



Determinants of technical efficiency of pig production systems in northern Uganda: a Stochastic Frontier approach

Caleb I. Adewale¹ · Elias Munezero¹ · Elly K. Ndyomugenyi² · Basil Mugonola¹

Received: 8 August 2023 / Accepted: 4 July 2024
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2024

Abstract

Meat consumption, particularly the consumption of pork, has increased substantially in most developing countries. In response, various production systems are being employed by pig farmers to produce pork to cover the demand-supply gaps. However, little is known about the technical efficiencies of these underlying production systems. This study examined the technical efficiency of smallholder pig production systems in northern Uganda using cross-sectional data. The study surveyed 240 pig farmers randomly selected and used descriptive statistics and stochastic frontier analysis to examine the data collected. Results revealed that age, access to credit, household size, education level, years of pig farming experience management system, and access to extension services were the key determinants of technical efficiency in the farrow to finish pig production system. Technical efficiency in the farrow to weaner pig production system was influenced by household size, level of education, access to credit, access to extension services, and management system. In the weaner-to-slaughter pig production system, determinants of technical efficiency included age, household size, access to credit, access to extension services, and breed of pigs. The study recommends that policies that would ensure sufficient access to credit by pig producers should be enacted to enhance production. Pig producers should be urged to wisely use credit received for the expansion of their pig farms rather than for other uses. Further, extension services tailored to pig production systems should be made available to pig farmers to enhance output and technical efficiency and to bridge the information gap between research institutes and the farmers.

Keywords Technical efficiency · Stochastic frontier · Pig production systems · Farrow to finish · Farrow to weaner · Weaner to slaughter · Northern Uganda

Extended author information available on the last page of the article

Introduction

The consumption of meat is on the increase in the world today leading to an upsurge in the production of livestock (Delgado 2005; Godfray et al. 2018). There has been an increase in the world's meat production in the last decade with most of the increase being documented in developing countries (Eriksson et al. 2005; Henchion et al. 2021). Livestock production is a core part of the agricultural sector of developing countries of which a common example is pig production. Pork production has immensely impacted the total productivity of meat in many countries of the world (Petrovska 2011). Pig production is one of the fastest-growing livestock sectors in the world and this trend is sure to linger on in the near-term years (FAO 2010). Meat originating from pigs is one of the commonest sources of animal protein in the human diet (Adewale and Belewu 2022). Pig production has gained ground in countries undergoing a transition from ruminant to monogastric livestock production. The shorter life span of pigs, increasing demand for pork, higher rates of return, and high feed conversion ratios of pigs are key rationales behind the popularity of pig production (Obayelu et al. 2017).

Pig production is an attractive substitute for ruminant production due to its relatively lower costs of production and limited space requirements. It also does not strive for grassland with other forms of livestock production (Phiri 2012). Furthermore, the selling of pigs and their by-products presents a decent opportunity for the rural and peri-urban population to earn income in a short time (Onyekuru et al. 2020). However, pig production in Uganda and other developing countries is constrained by inadequate animal husbandry skills, inadequate capital for business enlargement, diseases, poor quality feeds, inadequate access to credit for purchasing farm inputs, high cost of building materials, lack of access to veterinary services, and illiteracy of the farmers (Mugonya et al. 2019). These constraints result in resource inefficiency and low productivity of the pigs. In addition, the constraints result in the inability of pig farmers to increase their efficiency of production and become more competitive both in foreign and domestic markets (Jabbar and Akter 2008). Pig farmers need to meet the novel market regulations and requirements, but most times find it hard to adapt rapidly to the swift development of the global market (Manevska-tasevska et al. 2016). Moreover, it is difficult for them to attain high production efficiency since the existing farm management practices of pig production systems are inefficient and not helpful. Inadequate technology and high production costs are major factors that contribute to the technical inefficiency of pig production systems (Dorh et al. 2019). Particularly, inferior technology may limit the attempt to ensure advancement in food production hence the need to improve the managerial and technical capability of farmers and also to identify the most technically efficient production system (Petrovska et al. 2012). Production efficiency is enhanced by an improved state of technology adequacy, optimal farm size, efficient farm management practices, and least cost of production, which leads to a price reduction of outputs in the local market (Petrovska et al. 2012).

Pig production systems refer to the various operations farmers explore to produce pigs. They are classified based on the stages of pigs' growth. Pig production systems include the farrow to weaner (breeding), the weaner to slaughter (fattening), and the

farrow to finish (Kithinji 2018). The farrow-to-finish production system is the most common production system practiced in northern Uganda (Kithinji 2018). It has the longest duration of about 6 to 7 months from the farrowing stage and pigs weigh between 90 and 100 kg at maturity (Kagira et al. 2010). In the weaner-to-slaughter pig production system, weaned pigs are purchased at one to two months of age and are fed and fattened till they reach full maturity (Kagira et al. 2010). The farrow-to-weaner pig production system is characterized by a few sows that are used to produce piglets that are weaned after one to two months. They weigh on average 20 kg and are sold to other pig farmers who feed and fatten them for slaughter (Mbuthia et al. 2015). Pig production systems in the world are relatively intricate, not only in terms of production but in the economic sense. The social environment also seems to affect these production systems (Keraru et al. 2021). Farmers need to give consideration to the production cost structure to attain the target profit. With these three production systems, farmers may adopt any of the three options depending on their associated risks and capital requirements (Mbaso and Kamwana 2013).

Although numerous production strategies have been employed in raising pigs worldwide, smallholder pig farmers obtain meager profits from pig enterprises. This is because smallholder pig farmers lack good management techniques, which could have otherwise afforded them good returns from their production. The pig production systems used also seem to have varying potentials in terms of profit and technical efficiency, which have not been fully harnessed. In Uganda, farmers lack information on the pig production systems that give the highest return on investment, which could affect their choice of production systems and thus help to enhance technical efficiency. Several studies have been conducted on pig production systems from a general perspective (Hansen et al. 2006; Dione et al. 2014; Leslie et al. 2015; Mbuthia et al. 2015) but without focusing on the efficiency of these systems. In addition, very few studies have been conducted comparative research on pig production systems (Mbaso and Kamwana 2013; Keraru et al. 2021). Although Mbaso and Kamwana (2013) and Keraru et al. (2021) examined the profitability of the different pig production systems, their studies did not examine technical efficiency. In addition, little is known about the individual technical efficiency and the determinants of technical efficiency of these production systems. There is a paucity of literature on the comparative technical efficiency analyses of these production systems, especially in northern Uganda. Furthermore, the determinants of the technical efficiency of these production systems have not been considered in literature. This study sought to ascertain the determinants of technical efficiency of pig production systems in northern Uganda. Information on technical efficiency analysis of pig production systems is expected to serve as a suitable tool for agricultural researchers and planners. It also avails farmers of the relative importance of the factors of pig production which may help to make decisions that will enhance productivity.

Literature review

Efficiency is indispensable to productive growth in any given economy. It can be subdivided into allocative, economic, and technical efficiency. The concept of technical efficiency is grounded on input and output relationships (Adzawla et al. 2013). Technical efficiency results when observed output from a given set of inputs is more than the possible maximum output under certain technologies (Mugonola et al. 2013). Allocative efficiency occurs when the combination of inputs leads to cost minimization (Adzawla et al. 2013). However, Allocative inefficiency arises when farmers do not match marginal returns with the exact prices of the factor market (Muhammad-Lawal et al. 2009). The technical efficiency level of a specific firm is considered and featured by the relationship that exists between observed production and ideal production. The measurement of a firm's technical efficiency is premised upon deviations of observed output from the most efficient production frontier (Omonona et al. 2010). If a firm produces on the frontier, it is technically efficient. If a firm's production stays below the production possibility curve (PPC), then the firm is considered to be technically inefficient, with the proportion of the actual to the ideal production determining the efficiency levels of each farmer (Okoruwa et al. 2008).

