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Full Length Research Paper

Technical, allocative and economic efficiencies of keeping newly introduced chicken strains among smallholder farmers in selected areas of Tanzania: an application of stochastic data envelopment analysis approach

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Abstract

The study was conducted to investigate the technical, allocative and economic efficiency of keeping introduced chicken strain; Kuroiler and Sasso at the farm level by using the input constrained Stochastic Data Envelopment Analysis. Data were collected from farmers who participated in the African Chicken Genetic Gain project. The study applied a developmental research design, which involved providing of pre-brooded chicks to farmers in selected sites. The on-farm test involved a total of 202 farmers who were provided with six weeks old chicks. The findings show that farmers in the study sites were technically, allocatively and economically inefficient. The mean technical, allocative and economic efficiency indices were 19.9%, 68.8% and 12.9% respectively. In this regard, the study confirms the hypothesis that on average, smallholder chicken farmers were economically inefficient leading to the conclusion that there is considerable scope to improve chicken production and productivity through improving economic efficiency in input allocation and use. It is therefore, recommended that scaling up of the introduced chicken strains must be integrated with technical knowledge to ensure efficiency improves in keeping the introduced chicken strains. Moreover, actors in the poultry sub-sector should create better market information systems for efficient input procurement and sale of outputs.

Keywords: Economic Efficiency, Stochastic DEA, Chicken Strains, Farm level.

INTRODUCTION

Chicken farming is one of the widely practised agricultural activities with high potential for poverty reduction, enhancing food security especially for the poor and improved women's position in the household as well as in society in Tanzania (Roy, 2017). In Tanzania, the chicken contributes an economic value of about TZS 874 billion and 364 billion for meat and eggs respectively (Match Maker Associates Limited (MMA) and Transcend Enterprises Limited, 2018). Despite their contribution in national economy, the potential of the local chicken farming remains largely untapped (MMA and Transcend Enterprises Limited, 2018). In addition, despite the contri-

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bution of chicken farming to national Gross Domestic Product (GPD), income and food security, yet the sector faces several challenges. These challenges include low capital base, inefficient management, economic inefficiency, technical inefficiency, diseases and parasites and poor housing. Further, with little level of inputs supply among smallholder farmers, studies have shown that these households fail to harness the full potential of technological advancement because of input allocative errors (Shanmugam and Venkataramani, 2006).

There have been several initiatives aiming at improving local chicken productivity in Tanzania (URT, 2017). One of the recent initiatives was the introduction of and on farm testing of new and dual type chicken strains (Sasso and Kuroiler) by the African Chicken Genetic Gains (ACGG) project. Kuroiler and Sasso are claimed to be fast growing and can produce about 150 eggs per year under moderate management (World Society for the Protection of Animals, 2011; Rodelio and Silvino, 2013). . This output should at least be above the threshold level of resource inputs thereby enhancing efficient resources allocation to produce a given output at least cost (Ghatak and Ingersent, 1984). The study was conducted to investigate the technical, allocative and economic efficiency of keeping introduced chicken strain; Kuroiler and Sasso at the farm level.

Review of Analytical Issues

The seminal work of Farrell (1957) defines efficiency as the ability to produce a given level of output at the lowest cost. Further, Farrell (1957) classifies efficiency as Technical Efficiency (TE), Allocative Efficiency (AE) and Economic Efficiency (EE). The TE measures the ability of a firm to produce the maximum output from a given level of inputs, or achieve a certain output threshold using the minimum quantity of inputs, under a given technology. Meanwhile, AE is concerned with the use of inputs in optimal proportions to produce a given quantity of output at minimum cost, considering existing technology and input prices. Meanwhile, EE occurs when the cost of producing a given output is as low as possible and is a product of TE and AE.

