IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 15, Issue 10 Ser. I (October 2022), PP 11-17
www.iosrjournals.org

Determinants of Technical Efficiency among Small-scale Tilapia farmers in Northern Province, Zambia.

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Abstract:
The study analyzes the determinants of technical efficiency of small-scale tilapia fish production in Kasama and Mbala districts in Northern Province of Zambia. Data were collected from 120 small-scale tilapia fish farmers using a two-stage sampling procedure and interviewed using a questionnaire. The data were analyzed using descriptive statistics and stochastic production frontier approach. Result of the stochastic production frontier shows that farm size (pond area), number of fingerlings, amount of labour, quantity of local feed, commercial feed, and livestock manure positively and significantly affected fish output. While using mixed seed fingerlings negatively affected fish production. The technical efficiency score ranged between 20% and 89% with a mean of 58%, implying that there exists a possibility for farmers to increase the level of fish output by about 42% through efficient use of existing resources and technology. In the inefficiency model, the gender of a farmer, level of formal education, and fish farming experience had positive and significant influence on technical efficiency of fish farmers while pond size had significant negative influence on technical efficiency. To improve technical efficiency of small-scale fish production, encourage formal education, women participation, and strengthen provision of relevant extension services and adoption improved fish farming practices in particular use of mono-sex fingerlings and quality feeds among small-scale fish farmers in the study area.
Keywords:*Fish farming, Smallholder, stochastic production frontier, technical inefficiency, Zambia*

Date of Submission: 26-09-2022 Date of Acceptance: 11-10-2022

I. Introduction

In Zambia total fish production from capture fisheries and aquaculture is not keeping pace with demand that is driven by the growing population and rising incomes. The annual fish production for Zambia in 2017 estimated at 100,000 metric tons was below the annual national fish requirement of 160,000 metric tons (Ministry of Livestock and Fisheries, 2017).The per capita fish consumption in Zambia had declined from 10-14 kg person in the 1990s to 5.9 kg per person in 2011. The current per capita fish consumption level for Zambia is below the world average of 19.7 kg per head.

In Zambia, fish and fish products account for a large proportion of animal protein intake for majority of people and fish demand will continue to grow driven by population growth, rising incomes and high preference for fish. The deficit between domestic fish production and national fish requirement, is offset through importation of about 70,000 metric tonnes (MT) of fish annually. Zambia's annual total fish production of about 110,000 MT, consisted of 85,000 MT of fish from capture fisheries and 30,000 MT from aquaculture. In short, aquaculture contributes about 30% of annual domestic fish production (MLF, 2017).

Over the past two decades (2000-2020), aquaculture production in Zambia experienced rapid growth, rising from 5,125 MT in 2005 to 30,254 MT by 2017. Aquaculture production is undertake by small-scale farmers and large-scale fish farming enterprises. Although small-scale fish farmers are the majority, their contribution to aquaculture production is about 30% annually, and the largest contribution comes from large-scale commercial producers using mostly cage culture (FSMIU, 2017).

Small-scale aquaculture production in Zambia faces various challenges including: inadequate availability of fingerlings, lack of quality fish feed, inadequate supply of feed, low quality feeds, use of subsistence farming methods, lack of improved fish farming skills, and lack of capital and credit (Kaminski et al. 2017; Nsonga, 2015; and Musuka et al. 2012). Consequently, most small-scale fish farmers are characterized with low production, low productivity and inefficient use of resources. The average yield for small-scale tilapia farmers in Northern Province is between 500 to 1000 kg per ha against the potential yield of 7 500 kg per ha per year (Golparakrishnan, 1988). Under small-scale farming the average weight per fish at harvest is about 250 grams whereas for commercial fish farmers it is about 400 grams (Nsonga, 2015; Kaminski, 2017). These low productivity figures are similar to those of small-scale tilapia farmers in Malawi (Phiri and Yuan, 2018). This indicates that there is much scope of increasing fish production from aquaculture by enhancement of productivity under existing technologies.

