Research Article

Technical Efficiency of Cricket (*A. domesticus and G. bimaculatus*) Production: A Cobb-Douglas Stochastic Frontier Approach

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Technical efficiency measures the effectiveness of an enterprise given the available resources at disposal and how well it transforms these resources to get maximum output. This study therefore investigated the technical efficiency of cricket*, A. domesticus and G. bimaculatus*, production at JOOUST cricket farm using parametric approach. Stochastic frontier analysis was used to analyze the data collected from the farm between 2015-2017. Maximum likelihood estimates results indicated that labour, cotton wool and feed had significant effect on the technical efficiency of cricket production at 1% and 5% significant levels respectively. Species had significant positive (P<0.05) contribution to inefficiency while scale of production and experience had significant negative contribution to technical inefficiency at 5% and 1% significant level respectively. Production in the farm was characterized by decreasing returns to scale implying that labour saving technologies combined with proper feeding rates and cheap alternative to inputs such as cotton wool should be considered. In addition, production scale should be expanded to contribute to efficiency through the benefits of economies of scale. However, further research should be done on allocative efficiency to permit a rational and comprehensive economic efficiency conclusion.

Key words: Cricket, Cobb-Douglas, technical efficiency, stochastic frontier approach, production

INTRODUCTION

Increase in agricultural productivity is seen as a panacea to the persistent food insecurity especially in Sub Saharan Africa (Muhammad, 2016). This increased productivity can only be sustained if the smallholder farmers are utilizing their available scarce resources efficiently (Obare, *et al.*, 2010). Efficient farmers will be operating on the production frontier and increase in production can only be realized through introduction of new inputs or technology whereas, inefficient farmers operating below the frontier, can only improve their production through efficient utilization of their current inputs by eliminating factors causing inefficiency (Owuor and Shem, 2009).

Most edible insects are harvested in the wild and the practice of farming insects for food is relatively new (FAO, 2013; Hanboonsong, Tasanee and Durst, 2003). Large scale production systems have been introduced recently

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in many countries and rearing of edible insects is now emerging in animal production as an ecologically friendly aspect. Insect farming is performed largely by family-run enterprises that rear insects such as mealworms, crickets and grasshoppers in large quantities, mainly as pets or for zoos in temperate areas. Recently, firms have started to commercialize insects as food and feed but the proportion of production intended for direct human consumption is still minimal. Countries like Lao People's Democratic Republic, Thailand and Vietnam are rearing crickets for human consumption. In these countries, insects are typically collected from wild habitats or farmed by small-scale producers, to generate income and employment opportunities for rural households (Hanboonsong *et al.*, 2003). Strong market demand, effective support by university research and extension and innovative private-sector food processors and sellers have made insect farming a significant economic activity in Thailand. Insect value chain has emerged as a multi-million dollar sector providing income, employment, healthy and nutritious food for households (Hanboonsong *et al.*, 2003).

It has been reported that over a thousand-insect species have been used as traditional foods by humans and many still form an important part of the diet and economy of many societies (Riggi, Veronesi, Verspoof and MacFarlane, 2013; Pascucci *et al.*, 2015; Ayieko *et al.*, 2016). Some of the more popular insects eaten around the world include: crickets, grasshoppers, ants, beetle grubs and caterpillar (FAO, 2013). Edible insects have long been used by ethnic groups in Asia, Africa and South America as a cheap and sustainable source of protein. In South-East Asia, close to 164 species of edible insects are consumed, while in China, about 178 edible species have been identified and named (Van Huis, 2003). A survey done by FAO (2010) showed that close to 95 % of the population of Laos eat insects, of which ant eggs, crickets and grasshoppers were the most preferred groups.

In Africa, consumption of insects is widespread through-out the continent with some 250 species being consumed. For example, Riggi *et al.* (2013), observed that in Democratic Republic of Congo, 64% of the animal protein consumed by humans came from insects while winged termites were preferred to meat of mammals by many Zambians. In East Africa, Ayieko (2010) reported that the long-horned grasshopper is a delicacy especially in Uganda. The practice of eating insects is common among communities in western Kenya. Ayieko (2007) observed that several types of species are used as food in Kenya. These included winged termites and grasshoppers which are treated as delicacies among the Luo, Luhya and Kisii communities in Kenya.