Economic efficiency is the combined result of allocative and technical efficiencies. An economically efficient input-output mix would be on both the expansion path and the production function (Ogundari and Ojo 2006). In early studies, technical efficiency was determined using a deterministic production function employing mathematical programming techniques to compute its parameters. However, this approach had its limitations, including issues with the inadequate characteristics of the assumed error term, resulting efficiency estimates and statistical inference of the parameters (Ngombe 2017). To address this shortcomings, the Stochastic frontier production function was developed (Ogundari and Ojo 2006). This model introduced a more flexible representation of the production process by incorporating a random error term, which improved the accuracy of efficiency estimation. To estimate the frontier production function model, maximum likelihood procedures are used, as they are considered asymptotically more efficient than the corrected ordinary least square estimators (Muhammad-Lawal et al. 2009). Another method used to estimate technical efficiency is data envelopment analysis (DEA) (Tingley et al. 2005). However, our current study adopted the stochastic production frontier model due to the stochastic nature of most agricultural technologies i.e., factors not under the control of the farm which allows for the stochastic component of production. Some previous studies adopted the stochastic frontier approach to estimate efficiency (Ewuziem et al. 2010), (Aminu and Akhigbe-Ahonkhai 2017), (Ume et al. 2018), (Tuan et al. 2020), (Raja et al. 2022) while others used the data envelopment analysis (DEA) (Lansink and Reinhard 2004), (Yang et al. 2008), (Petrovska 2011), (Petrovska et al. 2012), (Havlíček et al. 2020), (Galanopoulos et al. 2006), (Atsbeha et al. 2020), (Zhang and Sun 2015).

Technical efficiency is a necessary precursor for a firm's economic efficiency as this results in the production feasibility and economic sustainability of such a firm. Assessment of the technical efficiency level of firms has generated wide research curiosity (Okoruwa et al. 2008). The study is imperative for producers such as farm-

ers, as it supports rational allocation of inputs and helps them to make rational decisions to achieve the desired level of output thus strengthening the capacity of a firm to adapt to changing market situations, economic hardships, and increasing cost of inputs. It is also pertinent for policymakers concerned with improving competitiveness and the economic performance of a firm and promoting the development of the economy (Kahan 2013). The assessment of technical efficiency shows the degree to which firms can use minimum inputs to produce maximum outputs (Guesmi et al. 2013).

Several empirical studies exist on the determinants of technical efficiency. Thi Ly et al. (2016) reported that the determinants of technical efficiency in Vietnam include income from pig production, years of farming experience, pig production cycle, live weight per fattening pig, access to credit, and veterinary service, educational status, and use of family labor. A similar study which was carried out by Ume et al. (2020) on the socioeconomic determinants of technical efficiency of pig production in Nigeria indicated that drugs and medication, feed intake, and labor affected pig farmers' output while household size, membership in organization, years of pig farming experience, and educational level were the socio-economic determinants of the technical efficiency of pig farmers. In a study conducted by Ewuziem et al. (2010) on the technical efficiency of pig farmers in Imo State, Nigeria, it was reported that years of experience in pig farming, level of education, environmental landscape, and quantity of waste generated among others positively influence technical efficiency while age was inversely related to technical efficiency. Umeh et al. (2015) study on the analysis of technical efficiency of pig production in Benue State, Nigeria revealed that labor and feed were significant and positively affected the production output, and education had a positive significant effect on technical efficiency. The mean efficiency was given by 0.97, implying a high level of technical efficiency of the farmers. The study further revealed that the farmers are often faced with challenges such as diseases, lack of access to credit, and inadequate access to extension services. Despite the pig farmers being technically efficient, efficiency could be further increased through access to credit facilities, adequate use of available resources, research and development, and use of extension services. Similarly, a study conducted by Onyenweaku and Effiong (2005) on the technical efficiency of pig production in Akwa Ibom State, Nigeria revealed that extension contact, farming experience, membership in farmers' associations/cooperative societies, gender, and farm size were important determinants of technical efficiency. Education, credit, age, and household size were found not to be significant. Aminu et al. (2017) sought to analyze the profitability and technical efficiency of pig production in Ekiti State, Nigeria. Findings showed that quantity of feed, herd size, labor, and capital were statistically significant at a 0.05 level of significance, and they increased the technical efficiency of selected pig farmers, while age, level of education, farming experience, breed of pigs reared, and household size reared reduced the level of inefficiency of farmers with the mean technical efficiency being 0.86. Furthermore, it was reported that efficiency could be enhanced by 14% through the effective use of the available resources with the current state of technology and this can be enhanced using those factors that reduced the inefficiency level of farmers. Micheni et al. (2020) in their study examined the profit efficiency of smallholder pig farmers in Tharaka-Nithi County, Kenya. They discovered that

five farms had a profit efficiency score of 1 and thus were efficient while the others were inefficient. The mean profit efficiency level was 40%, which implies that the efficiency level could be improved by 60% by decreasing excess use of inputs and ensuring adequate use of available resources. The study further recommended policy interventions relating to pig marketing, inputs, and financial assistance to enhance the livelihood of pig farmers. Petrovska (2011) analyzed the technical efficiency of pig production in farms in the Republic of Macedonia. Data Envelopment Analysis (DEA) model was adopted to estimate the technical efficiency of production across pig farm sizes in the country, with the levels of inputs used and outputs as the main component of the analysis. The findings showed that when considering a constant return to scale, the technical efficiency is consistently lower, with an average of 75%. However, when taking variable return to scale into account, the average technical efficiency from the input aspect is 90%, and from the output aspect, it is 87%. The average scale efficiency is determined by the ratio between constant and variable return to scale. Moreover, the results revealed significant differences between small and large pig farms concerning their location, size, and accessibility. Farmers' level of awareness and adoption of new production technologies played a crucial role in positively impacting the increase in the number of piglets per sow and reducing the mortality rate.

In a study conducted by Adetunji and Adeyemo (2012) on the economic efficiency of pig production in Ogbomosho area of Oyo State, Nigeria, it was revealed that the cost of feed, stocking cost, and, cost of labor had positive significant effects on the production output with an estimated gamma parameter (γ) of 0.780 which was highly significant. Age, gender, and size of the household had negative significant effects on economic inefficiency. The sum of elasticity was given by 1.191 and it indicated an increasing return to scale which probably might lead to overutilization of resources and inputs in terms of cost. However, the pig farmers were discovered to be operating on the production possibility curve and generally were economically efficient. The study suggested pig farmers' accessibility to institutional credit facilities, pens enlargements, better-quality breeding stocks, and provision of technical assistance could enhance production. Tian et al. (2015) ascertained the determinants of technical efficiency and productivity of hog production in China using a secondary data source (household-level panel data for the years 2004–2010). The result showed that the mean technical efficiency of hog production was 0.591. It was reported that farmers with specializations were more technically efficient than the others. Furthermore, it was reported that technical efficiency was higher in eastern China than in western and central China.

