricultural production. Existing studies [11,26,44] underscore that supplementary income enhances production in primary household activities by

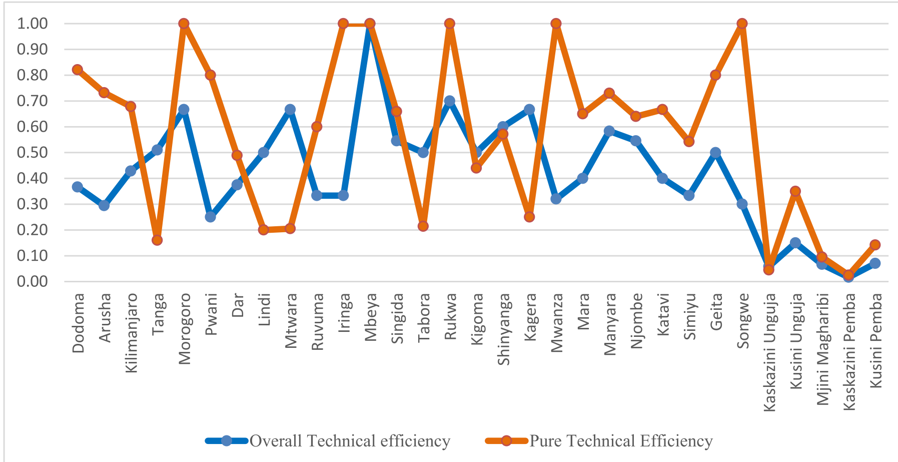

Fig. 7. Overall Technical Efficiency vs. Pure Technical Efficiency.

Table 7
Tobit regression on effects of smallholder farmers' health on technical efficiency.

Efficiency	Coef.	St. Err	t-value	p-value	[95 % Conf Interval]		Sig
Age	0.021	0.002	2.10	0.011	0.013	0.025	**
Sex	−0.023	0.011	−1.71	0.061	−0.035	−0.017	*
Years of schooling	0.089	0.005	2.98	0.008	0.003	0.059	***
Household size	−0.044	0.013	−2.16	0.044	−0.152	−0.013	**
Access to extension services	0.126	0.012	2.82	0.032	0.327	0.835	**
Land (ha)	−0.165	0.063	−2.63	0.010	−0.191	−0.341	**
Costs of seeds	−0.384	0.043	−3.27	0.000	−0.481	−0.288	***
Access to irrigation	0.199	0.028	3.53	0.000	0.142	0.723	***
Access to finance	0.364	0.019	4.91	0.000	0.386	0.946	***
Health status (Illness)	−0.297	0.001	5.04	0.000	0.453	0.874	***
Off-farm income	0.306	0.083	4.21	0.006	0.218	0.503	***
Regions	*Control*	*Control*	*Control*	*Control*	*Control*	*Control*	
Pseudo r-squared		0.442					
F-test		13.639	Prob > X^2			0.000	
Akaike crit. (AIC)		45.016	Bayesian crit. (BIC)			63.304	

***p < 0.01, **p < 0.05, *p < 0.1.

acting as a catalyst.

Moreover, access to both extension services and irrigation is found to have a negative and significant impact on the inefficiency model. This implies that these factors play a pivotal role in reducing inefficiency in cereal productivity. The negative effects in the inefficiency model suggest that extension services and irrigation positively affect SPF. As farmers gain access to these services, their potential to maximize cereal productivity increases. Research on irrigation [46–48] supports these findings, highlighting the positive and significant effects of irrigation on agricultural productivity and farm profitability.

Findings from Fig. 7 reveal variations in the overall technical efficiency of cereal production among small-scale farmers across different regions. Notably, the Mbeya region stands out with the highest score of 1.00, indicating superior technical efficiency, whereas the lowest score of 0.00 is observed in Kaskazini Pemba. Furthermore, when considering pure technical efficiency, prominent scores of 1.00 are achieved in regions such as Morogoro, Iringa, Mbeya, Rukwa, Mwanza, and Songwe. In contrast, regions like Kaskazini Unguja, Kaskazini Pemba, Mjini Magharibi, and Tanga exhibit comparatively lower scores in this aspect.