In parts of Africa insects are popular as food. However, they are generally harvested manually in the wild which makes them expensive, seasonal and vulnerable to extinction (Riggi *et al.*, 2013). Traditionally, the collection

of edible insects from their natural habitats has been practiced in Kenya for many years (Ayieko, 2007; 2010). However, presently this is not sustainable, thereby restricting consumption of edible insects. This calls for the intentional farming of edible insects for human food to address the issues of sustainability. Several reasons support the need to engage in entomophagy. First, research has established that entomophagy is an environmentally friendly alternative to traditional livestocking (Van Huis *et al.*, 2010; Premalatha *et al.*, 2011; Paoletti, 2005). Second, edible insects can have economic value apart from their obvious nutritional value. Third, edible insects are ideal mini livestock due to their ability to multiply quickly (Ayieko, *et al.*, 2010; Premalatha *et al.*, 2011).

Several studies have shown that insects constitute quality food and feed, have high feed conversion ratios, and emit low levels of greenhouse gases (Ayieko *et al.*, 2012; Pascucci et al, 2015). Gahukar (2011) pointed out that the house cricket efficiency of conversion of ingested food (ECI) is twice as efficient as pigs and broiler chickens, four times greater than that of sheep and six times higher than a steer when losses in carcass trim and dressing percentage are accounted for.

Whereas cricket farming has developed into an important component of animal production in a number of South - East Asia countries, in Kenya, until recently, one could only find fried winged termites as a favorite delicacy around the shores of Lake Victoria (Ayieko, 2007). However, currently there is growing interest in crickets and the demand for them is gradually being created as an alternative source of food and nutrition in Kenya. Nevertheless, for the growing interest to be sustained, cricket venture must be seen as to be technically efficient in production compared to the other enterprises. This has necessitated the investigation into its technical efficiency to permit rational comparison with other existing enterprises within the Lake Victoria region of Kenya.

Efficiency is the degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality (Hepelwa, 2013; Yegon, Kibet and Lagat, 2015). It is the ratio of output to input used and can be assessed in terms of technical, allocative, cost and dynamic efficiency (Coelli *et al.*, 2005). For efficiency to be attained, there are necessary and sufficient conditions that must be met given the firm's objectives. The necessary condition is met if in the production process there is no possibility of producing the same amount of product with fewer inputs and when there is no possibility of producing more product with the same amount of inputs (Obare *et al.*, 2010). On the other hand, the sufficient, condition encompasses individual and social goals and values. This condition allows for variations in the objectives of individual producers (Nyekanyeka, 2011; Obare *et al.*, 2010).

Studies done on efficiency of agricultural production in Sub-Saharan Africa (SSA) have yielded different results. Kitila and Alemu (2014), reported a 34% inefficiency among maize farmers in Ethiopia with seeds, land, labour and fertilizer having a positive and significant relation with maize production. Maize farmers in Zimbabwe and Zambia were found to be 35% and 50% technically inefficient (Muhammad, 2016). These inefficiency percentages implied that these farmers from Ethiopia, Zimbabwe and Zambia have 34%, 35% and 50% room for improving their production using their available inputs and technology while Irish potato farmers in Nyandarua district, Kenya had 43% room for improving their productivity (Obare, *et al.*, 2010).

The technical efficiency (TE) defined as the ratio of the firm or the farmer actual production to the optimal output, occurs when firms are obtaining the maximum output given certain inputs of production (Baten and Hossain, 2014; Hepelwa, 2013). The TE reflects the ability of the producer to obtain maximum outputs from a given set of inputs. Therefore, the producer is said to be technically efficient when the actual output is equal to the optimal output and the same producer is said to be inefficient when the actual production is less than optimal output or the frontier output (Muhammad, 2016). It involves structural transformation of the production function through introduction of new inputs and techniques of production (Muhammad, 2016; Taru, Lawal and Tizhe, 2011). A technically efficient firm will, therefore, be on the boundary' of its production possibilities frontier.

Cricket venture is an emerging farming enterprise that is poised to help alleviate protein deficiency and the success of its adoption lies in its efficient use of available scarce resources. This study therefore sought to determine the technical efficiency of cricket enterprise so as to provide guidelines to interested farmers on efficient input use.