Two separate branches are dominating the literature of efficiency analysis: the non-parametric; data envelopment analysis (DEA) (Farrell, 1957; Charnes *et al.,* 1978) and the parametric; stochastic frontier analysis (SFA) (Aigner *et al.,* 1977; Kuosmanen, 2006). The DEA is a non-parametric Linear Mathematical (LM) programming estimation (Coelli, 1996) which does not assume a particular functional form but is governed by the standard axioms of production theory: monotonicity, convexity, and homogeneity and is capable of handling multiple inputs and outputs (Farrell, 1957). The main strengths of the DEA include: its ability to accommodate multiple inputs and outputs; it does not require explicit a priori determination of a production function and it measures the efficiency of each Decision Making Unit (DMU) relative to the highest observed performance of all other DMUs rather than against some average (Coelli *et al.,* 2005). Furthermore, by incorporating many inputs and outputs simultaneously in the estimation, DEA provides a straightforward way of computing efficiency gaps between each DMU and the efficient producers (Coelli *et al.,* 2005).

The Stochastic Frontier Analysis, on the other hand is the stochastic treatment of residuals, decomposed into a non-negative inefficiency term and an idiosyncratic error term that accounts for measurement errors and other random noise (Kuosmanen, 2006). Further, SFA is capable of handling production analysis with single output and multiple inputs. However, SFA builds on the parametric regression techniques, which requires a rigid ex-ante specification of the functional form. One of the challenges applied economists have encountered in estimating flexible functional forms in the production or consumer context is that the theoretical curvature conditions (monotonicity, concavity or convexity and homogeneity axioms) that are implied by economic theory are frequently not satisfied by estimated production, costs, profit or indirect utility functions (Diewert and Wales, 1987).

However, the conventional DEA suffers from some limitations: it requires that the production process to be characterized by the observed input-output variables, which are free of errors. The model assumes that any deviations from optimal output levels are due to inefficiency, rather than errors. This is recognized as the most serious limitation of DEA (Farrell, 1957; Charnes *et al*., 1978; Kuosmanen, 2006; El-Demerdash *et al*., 2016). In this regard, DEA estimates tend to exhibit greater variability compared to stochastic frontier models, by either overestimating the mean TE (Bravo-Ureta *et al.,* 2007) or underestimating the efficiency measures (Sharma *et al*., 1997). Further, the DEA approach may erroneously categorise all DMUs operating with extreme input-output quantities as efficient, when there are insufficient comparable units (Charnes *et al*., 1995).

As the literature of DEA grew in both theory and application, researchers felt the need to incorporate stochastic considerations in order to effectively account for the presence of measurement and specification errors, and to consider the inherent variability in various business processes (Talluri *et al*., 2006). These efforts are meant to bridge the gap between SFA and DEA models by combining the strengths of both that automatically reduce the identified weakness. These efforts are viewed as stochastic extension of DEA in the same way as SFA extends the classic deterministic econometric frontier models (Kuosmanen, 2006) to have Stochastic Data Envelopment Analysis (SDEA). For example, Banker and Maindiratta (1992) proposed an amalgam of DEA and

SFA that combines a DEA-style nonparametric, convex, piecewise linear frontier with a SFA-style parametric composite error term consisting of noise and inefficiency components. Kuosmanen (2006) introduced the stochastic nonparametric envelopment of data (StoNED) model, which is an additive variant of Banker and Maindiratta's model. Brazdik (2008) proposed the chance constrained problems for DEA analysis that accounts for stochastic noise in the analysed data. Subhash (2004) modified the standard DEA model to measure relative efficiency in the presence of random variation in the all outputs produced from given deterministic inputs. Land *et al*. (1993) extended DEA to include the case of stochastic inputs and outputs through the use of chance constrained programming to form the SDEA which is also known as a Land, Lovell and Thore (LLT) model. The main goal of this model is to handle random variations in both input and output variables (Land *et al*., 1993; Bruni, 2013; El-Demerdash *et al*., 2016). The input constrained SDEA is applied to incorporate stochasticity in input measures into the decision-making process (Talluri *et al*., 2006). Given the shortfalls of SFA and DEA models, the input-oriented SDEA model was adopted for this study.