It has been shown that previous studies only focused on the technical efficiency of pig production generally without focusing on specific production systems. In addition, very few comparative studies have been conducted on the technical efficiency of pig production systems around the world. To the best of our knowledge, the drivers of the technical efficiency of different pig production systems have not been explored in literature. By analyzing three different pig production systems (farrow to finish, farrow to weaner, and weaner to slaughter), our study is novel and contributes to a nuanced understanding of pig farming efficiencies. This comprehensive approach allows for a detailed examination of how various factors (such as household size,

access to credit, and education level) differently affect the technical efficiency across production systems.

Materials and methods

Study area

The study was conducted in Lira (2.2581° N, 32.8874° E) and Kole (2.3701° N, 32.7633° E) districts, Lango Sub-Region, Northern Uganda (Fig. 1). Lango sub-region is estimated to have 2 million people. The sub-region is currently divided into 9 districts namely; Alebtong, Amolatar, Apac, Dokolo, Kole, Lira, Oyam, Otuke, and Kwania District. It's a relatively urbanized region with two Municipalities in Lira and Apac districts where manufacturing, trade, and services are evidently booming. The region experiences one long rainy season (unimodal type of rainfall), yet farmers still grow two crops in a year.

Sampling design

A cross-sectional survey design was used for the study from November 2021 to August 2022. A multi-stage sampling technique was used for the study. Firstly, Lira and Kole districts were selected purposively due to the predominance of pig farmers in these areas and the proximity of the two districts. Secondly, 10 Sub Counties were

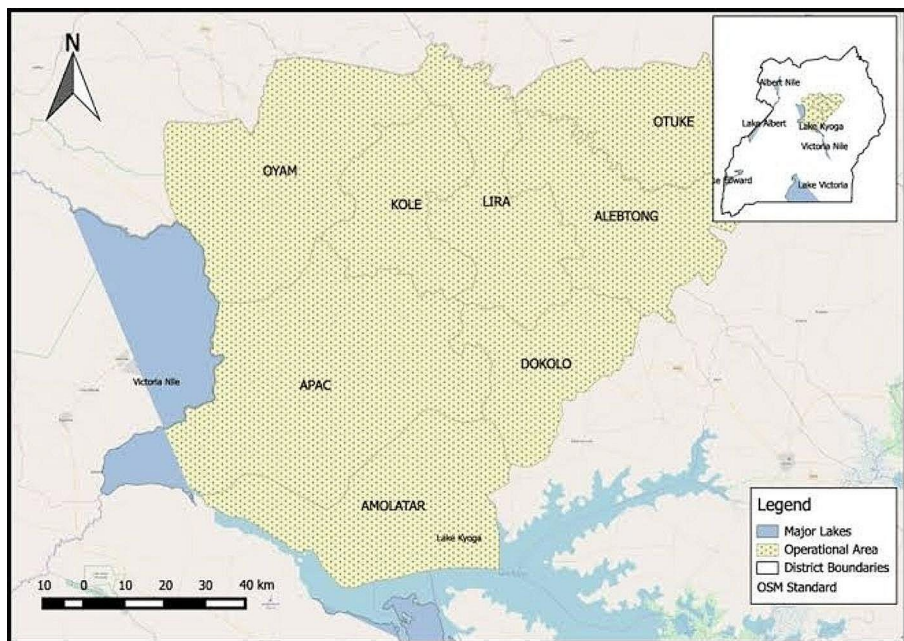


Fig. 1 Map of Lango Sub Region showing Lira and Kole districts

selected across the two districts. The sub-counties in Lira (Adekokwok, Ayago, Barr, City West, and Ngetta) and Kole (Aboke, Akalo, Alito, Ayer, and Bala) districts were purposively selected. Conclusively, a random sample of 240 pig farmers from the sub-counties of the two districts was drawn with the aid of a list provided by the pig farmers association.

Data collection

A pre-tested structured questionnaire was used to collect data on the production systems practiced by pig farmers, the profitability of pig production systems, and determinants of technical efficiency of the pig production systems. It constituted both open-ended and close-ended questions to obtain detailed information from pig farmers.

Data analysis: stochastic frontier approach

The Stochastic Production Function Frontier (SFPF) model of (Aigner et al. 1977) was adopted to assess the determinants of technical efficiency of pig production systems. Stochastic Frontier Approach (SFA) stands out as a robust analytical framework for this purpose because it not only quantifies the efficiency level among producers but also allows for the disentanglement of random errors from inefficiency effects. This is critical in agricultural settings where external factors such as weather, disease outbreaks, and market fluctuations can significantly affect production outcomes (Moutinho and Madaleno 2021). The SFA model incorporates a two-component error term to separately account for statistical noise and inefficiency, making it exceptionally relevant for studies in agricultural settings. This separation is crucial for accurately estimating the efficiency scores of the pig production systems under investigation, ensuring that the inefficiency estimates are not confounded by random shocks or measurement errors (Boyd and Doolin 2021; Chaovanapoonphol et al. 2022). Another compelling reason for the application of SFA is its ability to identify and quantify the impact of various factors on technical efficiency (Yasin 2020). In the context of northern Uganda's pig farming systems, understanding how variables such as access to credit, education level, and farm management practices influence efficiency is vital for targeted interventions. SFA facilitates this analysis through the efficiency effects model, which provides nuanced insights into how each factor contributes to efficiency variations across farms.

This analytical framework is particularly novel for this region and subject matter, offering a rigorous quantitative analysis that could enhance our understanding of efficiency determinants in pig production systems, a critical sector for agricultural development and food security in developing countries.

The SFPF production function was linearized in the form:

$$\begin{aligned} \ln Y_i = & \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 \\ & + \beta_3 \ln X_3 + \beta_4 \ln X_4 \\ & + \beta_5 \ln X_5 + V_i - U_i \end{aligned} \quad (1)$$

Where:

$X1 - X5$ are as defined in Table 1.

The term “ V_i ” represents random disturbances that arise from factors beyond the farmers’ control. These disturbances are assumed to follow a normal distribution with a mean of zero and a constant variance of σ^2v . Importantly, these disturbances are independent of the variable “ U_i .”

On the other hand, “ U_i ” stands for a non-negative random variable associated with technical production efficiency. It is also assumed to be normally distributed with a mean of zero and a variance of σ^2u . The conditional mean μ of U_i is believed to be influenced by various socioeconomic characteristics related to both the farm and the farmers. Additionally, these U_i values are assumed to be independent and identically distributed.

The input and output variables were selected carefully to ensure the accuracy of the SFA’s efficiency analysis and to avoid the risk of misspecification due to omitted variables or those that do not truly represent the production dynamics.

The inefficiency model is specified as:

$$\begin{aligned}
 U_i = & \delta_0 + \delta_1 W_1 + \delta_2 W_2 \\
 & + \delta_3 W_3 + \delta_4 W_4 + \delta_5 W_5 \\
 & + \delta_6 W_6 + \delta_7 W_7 + \delta_8 W_8 \\
 & + \delta_9 W_9 + \delta_{10} W_{10} + \epsilon - u
 \end{aligned} \tag{2}$$

Where:

U_i is the Inefficiency model;

$W_1 - W_{10}$ (as defined in Table 1).

δ are Parameters to be estimated.