METHODOLOGY

Study Area

This study was conducted at the Insect Farm of Jaramogi Oginga Odinga University of Science and Technology (JOOUST) within Bondo Sub-county, which lies between 0° 26° to 0° 90° and from longitude 33° 58° E and 34° 35° W. The sub-county has a modified equatorial climate with strong influence from local relief and the expansive Lake Victoria, which influence rainfall amounts and distribution (FAO, 2008). The sub-county has warm, dry and humid climate with mean annual rainfall ranging between 800-1600mm on bi-modal rainfall pattern of long rains occurring between March and May and short rains occurring between October and November. Temperatures too vary with mean of 22.5°C and evaporation varies between 2000 mm and 2200 mm annually (DEAP, 2007).

Experimental Design

The study was conducted at the Insect Farm facility at the Jaramogi Oginga Odinga University of Science and Technology (JOOUST). The crickets were reared in 100L plastic buckets each of which was stocked with 200 crickets. The buckets were covered with mosquito net to prevent entry of predators or escape of crickets. Drinking water was provided *ad libitum* in a saucer of 16cm diameter with a moist cotton wool, which was changed after every 3 days. To prevent anxiety, egg trays measuring 29cm x 29.5cm were placed vertically in the buckets to act as hide-outs. The experimental unit was replicated 3 times in each housing unit. Feed comprising of 100g of poultry grower's mash was provided *ad-libitum* for a week. Data on amount of feed consumed was recorded weekly and unconsumed feed was replaced. Temperature and relative humidity profiles were monitored by HOBO data loggers (U12-012 RH/TEMP; Onset Computer Corp., USA) which were placed in both housing units.

Data Types and Collection

The endogenous and exogenous data used in the study (Table 1) were collected from the insect farm within Jaramogi Oginga Odinga University of Science and Technology (JOOUST). The endogenous variable was the cricket output per cycle of production from 2015-2017. The exogenous variables were inputs used in the production: feed, cotton wool and labour. The description of experimental data is shown in Table1.

Table 1: Description of experimental data

Variable	Description	Measurement	A prior sign
Output	Dependent variable	Grams	+ or -
Independent Variables			
Feed	Amount of grower's mash ingested by the crickets	Grams	+ or -
Cotton wool	Rolls of 250g cotton wool bought from the shops	Grams	+ or –
Labour	Number of hours spent working in the cricket farm	Hours	+ or -
Parameters used in the Inefficiency model			
Cages	Number of cages were used as proxy to scale of production	Numbers	+ or –
Housing type	Two types, tunnel and prefabricated	1 = Tunnel 2= Prefabricated	+ or -
Experience	Measured in terms of cycles of production	Numbers	+
Species	Two spp. Of cricket, *G. bimaculatus* and *A. domesticus*	1= *G. bimaculatus* 2=*A.domesticus*	+or –

Empirical Modelling

The functional relationship as was suggested by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977)) is presented as:

$$q = f(x_1, x_2, ..., x_N) + v$$

…Equation (1)

Where,
q is the dependent variable which represents the output
X's are the independent variables and represents the inputs, and
v is the error term

The specification of both the ordinary least square (OLS) and deterministic models is written as;

OLS: $Y_i = \beta_0 + \beta_1 x_i + v_i$ --------Equation (2)
Deterministic: $Y_i = \beta_0 + \beta_1 x_i - u_i$ -------------------- (3)

Both models were combined to form a stochastic frontier model as specified below;

SFA: $Y_i = \beta_0 + \beta_1 x_i + v_i - u_i$ ------ Equation (4)
Where;
Y_i = output of the ith firm
β_0 = is the constant
β_1 = vector of unknown parameters
x_i = vector containing the logarithms of inputs
v_i = "noise" error term – symmetric (normal distribution). It represents changes in technical efficiency estimates unaccounted for by changes in the independent variables.
u_i = "inefficiency error term" - non-negative (half-normal distribution).

The following assumption was made on the distributions of *v* and *u*. Firstly, standard assumptions of zero mean, homoskedasticity and independence was assumed for elements of *v_i*. The *u_i*'s are identically and independently distributed non-negative random variables. Lastly, it was assumed that *v_i* and *u_i* were independently distributed. The distributional assumptions were crucial to the estimation of the parameters.

There are two major functions that measure the relation between inputs and outputs: Cobb-douglas and translog production functions. Although, translog function is flexible in its functional form and has less restrictions on substitutions possibilities of input variables, it suffers from collinearity due to the extended number of variables (Skevas *et al.*, 2018).