METHODOLOGY

Description of the study sites

The study was conducted in three regions namely Dodoma, Morogoro and Njombe where on farm testing were in Bahi, Ifakara and Wanging`ombe respectively. Dodoma Region is located in the central part of the country on Latitude: -6° 00' 0.00' South and Longitude: 36° 00' 0.00' East and it is situated at an elevation of about 1125M above sea level. The region is bordered by Manyara region to the North, Singida region to the West, Iringa region to the South and Morogoro Region to the Southeast. Dodoma is primarily semi-arid and covers an area of 41 311 square kilometres. Annual rainfall varies from 500 to 700 mm and annual average temperature of about 22.6°C. Between the driest and wettest months, the difference in precipitation is 129 mm and the average temperatures vary by 5.1°C (Climatic Data Org, 2016). Major crops include drought tolerant ones such as family of sorghum, groundnuts and sunflower. Four villages namely Mayamaya, Bahi-sokoni, Mudemu and Mpamatwa were purposively selected in case of Bahi district.

Morogoro region is administratively divided into six districts, namely Morogoro, Mvomero, Kilosa, Kilombero, Ulanga and Gairo. The region lies between Latitude 5 ^{o}58' and 10^{o}0' South of the Equator, and Longitude 35^{o}25' and 35^{o}30' East. The region is situated at an elevation of 525 M above sea level. It is bordered by seven other regions: Arusha and Tanga regions to the North, the Pwani region to the East, Dodoma and Iringa to the West and Ruvuma and Lindi to the South. The annual rainfall ranges from 600 to 1 200mm with average annual temperature of about 25^{o}C. The zone is characterized by an average annual rainfall of 1160 mm with average temperature of 16°C. There are typically two distinct long and short rainy seasons of March–May and November–January/February, respectively, but this pattern is often interrupted (Climatic Data Org, 2016). Rice and maize production, horticultural produces and bananas dominate the production system in Ifakara district. The on-farm test sites were located in four villages: Kibaoni, Kikwelila, Lipangalala and Lumemo.

Njombe region lies between Latitude 08^{o}40' and 10^{o}32' South of the Equator and between Longitude 33^{o}47' and 35^{o}45' East of Greenwich and situated at an elevation of about 2 000 M above sea level. The region borders Iringa region in the North, Morogoro region in the East and Ruvuma region in the South. It also borders the Republic of Malawi via Lake Nyasa and part of Mbeya region in the North-west and West. Its climate is classified as warm and temperate. In winter, there is much less rainfall than in summer. The average annual rainfall is 1160 mm with average temperature of 18.6°C (Climatic Data Org, 2016). On-farm test sites were located in four villages namely Ujindile, Uhambule, Msimbazi and Ufwala. Maize, sunflower, pulses and horticultural production dominate farming system of the sites.

Development Research design

To evaluate the technical efficiency, allocative efficiency and economic efficiency of the introduced chicken strains, a developmental research design was applied. The design assumes a traditional model of skills in which the unit of analysis is the individual farmer (AFNETA, 1992; Richey, 1994). According to Barrow and Röling (1989), the development and transfer of appropriate technologies should be a function of the farmers' socio-economic and management practices at the field level. The study design is in accordance to Thornton *et al.* (2017) who purport that testing and dissemination of technologies are at the core of development-oriented agricultural research.