Aquaculture plays an important role in the national economy ranging from employment creation, income generation, food security and poverty reduction and as such the development of aquaculture it is on the national agenda. In this regard, the government efforts in this sector include: aquaculture park development, genetic improvement of fish species for culture, training of fish farmers, fish feed improvement, and fingerling production (IAPRI, 2017). These efforts are expected to improve production and enable the country meet the growing fish demand. These efforts in promoting aquaculture are yet to produce the expected benefits because production and productivity of fish production remain low in the country. This includes Northern Province and Western province which have the largest numbers of small-scale fish farmers and areas with the highest potential for fish farming in the country. This point to the fact that a mere increase in number of small-scale fish farmers and their establishments may not necessarily assure increased supply of fish products. It is necessary that farms must be able to operate at full production potential and use resources efficiently (Phiri and Yuan, 2018). Thus, the identification of factors influencing the technical efficiency is important for finding measures to improve technical efficiency of fish farmers. This calls for production efficiency studies of fish farming but these are very limited in Zambia.Akter et al. (2020) noted that agricultural productivity can increase either through introduction of modern technologies or by improving the efficiency of inputs with existing technologies. However, in an economy like Zambia where resources are scarce and opportunities for new technologies are lacking, it would be cost effective to devote considerable efforts to the analysis of technical efficiency that will be able to show the possibilities to raise productivity by improving efficiency of farms without increasing the resource base or developing new technology. Thus, technical efficiency is the ability of a farm to produce a given level of output with a minimum quantity of inputs under a given technology.

Empirical studies on production efficiency in other countries in Africa and Asia mainly, have applied stochastic frontier model to analyze technical efficiency of fish farming. These studies include: Sharma and Leung (1998) who examined the technical efficiency and its determinants for a sample of fish pond farms from the Tarai region in Nepal and found mean technical efficiency of 77% and that adoption of regular fish, water, and feed management activities has a strong positive effect on technical efficiency. Dey et al. (2000) found a mean technical efficiency of 83% among tilapia grow-out operations in ponds in the Philippines and that total farm area, education and age of the farmers are some of the factors affecting technical efficiency and concluded that as growers in the Philippines have attained a high level of technical efficiency under existing technology, the introduction of new technology is a key to raising the productivity of tilapia farming. In India, Singh, et al. (2009) estimated technical efficiency of small-scale fish production using stochastic production frontier approach in West Tripura district, and found the mean technical efficiency of 66% and that seed quality was an important determinant of technical efficiency. The study suggested that the state government should ascertain the supply of quality fish fingerlings at adequate time and quantity to the farmers in the study area. In Ghana, Essifile and Crentsil (2014) found mean technical efficient of 73.8% for tilapia fish and that regional location, type of feed, fingerlings, and labour have positive significant influence on fish output while level of formal education, marital status, and membership in the fish farmer groups and extension contacts negatively influenced inefficiency. In Malawi, Mussa et al. (2020) applied the translog stochastic frontier and found the mean technical efficiency of 66% for tilapia fish that the determinants of tilapia output in Malawi were seed, fertilizer input and farm size. The major factors influencing the efficiency level of tilapia producers are sex of producer, age, and household size, access to extension, training and access to credit.

The above review of technical efficiency studies of fish production indicate that fish farmers across the various African and Asian countries exhibit technical inefficiencies and operate below the frontier, and that room exists for improving the situation. It is also further revealed that various socio-economic and institutional factors are determinants of technical inefficiency and these need to be identified as they tend to be situation specific. The literature search further indicate absence of production efficiency studies on fish farming in Zambia. Hence to fill this information gap, this study was initiated with the objective to estimate the level of technical efficiency of small-scale tilapia farmers and assess the factors affecting farm efficiency. The study was conducted among fish farmers in Mbala and Kasama districts in Northern Province and data were analyzed using the stochastic frontier approach.

II. Material and Methods

Study area

The study was conducted in Kasama and Mbala districts in Northern Province of Zambia. The Province and the districts are found in agro-ecological zone III of Zambia, which is a high rainfall zone, with above

1000mm of annual rainfall. There is tropical climate with two distinct seasons; the rainy season (late October-April) and the dry season (May to September). The region has good potential for the production of maize, soybeans, sweet potatoes, cassava, sorghum, beans and groundnuts and vegetables. In addition it has good potential for fish farming.