Table 1 Variables used in the stochastic frontier production function model

Variables	Description	Expected sign
Y =Pig output	Weight in Kg	
$X1$ =Capital	Amount in Ugx	+
$X2$ =Herd Size	Number of pigs	+
$X3$ =Cost of medication	Amount in Ugx	+
$X4$ =Quantity of feed	Kilograms	+
Inefficiency Model		
$W1$ =Age	Number in years	+
$W2$ =Gender	1= male, 0= female	-
$W3$ =Education level	1=tertiary education, 0=others	-
$W4$ =Household size	Number in years	-
$W5$ =Years of farming experience	Number in years	-
$W6$ =Management systems	1=Intensive, 0=others	-
$W7$ =Access to credit	1=yes, 0=no	-
$W8$ =Breeds of pig	1=large white, 0=others	-
$W9$ =Access to extension service	1=yes, 0=no	-
$W10$ =Membership in farmers’ cooperative	1=yes, 0=no	-

ε is a random error term, usually assumed to be normally distributed with mean zero.

u is the non-negative inefficiency term.

Results

Socio-economic and demographic characteristics of pig farmers

The results showed that both men and women in Lira and Kole districts engaged in pig production (Table 2) More married families engaged in pig production than their unmarried counterparts The majority of the pig farmers had access to the market ($p < 0.01$) with 82% access in Lira district compared to the 69% in Kole district. Most pig farmers lacked access to extension services ($p < 0.05$) and farmers in Lira district were more affected (90%) compared to those in Kole district (56%). In addition, farmers lacked access to credit ($p < 0.05$) with more farmers in Lira district (76%) affected than those in Kole district (44%). Majority of pig farmers in both districts are not members of farmers' associations or cooperative societies.

Results in Table 3 show the comparison of pig farmers' characteristics (continuous variable) by districts (Kole and Lira). The mean age of pig farmers in Lira and

Table 2 Comparison of categorical variables for pig farmers' socioeconomic characteristics by districts

Variables	Lira <i>N</i> =123	Kole <i>N</i> =117	Total <i>N</i> =240		
	Freq (%)	Freq (%)	Freq (%)	χ^2	Sig
Gender					
Male	62 (50.4)	69 (59.1)	131 (54.6)	1.776	0.183
Female	61 (49.6)	48 (41.9)	109 (45.4)		
Marital Status					
Married	95 (77.2)	108 (92.3)	203 (84.6)	10.912***	0.012
Single	12 (9.8)	5 (4.3)	17 (7.1)		
Widowed/Widower	10 (8.1)	3 (2.6)	13 (5.4)		
Divorced	6 (4.9)	1 (0.9)	7 (2.9)		
Ready Access to Market					
Yes	101 (82.1)	81 (69.2)	182 (75.8)	5.431**	0.020
No	22 (17.9)	36 (30.8)	58 (24.2)		
Access to Credit					
Yes	30 (24.4)	65 (55.6)	95 (39.6)	24.353***	0.000
No	93 (75.6)	52 (44.4)	145 (60.4)		
Access to Extension Services					
Yes	12 (9.8)	51 (43.6)	63 (26.3)	35.456***	0.000
No	111 (90.2)	66 (56.4)	177 (73.8)		
Membership in Farming Association/Cooperative Society					
Yes	5 (4.10)	65 (55.6)	70 (29.2)	76.950***	0.000
No	118 (95.9)	52 (44.4)	170 (70.8)		

Source Field survey 2022; χ^2 denotes Pearson chi-square coefficient; *** & ** denotes p value < 0.01 & p value < 0.05 , respectively

Table 3 Comparison of continuous variables for pig farmers' characteristics by districts

Variable	Mean			Mean difference	Sig
	Lira N=123	Kole N=117	Total N=240		
Age	38.3	40.9	39.6	-2.646*	0.079
Years of education	9.1	7.3	8.2	1.781***	0.001
Household size	5.4	6.1	5.8	-0.721**	0.025
Years of experience	4.5	4.4	4.4	0.120	0.767

Source Field survey 2022; χ^2 denotes Pearson chi-square coefficient; ***, ** & * denotes p value<0.01, p-value<0.05 & p-value<0.1, respectively

Kole was 38.3 and 40.9, respectively. The results of the t-test analysis were found to be statistically significant ($p=0.079$). Pig farmers in Lira had on average 9 years of education compared to an average of 7 years in Kole district (Table 3).

Determinants of technical efficiency of pig production systems

Table 4 shows the results of the stochastic frontier model used to estimate the technical efficiency of pig production systems. It was revealed that capital, herd size, and quantity of feed were statistically significant and influenced pig output in the farrow-to-finish production system. In the farrow to weaner production system, capital and cost of medication were statistically significant and hence influenced pig output. Furthermore, capital and quantity of feed were statistically significant and influenced pig output in the weaner-to-slaughter production system (Table 4).

From the technical efficiency component, factors that determined technical efficiency of the farrow to finish pig production system included age, household size, education level, years of pig farming experience, access to credit, access to extension services, and management system. Determinants of technical efficiency of the farrow to weaner pig production system include household size, access to credit, level of education, management system and access to extension services. In the weaner-to-slaughter pig production system, age, household size, access to credit, access to extension services, and breed of pigs were found to be statistically significant and hence exert influence on the technical efficiency of this production system (Table 4).

Technical efficiency distribution of pig production systems

Table 5 shows the technical efficiency distribution of the production systems which was obtained using the stochastic frontier production function. It was revealed that most (93.2%) pig farmers practicing the farrow to finish production system had technical efficiencies of >0.90 with a mean technical efficiency of 0.95. In the farrow to weaner production system, majority of pig farmers (64.5%) had technical efficiencies of <0.40 with a mean technical efficiency of 0.36 which was the lowest among the pig production systems. The weaner-to-slaughter pig production system recorded most (81.1%), pig farmers with a technical efficiency level of >0.90 .

Table 4 Maximum likelihood estimates for the parameters of the stochastic frontier production function for the pig production systems

	Farrow to Finish (<i>N</i> =73)	Farrow to Weaner (Breeding) <i>N</i> =93	Weaner to Slaughter (Fatten- ing) <i>N</i> =74
Variables	Coefficients (SE)	Coefficients (SE)	Coefficients (SE)
Constant	-8.145 (1.936) ***	-4.096 (2.181) *	-6.484 (2.041) ***
Capital	0.560 (0.201) ***	0.402 (0.220) *	0.451 (0.219) **
Herd size	0.393 (0.184) **	-0.262 (0.245)	0.115 (0.170)
Cost of treatment	0.003 (0.022)	0.097 (0.050) **	-0.000 (0.035)
Quantity of feed	0.209 (0.137) *	0.044 (0.097)	0.263 (0.130) **
Inefficiency Model			
Constant	-3.669 (1.709) **	0.699 (0.424) *	0.316 (0.533)
Age	0.041 (0.014) ***	0.001 (0.006)	-0.015 (0.009) *
Household size	0.167 (0.100) *	-0.075 (0.042) *	0.059 (0.034) *
Education level	0.087 (0.555) *	-0.036 (0.022) *	-0.028 (0.022)
Years of farming experience	-0.130 (0.076) *	-0.056 (0.040)	-0.015 (0.022)
Marital Status (1=Married; 0=Others)	0.114 (0.415)	-0.045 (0.173)	-0.097 (0.336)
Access to credit (1=Yes; 0=No)	-0.108 (0.428) ***	-0.023 (0.466) **	0.313 (0.212) *
Access to extension service (1=Yes; 0=No)	-0.606 (0.572) ***	-0.774 (0.260) ***	-0.036 (0.238) ***
Management system (1=Intensive; 0=Others)	0.035 (0.466) ***	0.462 (0.237) **	0.059 (0.192)
Breeds of pig (1=Large white; 0=Others)	0.183 (0.219)	0.262 (0.201)	-0.409 (0.200) **
Usigma constant	-5.060 (1.609) ***	-5.957 (3.332) *	-6.996 (4.175) *
Vsigma constant	-1.607 (0.158) ***	-1.505 (0.148) ***	-1.694 (0.161) ***
Sigma-u	0.080 (0.064)	0.051 (0.085)	0.030 (0.063)
Sigma-v	0.448 (0.035) ***	0.471 (0.035) ***	0.429 (0.035) ***
Lambda	0.178 (0.071) ***	0.108 (0.092)	0.071 (0.071)
Wald χ^2 (4)	148.15	46.14	97.03
Prob> χ^2	0.000	0.000	0.000
Log-likelihood function	-50.791	-62.022	-44.772