The selection of locations for establishing on-farm testing sites was based on Tanzania's Agro Ecological Zones (AEZs) to present the general farming systems in Tanzania. The AEZs range from high rainfall areas on the coast and highlands in the North, far West, South and Southwest, to arid and semi-arid areas in the interior of the country (URT, 2014). Accordingly, cropping patterns, climatic differences reflect biophysical characteristics for growth and stability of chickens. On-farm testing for introduced chicken strains across different AEZs was meant to facilitate farmers and other actors in poultry value chain evaluate the potential of the strains at farm level. Three assumptions underlie the design. First, selected farmers have had the experience in keeping chickens so that the design does not add any fixed cost such as chicken house, feeding facilities and drinkers. In other words, on-farm testing used already existing facilities. Secondly, time and labour spent in keeping introduced chickens and exiting local chickens were presumed similar and hence zero opportunity cost. Third, small-scale local farmers in Tanzania operate relatively similar in keeping chickens. Thus, any of AEZs fit for on-farm testing. According to ACGG (2015), households that were recruited to receive the chickens met the following criteria:

Chicken keeping households that had kept local chickens for a continuous period of at least two years prior to the baseline survey;

Keeping at least 15 adult chickens but no more than 50;

Willingness to accept 25 birds of randomly selected strain;

Commitment to provide some supplemental feeds and

Willingness to participate in the project for a minimum of 72 weeks.

Setting the basic criteria for selecting farmers to participate in on-farm testing, the baseline survey was conducted to identify the legible population in central semi-arid, Eastern sub-humid, Southern Highlands, Lake zone and Southern humid to represent different agro-ecologies in the country. Specifically, first step involved selection of three regions of Morogoro, Dodoma and Njombe to present AEZs. In each region, one district was selected purposively, taking into account the availability of villages which had about 20 and above households that have least 15 adult chickens but no more than 50. Secondly, out of the qualified villages, four of them from each district were selected randomly. Subsequent stages involved random selection of households from the long list of households that met the set criteria, followed by random selection of qualified farmers. The selected farmers were then given six-week pre-brooded chicks, each farmer receiving 25 chicks. Each farmer received either Kuroiler or Sasso strains. Chicks that were distributed had received all the recommended vaccination against Mareks, Newcastle Disease, Infectious Bronchitis and fowl pox before being distributed to farmers. Farmers continued keeping these strains based on their practices for keeping local chicken, but some additional feed supplementation using locally available materials. The introduced chicks were also with providing treatment and shelter under a semi-scavenging system (ACGG, 2016).

Data collection

Data for this study were mainly collected from farmers who participated in the ACGG project in selected on-farm testing sites. A total of 202 participant households from 12 villages were involved in the study. Out of the total famers, 111 farmers were Sasso strain keepers whereas 91 farmers were Kuroiler chicken keeping households. Data were collected through household surveys involving face-to-face interviews, observation and direct measurement. Direct observation was applied to rank quality of chicken house and accessories. The survey questionnaire was structured covering broad issues related to chicken enterprise: strains of chicken kept, the number of chickens, number of eggs sold, number of eggs hatched, number of eggs ready for selling, number of chicks/chicken sold and ready for sale, chicken keeping inputs (amounts and prices of feeders, brooder, chicks, eggs, feeds, medicines, vaccines, labour and time spent), number of dead chicken/chicks and the number of eggs not hatched. Feeds were weighed to determine the general supplementation levels. The participatory approach was applied to enable farmers to recall different situations, which made them change the feeding pattern. The feeding patterns were classified as: harvesting, harsh months, intermediate and no supplementation at all. In each situation, farmers were asked to estimate the level and frequency of providing feeds (kg/bundle) and medication (frequency) provided per twelve months were used in analysis.