Kasama is the Provincial capital and lies between 11˚00 S and 31˚00 E at an average altitude 1400m above sea level. The land is fairly flat and with light sandy loam soils mixed with some clay which is suitable for fish farming. Mbala lies between latitude 8˚ 50'S to 8.833˚S and on longitudes 31˚28 E to 31.467˚E. It is situated geographically at altitude of 1760 m above sea level and at the end of old great North road 165 km from North of Kasama. It borders Tanzania in the North, Mpulungu in the south west, Nakonde in the North east and Senga district in the South east. The soils are generally clay loam and has 1,200 mm of rainfall annually which is good for fish farming. Temperatures range from 15^{o} C in the cold season to 29^{o} C in the hot season. The district has many rivers that drain the area with the main ones being Saise, Lumi, Kalambo, and Luombe. The rivers are a source of water for the communities living along them and small scale fishing and fish farming activities. It is estimated that Mbala with about 600 fish farmers has the highest number in the province. It is also a leading producer of grain, vegetables and livestock in the province (CSO, 2016).

Data collection and sampling procedure

Multistage and random sampling methods were used in selecting the 120 smallholder fish farmers for the interview. Firstly, two districts namely Kasama and Mbala were purposively selected in Northern Province on grounds of high concentration of fish farmers. Secondly, four agricultural camps were purposively selected in each district. The four selected agricultural camps in Kasama district were; Nkole, Chibote, Munkonge, and Chilongoshi, while in Mbala district the camps were Kaka, Kawimbe, Chitoshi and Kalwilo. In each camp 15 farmers were randomly selected from district register of fish farming households with the help of Fisheries field assistants. A total of 120 smallholder fish farmers were interviewed using a pretested questionnaire. The data collection was done during February to May 2017 through face-to-face administration of a questionnaire conducted by Fisheries field assistants and camp extension staff. After data cleaning, 98questionnaires comprising 53% from Kasama and 47% from Mbala, were used in the analysis.

Analytical framework

The stochastic frontier production was adopted to measure the technical efficiency of small-scale fish farmers in this study. The model was first proposed by Aigner et al. (1977) andMeeusen and Van Den Broeck (1977). The advantage of this approach is that the error term captures noise, measurement error and inefficiency component /exogenous shocks beyond the control of the farmer. The stochastic frontier production function required for estimating farm level technical efficiency is specified as:

$$Y_i = f(X_i;\beta)\ exp\ (V_i - U_i) \quad \text{where } i = 1, 2, \ldots, n \qquad (1)$$

Here Y_i is the output of the i-th farm, X_i is denotes the actual input vector, β is vector of production elasticity coefficients and *Vi* denotes the random error not under the control of the famers, assumed to be independently and identically distributed as N (0, σ_v^2) , independent of U_i is one-sided error term that is independent of V_i and normally distributed as N (0, σ_u^2) , allowing the actual production to fall below the frontier without attributing all short falls in output from the frontier as inefficiency (Battese and Coelli, 1995).

The technical efficiency of the i-th farm (TE_i) is defined in terms of the ratio of the observed output to the output of the best producing (frontier) firm using the same the technology and given the levels of inputs used by that firm (Battese, 1991). Thus, the technical efficiency of firm *i* in the context of the stochastic frontier production is specified as:

$$TE_i = Y_i/Y_i^* = f(x_i, \beta) exp\ (V_i - U_i) / f(x_i, \beta)\ exp\ (V_i) = exp\ (-U_i) \qquad (2)$$

where

$Y_i = f(x_i, \beta) exp\ (V_i - U_i)$ is the observed production with inefficiency and

$Y_i^* = f(x_i, \beta)\ exp\ (V_i)$ is the frontier output quantity with no inefficiency.

The value of TE is bound between 0 and 1 such that 0 <TEi ≤1. When TE_i is 1, it indicates that a farmer is producing on the frontier with the available resources and technology and the farmers is said to be technically efficient. If TE_i is less than one, it implies that the farmer is producing on the production frontier for a given technology and resources. Such a farmer is said to be technically inefficient.