Source Field survey 2022; ***, ** & * denotes p value<0.01, p-value<0.05 & p-value<0.1 respectively

Discussions

Determinants of technical efficiency of pig production systems

The results of the stochastic production function frontier indicated that most of the inputs meet the a priori expectations with different significant levels. Capital was found to be statistically significant with a positive coefficient in the three pig production systems. This implied that a 1% increase in capital will increase the level of pig output by 0.56%, 0.402%, and 0.451% in farrow to finish, farrow to weaner, and weaner to slaughter pig production systems respectively. As more capital is dis-

Table 5 Technical efficiency distribution of pig production systems

	Farrow to Finish	Farrow to Weaner (Breeding)	Weaner to Slaughter (Fattening)
Efficiency Level	Freq (percent)	Freq (percent)	Freq (percent)
< 0.40	0 (0.0)	60 (64.5)	1 (1.4)
0.40–0.70	1 (1.4)	21 (22.6)	4 (5.4)
0.71–0.80	3 (4.1)	3 (3.2)	1 (1.4)
0.81–0.90	1 (1.4)	2 (2.2)	7 (9.5)
> 0.90	68 (93.2)	7 (7.5)	60 (81.1)
Minimum Efficiency	0.60	0.06	0.36
Mean Efficiency	0.95	0.36	0.91
Maximum Efficiency	0.99	0.95	0.99

Source Field survey 2022

tributed into the business for expansion and buying of feeds, it is expected that pig output will increase. This is in agreement with the findings of Aminu et al. (2017) who reported that capital had a positive significant effect on pigs' output.

Herd size showed a positive significant effect ($p < 0.05$) on pig output in the farrow to finish production system. Its coefficient implied that a 1% increase in the herd size will lead to an increase in the level of pig output by 0.393%. It is expected that the number of pigs produced will increase when the number of breeding stock is increased as there could be multiple piglets arising from the breeding of pigs. This is similar to the findings of Tuan et al. (2020) who reported that high stocking density increased pig output. However, this is in contrast with the findings of Etim et al. (2014) who found out that herd size had a negative significant effect on pig production. It argued that the timeliness of resources used tends to diminish with an increase in herd size thus resulting in a decrease in technical efficiency. Herd size was not statistically significant in the farrow-to-weaner and weaner-to-slaughter pig production systems.

The cost of medication was statistically significant ($p < 0.05$) only in the farrow-to-weaner pig production system. Its positive coefficient implied that a 1% increase in the cost of medication will increase pig output level by 0.097%. The positive significance of this variable also explains the importance of medication and vaccines to piglets and weaners in this pig production system. This is in accordance with the findings of Ewuziem et al. (2010) who indicated that the cost of medication exerted a positive influence on the output levels of pig farmers. On the contrary, cost of medication did not exert any influence on pig output in the farrow-to-finish and weaner-to-slaughter pig production system.

Quantity of feed had a positive significant effect on pig output in the farrow to finish ($p < 0.1$) and weaner to slaughter production system ($p < 0.05$). A 1% increase in the quantity of feeds fed to pigs will lead to an increase in pig output levels by 0.209% and 0.263% in the farrow-to-finish and weaner-to-slaughter pig production systems, respectively. This could be that higher feed intake by pigs will lead to an increase in their weight. This was similarly reported by Umeh et al. (2015) indicating that feed had a positive significant effect on production output in terms of pig weight which in turn leads to an increase in profitability of pig farmers. In contrast, quantity of feed was statistically insignificant in the farrow-to-weaner pig production system.

The inefficiency model shows the variations in technical efficiency among the pig production systems which were highly related to their socioeconomic characteristics and institutional factors. The significant variables are the determinants of the technical efficiency of pig production systems in the study area. Age was found to be statistically significant in the farrow-to-finish ($p < 0.01$) and weaner-to-slaughter pig production systems ($p < 0.10$). The positive coefficient of age in the farrow-to-finish pig production system implied that technical inefficiency increased with age suggesting that the younger pig farmers are more technically efficient than the older farmers. This suggests that young farmers in this production system are more agile and are full of energy to ensure optimum pig production. Etim et al. (2014) in their study in Nigeria also indicated that age had a positive significant effect on technical inefficiency. However, this is not the case with the weaner-to-slaughter pig production system due to its negative coefficient which implied that technical inefficiency declined with age signifying that older farmers are more technically efficient than younger farmers. This suggests that over time, specialization is likely to develop, leading to improved production methods and increased efficiency. It could also be because mental strength correlates with advancing age. This conforms with the findings of Adetunji and Adeyemo (2012) who reported that age had a negative significant effect on technical inefficiency suggesting that older farmers are more likely to adopt novel technology to improve efficiency. (Olsen and Henningsen 2011 in a similar study reported that the technical efficiency of pig producers increased with an increase in age and later declined implying that middle-aged farmers are the most efficient. Age was statistically insignificant in the farrow-to-weaner pig production system.

Household size was statistically significant ($p < 0.10$) in the three pig production systems. The positive coefficient of this variable in the farrow-to-finish and weaner-to-slaughter pig production systems implied that technical inefficiency increased with household size suggesting that pig farmers with few household members are more technically efficient than those with more household members. This could mean that resources that could have been invested into pig production in these systems were being diverted to meet household needs. This was not the case for the farrow-to-weaner pig production system due to its negative coefficient which implied that technical inefficiency declined with household size. In other words, pig producers with more household members are more technically efficient and this could mean that they serve as family labour and help to reduce the cost of hiring labour. This is in line with the findings of Aminu et al. (2017) who reported that technical inefficiency effects decreases as the household size of pig farmers increases.

Education level was statistically significant ($p < 0.10$) in the farrow to finish and farrow to weaner pig production significant and statistically insignificant in the weaner to slaughter pig production. The implication of the positive coefficient of education level in the farrow to finish production system is that as education level increases, technical inefficiency increases. This could be because well-educated pig farmers had little time for pig production activities and probably were engaged in white-collar jobs. On the contrary, education level had a negative effect on technical inefficiency in the farrow to weaner pig production system implying that as education level increases, technical inefficiency decreases. This suggests that well-educated pig farmers are knowledgeable and highly skilled to ensure pig production is at an

optimal level. In other words, farmers who are educated achieve higher technical efficiency levels in this production system. This is in agreement with the findings of Ewuziem et al. (2010) who reported that technical efficiency was positively influenced by education.