Data analysis

The present study applied the input oriented Stochastic DEA framework by using the Data Envelopment Analysis Program (DEAP V2.1) to analyse economic efficiency. Farmers participating in on-farm testing of the introduced chicken strains were the decision-making units (DMUs) under this analysis. Suppose there are n homogenous Decision-Making Units (DMUs), in order to produce r number of outputs (r=1,2,3,…k), s number of inputs are utilized (s=1,2,3,… m,) by each DMU i (i=1,2,3,…n). Assume also that the input and output vectors of i^{th} DMU are represented by x_i and y_i, respectively and data for all DMUs be denoted by the input matrix (X) m×n and output matrix (Y) k×n. The input minimization process to measure technical efficiency for each DMU can be expressed as in equation 4.1:

$$\mathrm{TE} = \mathrm{Min}_{\theta\lambda}\theta$$

Subject to:

$$-y_i + Y\lambda \geq 0,$$
$$\theta X_i - Y\lambda \geq 0$$
$$N1' \leq 1$$
$$\lambda \geq 0 \qquad 1$$

where, in the restriction N1'λ=1, N1' is the convexity constraint, which is an N×1 vector of ones and λ is an N×1 vector of weights (constants) which defines the linear combination of the peers of the i^{th} DMU. $1 \leq \theta \leq \infty$ and θ-1 is the proportional increase in outputs that could be achieved by the i^{th} DMU with the input quantities held constant and $1/\theta$ defines a technical efficiency score which varies between zero and one. If θ =1 then the farm is said to be technically efficient and if $\theta < 1$the farm lies below the frontier and is technically inefficient.

Similarly, to estimate economic efficiency (EE), a cost minimizing DEA is specified as in equation 4.2:

$\mathrm{EE} = \mathrm{Min}_{\lambda x_i^*} W_i' X_i^*$

Subject to:

$-y_i + Y\lambda \geq 0,$

$X_i^* - X\lambda \geq 0,$

$N1', \lambda = 1,$

$\lambda \geq 1 \qquad 2$

Where, W_i' is a transpose vector of input prices for the i^{th} DMU and X_i^* is the cost-minimizing vector of input quantities for the i^{th} farm given the input prices W_i and total output level yi. Economic efficiency is measured as the ratio of potential minimum cost of production ($W_i'X_i^*$) to the actual cost of production ($W_iX_i^*$).

However, most data are stochastic and noisy with additive observation or measurement errors, which are often assumed to be normally distributed (Morita and Seiford, 1999) and are determined in term of standard variance. The variance of each input or output is estimated as:

$$\hat{\sigma}^2 = \frac{1}{N_j - 1} \sum_{k=1}^{N_j} (x_j^k - \bar{x}_j)^2 \qquad 3$$

Accordingly, Morita and Seiford (1999) argue that in the presence of stochastic variation, there are two situations to utilize the stochastic information of DMUs. The inputs and outputs stochastic variations are expressed as ($X_0 + \delta x$) and ($Y0 - \delta y$) respectively (Morita and Seiford, 1999 and Huang and Li, 2001). Therefore the Stochastic Data Envelopment Analysis (SDEA) for i^{th} DMU is determined as following (Equation 4):

$\mathrm{TE} = \mathrm{Min}_{\theta\lambda}\theta$

Subject to:

$(-Y_i + Y\lambda) + \delta_{yi} \geq 0,$

$(\theta X_i + \delta_{xi}) - Y\lambda \geq 0$

$N1' \leq 1$

$\lambda \geq 0 \qquad 4$

and EE is determined as in equation 4.5:

$\mathrm{Min}_{\lambda xi^*} W_i'(X_i + \delta_{xi})^*$

Subject to:

$(-Y_i + Y\lambda) + \delta_{yi} \geq 0,$

$(X_I^* + \delta_{xi}) - (X + \delta_{xi})\lambda \geq 0$

$N1' = 1 \qquad 5$

Allocative efficiency can be estimated as the ratio of economic to technical efficiencies as:

$$\mathrm{AE} = \mathrm{EE}/\mathrm{TE} \qquad 6$$

RESULTS AND DISCUSSIONS

Distribution of efficiency measures

A summary of the results as presented in Table 1 indicates that the mean TE was 19.9 and 18.2 for Sasso strain and Kuroiler strains respectively. The implication is that there exists about 80% potential for targeted farmers to increase their production as well as their income given the level of inputs supplied. Comparing Sasso strain household farmers and Kuroiler household farmers, generally, the difference in TE efficiency is not statistically different with Z calculated less than 0.65 (Critical Z value= 1.97). The maximum estimated TE is 1 in both strains, which means that some farmers were tangent to the frontier (Coelli *et al.,* 2005).