The determinants of technical efficiency can be considered by simultaneously estimating the production frontier and an equation for efficiency effects. Battese and Coelli (1995), proposed a model in which the technical inefficiency effects in a stochastic production frontier are a function of other explanatory variables. The technical inefficiency model, *Ui* is defined as:

$$U_i = \delta_0 + \delta_i Z_{ij} \qquad (3)$$

Where *Zi* represents the vector of explanatory variables that may influence the technical efficiency of a farm, δ_i is a vector of parameters to be estimated.
The unknown parameters for the stochastic frontier production function and the inefficiency effects model are obtained using the Maximum Likelihood Estimation (MLE) simultaneously. The variance of the parameters of the likelihood function are estimated as;

$$\delta^2 = \delta_v^2 + \delta_u^2 \text{ and } \gamma = \delta_u^2 / \delta^2 \text{ , so that } 0 \le \gamma \le 1 \quad (4)$$

Here gamma (γ) represents the proportion of error variance that can be attributed to technical inefficiency (Battese and Coelli, 1995).

Empirical model: Stochastic frontier and inefficiency models

The stochastic production frontier (SPF) analysis approach requires that a functional form be specified for the frontier production function. The production technology of fish farms in this study is assumed to be specified by the Cobb Douglas frontier production function defined as follows:

$$InY_i = \beta_o + \beta_1 InX_1 + \beta_2 InX_2 + \beta_3 InX_3 + \beta_4 InX_4 + \beta_5 InX_5 + \beta_6 InX_6 + V_i — U_i \quad (4))$$

Where: InY_i= Fish output (kg), X_1=Farm size or total Pond area (m^2), X_2=Total labour (Mondays), X_3=Number of fingerlings, X_4=Manure (kg), X_5= Local Feed (Kg), and X6 =Commercial feed (kg), and (V_i—U_i) = Composite error term.
The technical inefficiency model U_i is also defined as;

$$U_i = \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8 + e$$

Where: Z_1= Gender of the respondent (years), Z_2= Age of the respondent (years), Z_3=Formal education attained (years), Z_4= Experience in farming (Years), Z_5 = Marital status, Z_6 =Land tenure, Z_7= Extension contacts, Z_8=Seed type (type of fingerlings).

The study employed one stage approach, in which the inefficiency effects were expressed as explicit function of a vector of farm specific variables as proposed by Battese and Coelli (1995). Therefore, the parameters of the production function were simultaneously estimated with those of an inefficiency model. Furthermore, the maximum likelihood estimation procedure was used to estimate the production frontier. The analysis was done using Stata 12 version. The software also generated the variance parameters (λ, δ^2, γ) and the mean technical efficiency (TE) as well as farm level efficiencies.

Diagnostic tests for multicollinearity using Variance Inflation Factor (VIF) and test for heteroscedasticity using Breusch Pagan tests were conducted before running the models. Since the estimated VIF mean value of 3.10 was below 10.0, it indicated absence of multicollinearity. The Chi-square value of 0.17 (df=1), p=0.675 for Breuch Pagan test was found to be insignificant at 5% probability level.This ruled out presence of heteroscedasticity in the data.

III. Resultsand Discussion

Demographic and socio-economic characteristics of sampled respondents

As shown in Table 1, 71% of the households were male-headed household and 29% of the respondents were female-headed household heads. The average age of the respondents was 53.8 years. This indicates that most of the respondents were at the most productive stage of their life. Majority were married (93%) and had an average household size of 8.7 persons. On average sampled household heads have 9.3 years of formal education, this is equivalent to basic education (Grade 9 or junior secondary school education). The respondents have on average 8.9 years of fish farming experience, indicating that this activity is relatively new to most sample farmers.

Majority of respondents used own land (i.e. traditional land) for fish farming and only 4.67 percent of the sampled farmers used rented land. Regarding membership in association, 38% were cooperative members and 62% were non-members. In the Zambian setting cooperative membership is important in that to access subsidized inputs and credit facilities which are necessary to increase fish production and productivity these come through cooperatives. The respondents had an average of 3 extension visits per year.

The main inputs used in the production were earthen ponds, feed, labour, livestock manure and fingerlings. The average amounts used during the production season (duration of 8 months) were: 35.7 kg of local feed, 18.8kg of commercial feed, 38.1 kg of animal manure, and 67 man days of labor. The mean fish yield per farm per year in the study area was 59.3 kg harvested from an average earthen pond size of 579 m^2.