Years of pig farming experience showed a negative significant relationship ($p < 0.10$) with technical inefficiency in the farrow to finish pig production system. In other words, the higher the years of experience of pig farmers, the more the level of technical efficiency. This helps to explain the fact that highly experienced farmers have adequate managerial and technical skills to ensure optimum production. Raja et al. (2022) in a recent study carried out in India stated that years of pig farming experience positively influence technical efficiency in pig production. Years of farming experience were not significant in the farrow-to-weaner and weaner-to-slaughter pig production system.

Access to credit showed a significant effect on technical inefficiency at different levels in the three pig production systems. The negative coefficient of the variable in the farrow to finish and farrow to weaner pig production system implied that technical inefficiency increased with limited or no access to credit. It can be said that the technical efficiency of these production systems increased with the availability and accessibility of credit. Pig farmers having access to credit were 10.8% and 2.3% more technically efficient than those who did not have access to credit in the farrow to finish and farrow to weaner pig production systems respectively. The positive coefficient of access to credit in the weaner-to-slaughter pig production system implied that technical inefficiency increased with increased access to credit. This could be that pig farmers diverted agricultural loans and grants meant for their pig farming business to other needs thereby decreasing technical efficiency. Ume et al. (2018) also noted that technical efficiency tends to increase with pig farmers' increased access to credit which could be due to credit diversion to non-farm engagement.

Access to extension service was found to be statistically significant ($p < 0.01$) and negatively exerted an influence on the technical inefficiency levels of the three production systems which were according to apriori expectation. In other words, access to extension services influenced technical efficiency positively thus improving the productivity of pig production systems. This aligns with the findings of Raja et al. (2022) who reported that pig farmers acquire knowledge through training programs facilitated by extension workers.

However, management system had a positive significant effect on technical inefficiency in the farrow to finish and farrow to weaner pig production systems which were contrary to apriori expectations. The positive significant coefficient ($p < 0.01$) of the intensive management system in the farrow-to-finish pig production system implied that it is 3.5% less technically efficient than the semi-intensive management system. Similarly, intensively managed pigs were 46.2% less technically efficient than the semi-intensively managed pigs in the farrow to weaner pig production system. This probably has to do with the cost of feeding and medication in the intensively managed pigs which is more than the costs incurred in the semi-intensively managed pigs. This situation could be contributing to technical inefficiency in the intensive pig management systems. In a similar study conducted by Aminu et al. (2017), management system was presented as an important determinant of pig pro-

duction. Management system was statistically insignificant in the weaner-to-slaughter pig production system. In terms of pig breeds, it was only found to be statistically significant ($p < 0.05$) and negatively exerted an influence on the technical inefficiency levels of the weaner-to-slaughter pig production system.

The negative coefficient of pig breeds implied that the large white breeds of pigs were 40.9% more technically efficient than all other breeds of pigs in the weaner-to-slaughter production system. This could be a result of the good qualities they possess such as their faster growth rate which puts them at an advantage over other breeds. Aminu et al. (2017) also reported that pig breed was a significant determinant of the technical efficiency of pig production in Nigeria.

Technical efficiency distribution of pig production systems

The individual technical efficiency levels of the three pig production systems showed that most (93.2%) pig farmers in the farrow-to-finish production system had technical efficiencies above 0.90. They had a minimum, maximum, and mean technical efficiency of 0.60, 0.99, and 0.95 respectively with the mean technical efficiency indicating that their actual output lies 5% below the frontier output. Majority (64.5%) of pig farmers in the farrow to weaner production system had technical efficiencies of less than 0.40. They had a minimum, maximum, and mean technical efficiency of 0.06, 0.95, and 0.36, respectively. This indicates a low level of technical efficiency for the farrow to weaner pig production system and suggests that the technical efficiency of pig farmers in this system could be increased by 64% through the adequate use of available resources, giving proper attention to piglets, and adopting best farming practices. 81.1% of pig farmers practicing the weaner-to-slaughter production system had technical efficiencies of above 0.90. Their minimum, maximum, and mean technical efficiency was given as 0.36, 0.99, and 0.91 respectively with the mean technical efficiency indicating that their actual output lies 9% below the frontier output. Although none of the production systems was fully technically efficient, the farrow-to-finish production system displayed the highest level of technical efficiency followed by the weaner-to-slaughter pig production system. The farrow-to-weaner pig production system exhibited the lowest level of technical efficiency. A similar study by Larue and Latruffe (2009) reported 0.82, 0.89, and 0.82 as the mean total technical efficiency of the farrowing, finishing, and farrow-to-finish farms respectively. Efforts should be made towards improving efficiency levels and ensuring optimum production in the farrow to weaner pig production systems. Raja et al. (2022) suggested that efficient extension services should be established to enable pig farmers to be informed about advanced technology and management practices that can help to enhance efficiency.

Conclusion and policy recommendations

It can be concluded that the farrow-to-finish production system displayed the highest level of technical efficiency followed by the weaner-to-slaughter pig production system. The farrow-to-weaner pig production system exhibited the lowest level of

technical efficiency. Averagely, pig farmers practicing the farrow to finish, farrow to weaner, and weaner to slaughter production systems had the opportunity to improve their technical efficiency levels by 5%, 64%, and 9% respectively using a better combination of inputs and technology. Our findings underscore the critical role of age, household size, access to credit, education level, years of pig farming experience, access to extension services, and management system as key determinants of technical efficiency across different pig production systems. Notably, the nuanced analysis of three distinct production systems (farrow to finish, farrow to weaner, and weaner to slaughter) provides a comprehensive understanding of the sector's efficiency landscape, offering targeted insights for stakeholders in similar agricultural contexts. To increase technical efficiency, the study recommends that adequate training and capacity-building programs especially on the farrow to weaner pig production system should be organized by the government in collaboration with agricultural institutes to improve the technical efficiency of farrow to weaner production system. Furthermore, pig farmers practicing the weaner-to-slaughter production system should be encouraged in their pig-rearing business by the provision of an improved large white breed of pigs. The study also suggests that agricultural policies that would ensure sufficient access to credit by pig producers should be enacted. Encouragement should be given to pig farmers to prudently utilize credit for expanding their pig farming activities rather than diverting it to other purposes.

This research contributes to the methodological discourse by demonstrating the applicability and relevance of SFA in the agricultural sector of developing countries, where data limitations and the stochastic nature of agricultural production often present significant analytical challenges. The study's findings highlight the potential for enhancing pig production efficiency through focused interventions such as improved access to credit, tailored extension services, and education programs aimed at equipping farmers with the necessary skills and knowledge.

Importantly, the study's emphasis on the variability of efficiency determinants across different production systems suggests that a one-size-fits-all approach may not be effective in addressing the efficiency challenges in the pig farming sector. Instead, policies and interventions need to be system-specific, reflecting the unique characteristics and needs of each production system.

By bridging the gap in empirical research on pig production efficiency in northern Uganda, this study not only adds to the existing body of knowledge but also lays the groundwork for future research aimed at understanding the determinants of technical efficiency in agricultural production systems more broadly. The study's recommendations for policy and practice have the potential to guide the development of more efficient, sustainable, and profitable pig farming practices, contributing to economic development and food security in the region.