4.4. *Effects of smallholder farmers' health on cereal productivity*

The outcomes presented in Table 7elucidate the impact of smallholder farmers' health on cereal productivity, with the dependent variable being the technical efficiency scores of cereal production. Furthermore, the findings concerning the pivotal demographic characteristics of smallholder farmers, including age, sex, education, and household size, are in alignment with the SFA regression results in the inefficiency model as displayed in Table 6. This alignment is evident in terms of both the directional signs and the levels of statistical significance. These congruent patterns suggest that these sociodemographic variables significantly contribute to explaining the efficiency of cereal productivity within the smallholder farming community in Tanzania.

The findings presented in Table 7 reveal significant trends in relation to the impact of various factors on cereal productivity efficiency among smallholder farmers. Notably, increased access to extension services has been found to correspond with a 12.6 % increase in the likelihood of improved cereal productivity efficiency across smallholder farmers, demonstrating statistical significance. These findings resonate with the conclusions drawn in separate studies conducted within developing countries [4,9,49], which assert that enhanced access to agricultural knowledge contributes to the reduction of both pre- and post-harvest losses, ultimately elevating food crop productivity.

Moreover, this study underscores that larger cultivation acreage for cereals does not necessarily translate to higher efficiency. The results indicate that a one-acre increase in cereal production land leads to a notable decline in efficiency, with a reduction of 16.5 %. These outcomes emphasize that the size of cultivation land alone does not guarantee efficiency; instead, it is the amalgamation of factors that facilitate cost minimization while maximizing outputs that plays a more crucial role. This perspective is corroborated by the work of Ngango and Hong

Table 8
Regression results on the effects of cereal technical efficiency on welfare.

	Welfare indicators		
	Food security *(1= food secured, 0= food insecure)*	Income	Nutrition status *(1=malnourished, 0 = no malnourished)*
Residence (Urban)	0.0588 (0.07116)	0.12914** (0.00140)	−0.18119*** (0.00253)
Age	−0.12881 (0.02501	−0.01451*** (0.00119)	0.05772 (0.17428)
Sex (Female)	0.07234*** (0.0013)	−0.11045** (0.00504)	−0.08910 (0.21168)
Years of schooling	0.20051** (0.00215)	0.26252*** (0.07813)	0.33672*** (0.001635)
Household size	0.09725 (0.08244)	0.02882* (0.01320)	0.13811 (0.28640
Access to extension services	0.34013*** (0.00152)	0.04815* (0.01573	0.07994 (0.17889)
Land (ha)	0.21814 (0.31182)	0.11035 (0.16216)	0.05531 (0.18073)
Costs of seeds	−0.08250*** (0.00096)	−0.11005 (0.14782)	−0.19549 (0.3304)
Access to irrigation	0.28557** (0.00328)	0.100147** (0.01718)	−0.22953 (0.15056)
Access to finance	0.24107 (0.14885)	−0.15896** (0.03271)	−0.10042*** (0.01003)
Cereal Technical efficiency	0.35327*** (0.00621)	0.24914*** (0.00017)	−0.36607*** (0.00040)
Access to market	0.20103 (0.15756)	0.08147** (0.02191)	−0.07189 (0.13579)
Storage facilities	0.21662** (0.05021)	0.13015*** (0.00224)	0.06445 (0.25336)
Sample size	28,548	28,548	28,548
R squared	0.5163	0.3944	0.3508
Instrumented	Cereal Technical efficiency scores		
Instrument	Distance to water source		
Wald test of exogeneity	Corr = 0.045	Chi-square = 342.08	Prob > chi2 = 0.0000

Standard errors in parenthesis.
***p < 0.01, **p < 0.05, *p < 0.1.

[38], who conducted a study in Rwanda and came to a similar conclusion.