The stocking rate of fingerlings was about 0.77 fingerlings per square meter based on the mean pond size of 579 m^2 and an average of 689 fingerlings used. This fingerling stocking rate is below the recommended stocking rate of 2 to 6 fingerlings per m^2 for small-scale fish farmers in Zambia under extensive farming system. Majority of farmers (92.5%) used mixed-sex fingerlings and only (7.5%) stocked ponds with sex-reversed fingerlings. The quality of fingerlings is a concern in that most seed was obtained from fellow farmers and quality is questionable. The mixed-sex fingerlings often leads to survival competition among fish, hence it reduces growth rates, increases cost of production and reduces productivity. In addition mixed fingerlings are labour intensive for those farmers who want to separate fish by sex (Singas and Manus, 2014).

Table 1: Summary statistics of socio-economic characteristics of respondents

Variable	Observation	Mean	Std. Dev.	Min	Max
District (1=Kasama, 0=Otherwise)	98	0.53	0.50	0	1
Gender (0=Male, 1= Female)	98	0.29	0.45	0	1
Age (years)	98	53.96	12.57	20	78
Married (1=Yes, 0=N0)	98	0.12	0.33	0	1
Education (Years)	98	8.41	2.52	4	15
Experience (years)	98	16.88	8.14	2	66
Membership (Yes=1, 0=N0)	98	0.62	0.49	0	1
Extension visits	98	3.10	2.30	1	14
Land Tenure (1=yes, 0=No)	98	0.12	0.33	0	1
Pond area (sqm)	98	579.85	1394.66	100	14000
Used mixed-sex fingerlings (1=yes,0=No)	98	0.83	0.38	0	1
Fingerlings number	98	666.73	464.30	100	2000
Fish Yield (Kg)	98	59.26	58.80	5	250
Local Feed (Kg)	98	32.59	31.02	2	125
Commercial feed (kg)	98	17.71	16.88	2	75
Animal manure (Kg)	98	33.64	29.98	2	150
Farm labour days	98	66.51	35.57	10	180

Sources: Field data

Stochastic production frontier Cobb-Douglas estimation

Table 2 presents the maximum likelihood estimate (MLE) of the parameters for the frontier production function and the variance parameters of the model. The result revealed that the variance parameter sigma square (δ) was 0.709 and significant ($P < 0.01$). This indicates a good fit and correctness of the distributional form of assumption for the composite error term. The gamma (γ) which is the proportion of deviation from the frontier that is due to inefficiency was 0.90 and significant ($p < 0.01$). This means that about 90% of the variations of the fish farmers' output are due to differences in technical efficiency.

The estimates of the stochastic production function show that six of the variables included in the model had significant positive influence on fish production. The coefficient for pond size (0.384) was positive and significant ($p<0.01$). This implies that a 1% increase in pond size would lead to 0.384% increase in the fish yield.

The coefficient for commercial feed ((0,267) was positive and significant ($p<0.01$), meaning that a 1% increase in feed intake would increase fish output by 0.267%. Similarly an increase by 1% in number of fingerlings, quantity of animal manure used and quantity of labour used would result in 0.258%, 0.235%, and 0.168% increase in fish output, respectively.

The finding of positive effect of ration feeding on improved fish productivity concurs with Essilfie and Crentsil (2014) who pointed that provision of quality feed reduced stunted growth and improvement of feed along with other inputs can have an overall positive significant effect on output. The quantity and the quality of feed influence the performance and the size of the fish. Similar findings were reported by Olagunju*et al.* (2007).

Conversely, the use of mixed sex fingerlings has a negative significant ($p<0.01$) effect on fish yield. The coefficient of -0.35, implies that using mix sex seed would reduce fish output by 35% relative to using single sex male fingerlings, other factors held constant. This results agrees with Singh et al. (2015) that the practice of using mixed sex fingerlings reduced fish production.

Technical efficiency score of fish producers and sources of inefficiencies

The result of the frontier model in Table 2 indicated that the mean technical efficiency of the sample farmers was 58.1%, and it ranged from 14.8 to 90%. This indicates that, there is a wide efficiency gap among the sample fish producers in the study area. The mean TE score suggests that farmers had the opportunities to increase the output by 41.9% using the existing technology and input level.