Study limitations

The Stochastic Frontier Analysis (SFA) applied in the study to assess technical efficiency in pig production systems in northern Uganda, while methodologically sound, operates under specific assumptions that may not fully encapsulate the complexities of agricultural data. The decomposition of the error term into inefficiency and noise

components presupposes distributions (truncated normal for inefficiency, normal for noise) that might not accurately reflect real-world data, potentially skewing efficiency scores. SFA simplifies the production process, which may overlook important contextual and environmental factors affecting efficiency in pig production systems. Moreover, the reliance on cross-sectional data captures efficiency at a single point, missing the nuances of efficiency evolution over time that market shifts, technological progress, or policy changes could influence. To strengthen SFA results, further studies should include robustness checks with alternative distribution, the use of complementary methods like Data Envelopment Analysis (DEA), and the incorporation of longitudinal data to account for temporal variations and trends.

Acknowledgements Our heartfelt thanks to the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and the Mastercard Foundation for funding this study.

Author contributions Caleb I. Adewale: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Visualization; Roles/Writing - original draft; and Writing - review & editing. Elias Munezero: Formal analysis; Software; and Writing - review and editing. Elly K. Ndyomugenyi: Conceptualization; Methodology; Supervision; and Writing - review & editing. B. Mugonola: Conceptualization; Methodology; Supervision; and Writing - review & editing.

Funding This work was supported by the MasterCard Foundation grant to the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and Gulu University, under the project “Transforming African Agricultural Universities to meaningfully contribute to Africa’s growth and development (TAGDev)”.

Data availability The datasets used during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

References

- Adetunji M, Adeyemo K (2012) Economic efficiency of Pig Production in Oyo State, Nigeria: a stochastic production Frontier Approach. *Am J Experimental Agric* 2(3):382–394. <https://doi.org/10.9734/ajea/2012/746>
- Adewale CI, Belewu KY (2022) Economic analysis of snail production and its contribution to food security of farming households in Nigeria. *Agricultura Trop et Subtropica* 55(1):159–168
- Adzawla W, Fuseini J, Donkoh SA (2013) Estimating technical efficiency of cotton production in Yendi Municipality, Northern Ghana. *J Agric Sustain* 2(1):115–140
- Aigner D, Lovell CAK, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. *J Econ* 6(1):21–37
- Aminu FO, Akhigbe-Ahonkhai CE (2017) Profitability and technical efficiency of Pig Production in Nigeria: the case of Ekiti State. *Agricultura Trop et Subtropica* 50(1):27–35. <https://doi.org/10.1515/ats-2017-0004>
- Atsbeha DM, Flaten O, Olsen HF, Kjos NP, Kidane A, Skugor A, Prestløkken E, Øverland M (2020) Technical and economic performance of alternative feeds in dairy and pig production. *Livest Sci* 240:104123

- Boyd GA, Doolin M (2021) An alternative approach to estimation of the energy efficiency gap in food processing. *Energ Effi* 14(3):29
- Chaovanapoonphol Y, Singvejsakul J, Sriboonchitta S (2022) Technical efficiency of Rice Production in the Upper North of Thailand: clustering copula-based stochastic Frontier Analysis. *Agriculture* 12(10):1585
- Delgado CL (2005) Rising demand for meat and milk in developing countries: Implications for grasslands-based livestock production. In *Grassland: A Global Resource* (pp. 29–39). Wageningen Academic Publishers The Netherlands. <https://doi.org/10.3920/978-90-8686-551-2>
- Dione MM, Ouma EA, Roesel K, Kungu J, Lule P, Pezo D (2014) Participatory assessment of animal health and husbandry practices in smallholder pig production systems in three high poverty districts in Uganda. *Prev Vet Med* 117(3–4):565–576. <https://doi.org/10.1016/j.prevetmed.2014.10.012>
- Dorh LE, Gindi AA, Gona A (2019) Analysis of Technical Efficiency of Pig Production in Southern Kebbi State, Nigeria. *J Agricultural Econ Ext Rural Dev* 7(6):904–912
- Eriksson IS, Elmquist H, Stern S, Nybrant T (2005) Environmental systems analysis of pig production: the impact of feed choice. *Int J Life Cycle Assess* 10(2):143–154. <https://doi.org/10.1065/lca2004.06.160>
- Etim NA, Etim NN, Offiong EEA (2014) Estimation of efficiency in small scale pig production. *Eur Int J Sci Technol* 3(6):111–118
- Ewuziem JE, Onyenobi VO, Ironkwe AG (2010) Technical efficiency of pig farmers in Imo State Nigeria: a translog stochastic frontier production function approach. *Nigerian Agricultural J* 41(1):151–158. <http://www.ajol.info/index.php/naj/article/view/90586>
- FAO (2010) Meat projects. OECD/FAO 2010. *OECD-FAO Agricultural Outlook 2010*, 17
- Galanopoulos K, Aggelopoulos S, Kamenidou I, Mattas K (2006) Assessing the effects of managerial and production practices on the efficiency of commercial pig farming. *Agric Syst* 88(2–3):125–141
- Godfray HCJ, Aveyard P, Garnett T, Hall JW, Key TJ, Lorimer J, Pierrehumbert RT, Scarborough P, Springmann M, Jebb SA (2018) Meat consumption, health, and the environment. *Science* 361(6399):eaam5324
- Guesmi B, Serraa T, Featherstone AM (2013) Technical efficiency of Kansas arable crop farms: a local maximum likelihood approach. *Agricultural Economics*, 46 (2015) 703–713. <https://doi.org/10.1111/agec.12186>
- Hansen LL, Claudi-Magnussen C, Jensen SK, Andersen HJ (2006) Effect of organic pig production systems on performance and meat quality. *Meat Sci* 74(4):605–615
- Havlíček J, Dömeová L, Smutka L, Řezbová H, Severová L, Šubrt T, Šrédľ K, Svoboda R (2020) Efficiency of pig production in the Czech Republic and in an international context. *Agric (Switzerland)* 10(12):1–18. <https://doi.org/10.3390/agriculture10120597>
- Henchion M, Moloney AP, Hyland J, Zimmermann J, McCarthy S (2021) Trends for meat, milk and egg consumption for the next decades and the role played by livestock systems in the global production of proteins. *Animal* 15:100287
- Jabbar MA, Akter S (2008) Market and other factors affecting farm specific production efficiency in pig production in Vietnam. *J Int Food & Agribusiness Mark* 20(3):29–53
- Kagira JM, Kanyari PWN, Maingi N, Githigia SM, Karuga JW (2010) & others. Characteristics of the smallholder free-range pig production system in western Kenya. *Tropical Animal Health and Production*, 42(5), 865–873
- Kahan D (2013) Market-oriented farming: an overview. Food and Agriculture Organization of the United Nations. © FAO 2013. E-ISBN 978-92-5-107540-1
- Keraru EN, Harianto H, Yusalina Y (2021) Profitability of the three types of Smallholder Pig Farming in Indonesia: an adaptation of Enterprise Budgeting Method. *Buletin Peternakan* 45(4):262. <https://doi.org/10.21059/buletinpeternakan.v45i4.68763>
- Kithinji RK (2018) Factors influencing pig production in Embu west, Embu county, Kenya. (Doctoral dissertation)
- Lansink AO, Reinhard S (2004) Investigating technical efficiency and potential technological change in Dutch pig farming. *Agric Syst* 79:353–367. [https://doi.org/10.1016/S0308-521X\(03\)00091-X](https://doi.org/10.1016/S0308-521X(03)00091-X)
- Larue S, Latruffe L (2009) Agglomeration externalities and technical efficiency in French pig production. Working Paper SMART – LERECO N°09–10
- Leslie EEC, Geong M, Abdurrahman M, Ward MP, Toribio J-AL M. L (2015) A description of smallholder pig production systems in eastern Indonesia. *Prev Vet Med* 118(4):319–327
- Manevska-tasevska G, Hansson H, Labajova K (2016) Impact of Management practices on persistent and residual technical efficiency – a study of Swedish pig Farming. *Manag Decis Econ* 38(6):890–905. <https://doi.org/10.1002/mde>