Furthermore, the findings within Table 7 highlight that illnesses exert a significant negative influence on cereal productivity. Specifically, ill smallholder farmers demonstrate lower efficiency compared to their healthy counterparts, with illness leading to a substantial decrease of 29.7 % in efficiency. These outcomes align with the conclusions reached by Kitole [6], who found that ill health adversely affects maize production among smallholder farmers in Tanzania by reducing the number of working days and diverting income from agriculture to cover treatment costs. Moreover, given the limited healthcare financing mechanisms prevalent in many developing countries, the vulnerability of the poor and rural communities to health-related challenges further impedes efforts aimed at achieving food security and overall welfare development [11,26].

4.5. *Effects of cereal technical efficiency on smallholder farmers' welfare*

The results showcased in Table 8 illuminate a positive correlation between the level of technical efficiency among cereal farmers and their likelihood of attaining food security (0.35327, $p < 0.01$). Similarly, the outcomes underscore that heightened technical efficiency is intricately linked to increased income levels among cereal farmers (0.24914, $p < 0.01$). The observed positive impact on income signifies that smallholder farmers have adeptly translated the gains in efficiency into tangible economic advantages for their households.

Furthermore, the findings pertaining to nutritional status underscore that as farmers elevate their technical efficiency in cereal production, their vulnerability to malnutrition diminishes. This inference is drawn from the negative correlation established between technical efficiency and household nutrition status (−0.36607, $p < 0.01$). As such, the evidence presented in this study aligns with earlier research conducted by Sapkota and Joshi [23], and Kodua [51], both of whom assert that technical efficiency practices among smallholder farmers results in improved food output, reduced expenditure, and consequently, higher household income. Additionally, these practices contribute to the overall sustainability of smallholder farmers' well-being, encompassing not only financial resilience but also the preservation of the environment.

5. Conclusion

This study delved into the intricate relationship between the health status of smallholder farmers and their productivity in cereal crop cultivation, while also uncovering the subsequent implications for the well-being of this predominant agricultural group, especially in developing nations like Tanzania. The research findings underscore the substantial influence of socio-demographic attributes, resource access, and health conditions on the technical efficiency of cereal production. A crucial revelation emerged, highlighting the detrimental impact of inadequate health on technical efficiencies. This underscores the pressing need to address the health challenges faced by smallholder farmers to uplift their overall quality of life, enhance efficiency, and amplify productivity in cereal farming.

Moreover, a significant and noteworthy correlation surfaced between technical efficiency and pivotal welfare indicators, including the income, food security, and nutritional status of smallholder farmers. Elevated technical efficiencies were closely linked to higher income levels and an increased probability of achieving food security. Additionally, the study identified a positive association between improved nutritional status and higher technical efficiency, leading to a decrease in malnutrition prevalence within smallholder farming communities. In sum, these revelations underscore how technical efficiency intricately interlaces with the welfare and prosperity of smallholder farmers, emphasizing the interplay between farming practices, efficiency, and overall well-being.

In light of these findings, a series of recommendations have been formulated to bolster the health, technical efficiency, and holistic welfare of smallholder farming communities. Noteworthy proposals encompass the establishment and execution of health initiatives tailored to augment smallholder farmers' access to healthcare services. Concurrently, programs fostering awareness around health matters and promoting healthy lifestyles warrant integration. Gender-sensitive initiatives targeting the specific health requisites of both male and female farmers are of paramount importance.

Furthermore, the amalgamation of health-related knowledge within educational campaigns, driven by governmental and non-governmental entities, has the potential to positively impact health outcomes. Extension services incorporating health management practices can further amplify agricultural productivity and elevate the overall welfare of smallholder farmers. The introduction of nutrition-focused interventions emerges as a vital strategy to bolster the well-being and productivity of farmers. In closing, the advocacy for sustainable farming practices, the pursuit of equitable resource access, and the continuous monitoring and evaluation mechanisms collectively contribute to the betterment of smallholder farmers' quality of life and the optimization of efficiency in cereal production.

CRediT authorship contribution statement

Felician Andrew Kitole: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Felister Y. Tibamanya:** Methodology, Writing – review & editing. **Jennifer Kasanda Sesabo:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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