To identify the sources of technical inefficiency, the technical inefficiency variables were estimated by using the one stage estimation approach of the frontier model. The statistically significant variables in the inefficiency model are discussed below.

Table 2: Results of the Cobb-Douglas stochastic production function estimation

Variable		**Coefficient**	**Std. Err.**	**z**	**P>|z|**
Production Frontier:					
Constant	β_0	-1.468	0.642	-2.290	0.022
LNPondarea	β_1	0.384***	0.096	3.990	0.000
LNComercialfeedKg	β_2	0.267***	0.053	5.060	0.000
LNFingerlinNo	β_3	0.258***	0.085	3.040	0.002
LNManureKg	β_4	0.235***	0.059	3.980	0.000
LNFamlabourdays	β_5	0.168*	0.097	1.740	0.082
Used Mixed-sex seed	β_6	-0.350**	0.141	-2.490	0.013
Inefficiency Model:					
Constant	δ_0	0.530	4.767	0.110	0.911
SexHH	δ_1	-1.006**	0.493	-2.040	0.041
LNAgeYrs	δ_2	0.521	1.602	0.330	0.745
LNEducationYrs	δ_3	-1.253*	0.658	-1.910	0.057
LNExperYrs	δ_4	-0.212	0.721	-0.290	0.769
Membership	δ_5	-0.720*	0.398	-1.810	0.071
ExtensionDays	δ_6	0.451	0.313	1.440	0.149
Variance parameters					
sigma2	σ^2	0.709	0.177	4.002	0.000
lambda	λ	3.006	0.212		
Gamma	γ	0.900			
Loglikelihood		-76.575			
Wald Chi2(6)		252.95			0.000
Mean technical efficiency	TE	0.583			
Technical efficiency: Mean=0.581, minimum=0.1408, and maximum=0.900					

LR test of sigma_u=0: chibar2(01) = 4.46 Prob>=chibar2 = 0.017
***Significant at 0.01 level; **Significant at 0.05 level; *Significant at 0.10 level.

Sex of farmer: The dummy variable for female farmer showed a significant ($p<0.05$) negative relationship with technical inefficiency. This indicates that female fish farmers were more technically efficient than male fish farmers. This result was unexpected. The finding concurs with Mussa et al. (2020) that technical efficiency was influenced by sex of the producer in Malawi. The finding implies that women participation in fish farming and empowerment of women contributes to optimal use of inputs and improved aquaculture performance (Aung et al. 2021).

Level of education: As expected the coefficient for education level of farmers was negative and significantly at 10% level affected the level of technical efficiency. This means that more educated fish farmers have higher technical efficiency than less educated farmers. The finding is in in-line with Bravo-Ureta and Pinheiro (1997) andEssifile and Crentsil (2014) that education is positively related to technical efficiency.

Farmer group membership: It had negative significant ($p<0.10$) influence on technical inefficiency level. This means that, compared to non-group members, the fish farmers belonging to farmer groups or associations have higher technical efficiency. This finding agrees with that of Essifile and Crentsil (2014) and Nades et al. (2017) that membership in the fish farmer groups and extension contacts negatively influenced inefficiency.However, it contradicts findings reported by Hakim et al. (2021) that groups' membership had no significant effect on technical efficiency among Indonesian farmers.

IV. Conclusion

This paper contributes to the debate on efficiency of smallholder aquaculture. It analyzed the technical efficiency of small-scale tilapia farmers in Northern Zambia using the stochastic production function approach. Result clearly shows that the fish farmers were inefficient as they were operating below the frontier. It also identifies the some determinants of inefficiency. The mean technical efficiency of 58% implies that there is an opportunity to improve efficiency level and increase fish output by 42% using the exiting inputs and technology. Some appropriates measures to take to improve technical efficiency includes: proving training to farmers on improved fish farming practices and yielding enhancing technologies in particular use of single sex male fingerlings instead of the common practice of using mixed sex seed. In addition, encourage formal education among fish farming communities, group membership and enhance women participation in fish farming through some empowerment programs.

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Banda DC and Musaba EC. "Determinants of farm-Level Technical Efficiency among Small-scale Tilapia farmers in Northern Province, Zambia.*IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 15(10), 2022, pp. 11-17.