- Mbaso M, Kamwana B (2013) Comparative analysis of profitability among feeder-pig, pig-finishing, and farrow-to-finish production systems under the Smallholder Improvement Management System in Ntcheu District of Central Malawi. *Livest Res Rural Dev*, 25(10)
- Mbuthia JM, Rewe TO, Kahi AK (2015) Evaluation of pig production practices, constraints and opportunities for improvement in smallholder production systems in Kenya. *Trop Anim Health Prod* 47(2):369–376. <https://doi.org/10.1007/s11250-014-0730-2>
- Micheni P, Nyairo N, Bekele N, Kosgei G (2020) Profit efficiency of smallholder pig farmers in Tharaka-Nithi County, Kenya. *J Econ Sustainable Dev* 11(10):141–146
- Moutinho V, Madaleno M (2021) Assessing eco-efficiency in Asian and African countries using stochastic frontier analysis. *Energies* 14(4):1168
- Mugonola B, Vranken L, Maertens M, Deckers J, Taylor DB, Bonabana-Wabbi J, Mathijs E (2013) Soil and water conservation technologies and technical efficiency in banana production in upper Rwizi micro-catchment, Uganda. *Afr J Agricultural Resource Econ* 8(311–2016–5608):13–28
- Mugonya J, Kalule SW, Ndyomugenyi EK (2019) Determinants of innovation behaviour among pig farmers in Northern Uganda. *Afr J Rural Dev* 4(3):363–374
- Muhammad-Lawal A, Omotesho OA, Falola A (2009) Technical Efficiency of Youth Participation in Agriculture: a case study of the Youth - in - Agriculture Programme in Ondo State, South Western Nigeria. *Nigerian J Agric Food Environ* 5(1):20–26
- Ngombe JN (2017) Technical efficiency of smallholder maize production in Zambia: a stochastic meta-frontier approach. *Agrekon* 56(4):347–365
- Obayelu AE, Ogunmola OO, Sowande OK (2017) Economic Analysis and the determinants of Pig Production in Ogun State, Nigeria. *Agricultura Trop et Subtropica* 50(2):61–70. <https://doi.org/10.1515/ats-2017-0007>
- Ogundari K, Ojo SO (2006) An examination of technical, economic and allocative efficiency of small farms: the case study of cassava farmers in Osun State of Nigeria. *J Cent Eur Agric* 7(3):423–432
- Okoruwa V, Ogundele O, Oyewusi BO (2008) Efficiency and productivity of rice farmers in north central Nigeria. In *Rice policy and food security in sub-Saharan Africa. Proceedings of a workshop held on 7–9 November 2005, Cotonou, Benin* (pp. 56–69). West Africa Rice Development Association (WARDA)
- Olsen JV, Henningsen A (2011) Investment utilisation, adjustment costs, and technical efficiency in Danish pig farms. (No. 2011/13). FOI Working paper
- Omonona BT, Egbetokun OA, Akanbi AT (2010) Farmers Resource—Use and Technical Efficiency in Cowpea Production in Nigeria. *Econ Anal Policy* 40(1):87
- Onyekuru NA, Ukwuaba IC, Aka EO (2020) Economics of piggery enterprise in Nigeria: a case study of Udi Local Government area of Enugu State, Nigeria. *Agro-Science* 19(2):6–12
- Onyenweaku CE, Effiong EO (2005) Technical efficiency in pig production in Akwa Ibom State, Nigeria. *Int J Agric Rural Dev* 6(1):51–57
- Petrovska M (2011) Efficiency of pig farm production in the Republic of Macedonia - Data Envelopment Analysis approach. *Master's thesis*, 708. ISSN 1401–4084
- Petrovska M, Martinovska-Stojcheska A, Ohlmer B, Kotevska A (2012) Technical efficiency of Macedonian pig farms (709-2016-48461).
- Phiri RE (2012) Determination of piggery business profitability in Balaka District in Malawi. *Livest Res Rural Dev* 24(8):177
- Raja MB, Selvakumar KN, Pandian ASS, Sundaram SM, Anbukkani P, Jayanthi R (2022) Profitability and efficiency of pig production in Tamil Nadu. *Indian J Anim Sci* 92(3):365–369
- Thi Ly N, Nanseki T, Chomei Y (2016) Technical efficiency and its determinants in Household Pig production in Vietnam: a DEA Approach. *Japanese J Rural Econ* 18(0):56–61. <https://doi.org/10.18480/jjre.18.56>
- Tian X, Sun Ffei, Zhou Yheng (2015) Technical efficiency and its determinants in China's hog production. *J Integr Agric* 14(6):1057–1068. [https://doi.org/10.1016/S2095-3119\(14\)60989-8](https://doi.org/10.1016/S2095-3119(14)60989-8)
- Tingley D, Pascoe S, Coglan L (2005) Factors affecting technical efficiency in fisheries: stochastic production frontier versus data envelopment analysis approaches. *Fish Res* 73(3):363–376
- Tuan TB, Yin T, Cuong TH, Tiep NC, König S (2020) Production efficiency analysis of indigenous Pig production in Northwest Vietnam. *Vietnam J Agricultural Sci* 3(4):882–891. <https://doi.org/10.31817/vjas.2020.3.4.11>
- Ume S, Ezeano C, Onunka BN, Agu CI (2018) Technical efficiency of Pig Production in Enugu North Agricultural Zone of Enugu State, Nigeria. 5(September):61–69

- Ume SI, Onwujiariri EB, Nnadozie A (2020) Pig Farmers' socioeconomic characteristics as determinant to Pig Production and profitability in the tropics. *Int J Res Rev* 7(April):1–12. https://www.ijrrjournal.com/IJRR_Vol.7_Issue.4_April2020/IJRR0050.pdf
- Umeh JC, Ogbanje C, Adejo MA (2015) Technical Efficiency Analysis of Pig production: a sustainable animal protein augmentation for nigerians. *J Adv Agricultural Technol* 2(1). <https://doi.org/10.12720/joaat.2.1.19-24>
- Yang C, Hsiao C, Yu M (2008) Technical efficiency and impact of environmental regulations in farrow-to-finish swine production in Taiwan. *Agric Econ* 39(1):51–61
- Yasin MZ (2020) Firm's trade activities to promote technical efficiency and total factor productivity: the growth accounting and the stochastic frontier approach. *Econ Bull* 40(4):3020–3032
- Zhang Y, Sun S (2015) An analysis of pig production efficiency and regional differences in China based on Malmquist-DEA model and inter-provincial panel data. *Asian Agricultural Res* 7(11):12

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Authors and Affiliations

Caleb I. Adewale¹  **Elias Munezero¹** · **Elly K. Ndyomugenyi²** · **Basil Mugonola¹**

✉ Caleb I. Adewale
calebadewale02@gmail.com

¹ Department of Rural Development and Agribusiness, Faculty of Agriculture and Environment, Gulu University, P.O Box 166, Gulu, Uganda

² Department of Animal Production and Range Management, Faculty of Agriculture and Environment, Gulu University, P.O Box 166, Gulu, Uganda