However, Fig. 1 shows that, about 81% of farmers were operating below 20% efficiency level while only 7% attained efficiency level of above 80% TE index. This implies that there was possibility of more output by using the same amount of inputs or applying small input mix to produce the same outputs. Comparing with other studies on technical efficiency of keeping chickens, the present results indicate lower efficiency score. For example, Ojo (2003) found the technical efficiency among Osun State of Nigeria farmers to vary widely between 0.24 and 0.93 with a mean of 0.76 and about seventy nine percent of the farmers had TE exceeding 0.70. Likely cause of lower efficiency indices is provision unstandardized supplements with high variation among farmers (Table 2). According to Muchadeyi *et al*. (2004), different birds are known to require different amounts of nutrients, depending on the production stage. For example, laying hens will require more for reproduction, whilst growers require more for tissue deposition.

Additionally, Table 2 indicates that farmers predominantly supplemented their chickens using energy-rich feeds (maize bran and rice bran) while protein rich ingredients and a mineral feeds were provided at lower levels and by very few farmers. The revealed feeding situation is in accordance to FAO (2019) that, the village poultry sector management is minimal and simply involves keeping the birds under free-range and scavenging conditions around the homesteads and rarely bestowing limited amounts of grain or bran. Accordingly, shortage of protein in the nutrition of chickens in rural areas is the major constraint in balancing diet for improved input output relationship.

It is acknowledged that diseases make poultry production a risky venture. Vaccination and treatment play great role in technical efficiency as they contribute much on mortality rate, eggs production and weight gain. Farmers and extension officers reported the signs of egg peritonitis and related infections as the plausible causes of mortality. Egg yolk peritonitis is the inflammatory reaction of peritoneum caused by the presence of yolk material in the coelomic cavity (Srinivasan *et al*., 2013).

The AE index varies across farmers from 13.8% to 100% and 0.7% to 100%, with a mean of 68.8% and 59.6% among Sasso and Kuroiler keeping farmers respectively. The result for mean allocative efficiency also suggests that the cost of production could be reduced by 31.2% and 40.4% in Sasso and Kuroiler keeping respectively. On one hand, these results relate to results by Daryanto

Table 1. Summary statistics of technical, allocative and economic efficiency indices.

Statistics	**TE**	**AE**	**EE**
	Sasso		
Mean	19.9	68.8	12.9
Standard Deviation	25.2	24.4	18.5
Minimum	2.2	13.8	0.9
Maximum	100.0	100.0	100.0
	Kuroiler		
Mean	18.2	59.6	11.8
Standard Deviation	23.8	24.6	22.0
Minimum	2.4	0.7	0.7
Maximum	100.0	100.0	100.0
z-value	0.65	0.01	0.07
Critical z value	1.97		

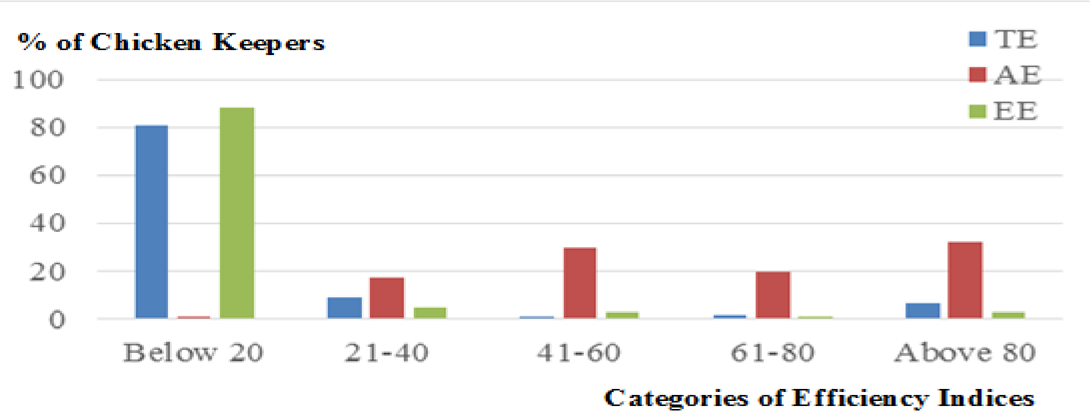

Fig.1. Distribution of technical, allocative and economic efficiency indices.

Table 2. Summary statistics for feeds supplement per 12 months.

Statistics	Maize bran (kg)	Rice bran (kg)	sunflower cake (kg)	Fishmeal (kg)	Minerals (kg)	Vegetables (bundle)
Kuroiler strain						
Mean±SD	7.5±4.6	6.6±3.6	1.8±1.8	0.6±0.6	0.5±0.6	2.3±0.9
% of farmers	100	63	64	37	52	19
Sasso strain						
Mean±SD	9.5±5.0	5.2±2.1	3.1±2.2	0.9±0.7	0.6±0.6	3.2±3.0
% of farmers	100	16	51	15	30	24

(2014) who established that farmers were allocatively inefficient with a mean index of 70.0%.

Comparably, farmers who participated in on-farm testing of introduced chicken strains were more allocatively efficient that those from Kaduna state in Nigeria whereby the mean allocative efficiency index was 35% (Saliu *et al*., 2015). However the results gave lower efficiency indices compared to other studies (Mahjoor, 2013; Omar, 2014). Singh *et al.* (2001) asserted that low and poor capital utilization in purchasing inputs is likely the cause of inefficiency in resources allocation, which leads to low economic efficiency scores.

Lastly, farmers were also found to be economically inefficient with a mean EE index of 12.9% and 11.8% among Sasso and Kuroiler strains farmers respectively. This implies that farmers could reduce current average cost of production by 87.1 and 88.2% to achieve the minimum cost of production relative to the efficient farmers given the current output level. These results are similar to those of Heise *et al.* (2015) who undertook analysis of economic potential for investing in poultry sector in Nigeria. Their results show that, from an economic perspective, many producers manage their poultry farms inefficiently and therefore lose highly promising cost savings opportunities.

However, differences identified in efficiency indices between farmers provided with Sasso and those who received Kuroiler strain were not statistically significant at 5% significance level. Figure 1 shows distribution of EE whereby 88% of farmers were highly economically inefficient with EE indices of less than 20%. Meanwhile, Fig. 1 indicates that only 4% of target farmers had economic efficiency score greater ranging between 61% and 80%. The relatively low levels of economic efficiency indices imply that, farmers were in a better position to improve production and productivity just by reallocating inputs levels under market prices. Moreover results of the current study are inconsistent with other poultry efficiency studies in terms of the low efficiency indices scores obtained. For example, results by Ohajianya *et al*. (2013) found that mean economic efficiency among local chicken farmers in Imo State Nigeria was 21%. This is probably due to lack of technical know-how to prepare feeds and supply them to chicken timely and at low cost. Accordingly, Dogan *et al.* (2018) put forth that, another possible explanation of the low economic efficiency scores may be the low capital utilization ratios of the farms.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that farmers participated in on-farm testing of the introduced chicken strains were technically, allocatively and economically inefficient in keeping these chickens. The low mean technical, allocative and economic efficiency indices were suggests that there is considerable scope to improve chicken productivity in the study sites given the levels of inputs used. It is recommended that poultry stakeholders with the intention to support scaling up of the introduced chicken strains, has to develop strategies, which will improve technical efficiency, allocative efficiency and economic efficiency to improve productivity.

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