Cobb-Douglas function was used to specify the production function in the stochastic frontier analysis. In addition to its linearity in parameters and ease of estimation using ordinary least square, it can easily accommodate the few number of input parameters being estimated. Its simplicity and computational feasibility, that is, its regression coefficients give the elasticities of production, which is defined as the percentage change in the level of output resulting from a one percent change in the level of input, (*ceteris peribus*). These elasticities are independent of the level of inputs. (Henderson and Kingwell, 2002; Coelli *et al.*, 2005). It also makes it possible for diminishing marginal returns to occur without losing too many degrees of freedom, implying that Cobb-Douglas function is an efficient user of degrees of freedom.

Specification of the Cobb-Douglas function was;

$$Y_i = \exp^{(\beta_0 + \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + ... \beta_n \ln x_{ni})} \times \exp^{(v_i)} \times \exp^{(-u_i)} \text{--------(5)}$$

This can be log-linearized by taking the natural $\log_e$ of both sides for ease of estimation, resulting into equation 8.

$$\ln Y_i = \beta_0 + \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + ... \beta_n \ln x_{ni} + v_i - u_i \text{--------------- (6)}$$

The two error terms were combined such that the specification becomes;

$$\ln Y_i = \beta_0 + \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + ... \varepsilon_i \text{---------------------------- (7)}$$

such that the production elasticity for inputs becomes the β's and scalar elasticity becomes the ε. Weights of the inputs were used as variables in the equation. Maximum Likelihood was used to estimate the model because it is asymptotic, i.e. it has the desirable properties of a large data (Obare *et al.*, 2010).

Variables that affected technical efficiency of cricket production were estimated by the inefficiency model specified by Battesse and Tessema (1992) and Coelli *et al.* (2005) as shown in equation 8;

To measure technical efficiency, the ratio of the observed output to the ratio of corresponding stochastic frontier output was calculated as follows;

$$TE_i = \frac{\exp(\beta_0 + \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + \cdots . \beta_n \ln x_{ni} + v_i - u_i)}{\exp(\beta_0 + \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + \cdots . \beta_n \ln x_{ni} + v_i)}$$

$$TE_i = \exp(-u_i) \text{ --------------------------- (8)}$$

This measure of efficiency is between zero and one. If $u_i = 0$ it means that the enterprises are fully efficient and lie on the frontier. In this case the stochastic frontier production function reduces back to simple production function which indicates that there is no inefficiency and the error term is only the factors that are outside from the enterprise control. If $u_i > 0$ it means the output lie below the frontier which indicates that the enterprises are inefficient. It measured the output of the cricket enterprise in relative to the output that could be produced by a fully efficient enterprise using the same input vector.

Calculation of determinants of inefficiency relied on equation 9 below.

$$-u = \sum_{i=1}^{n} \alpha i z i + w i \text{…………………….... Equation (9)}$$

Where $-\mu$ was the inefficiency component, z_i is a vector of non-farm-variables affecting inefficiency which were: species, scale of operation, housing type and experience, αi is the parameter to be estimated and wi is composed random error term.

Species, scale of operation, housing type and experience comprised the non-farm variables that were regressed against the inefficiency component to establish their magnitude of contribution to technical inefficiency. The maximum-likelihood estimates of β and δ coefficients were estimated simultaneously using the computer program STATA 15.

Data Analysis

Time series data is prone to trend, cycles and seasonality (Greene, 2003). To ensure that the estimates from the data are not biased, the series must be stationary, meaning the mean and variance must be constant throughout the experiment time while the covariance must depend only upon the time periods between two values (Maddala, 1992). A stochastic trend is manifested in a series if the series moves upward and downward as a result of stochastic effects meaning its mean is a function of time. To detrend or test for stationarity of data in the series, Augmented Dickey-Fuller (ADF) test was used because it takes into account the cointegration problem (Greene, 2003; Maddala, 1992). Data was further subjected to normality, serial correlation and heteroscedasticity tests. Durbin's alternative and Breusch-Godfrey test were used to test for autocorrelation and where serial correlation was detected, the data was transformed through lagging. Jarque-Bera's test was used to test normality because it shows consistent result irrespective of the number off observations. It shows robust results because of the its asymptotic characteristic. Normality of the error term is necessary for the efficiency and consistency of the estimates to hold.

RESULTS AND DISCUSSION

Summary Statistics of Variables used in the Study

Summary statistics of the output and input variables used in the stochastic model are presented in Table 2. Average feed, labour and cotton wool were 9.70±5.56g, 3.60±0.20hrs, 131.76±1.6g respectively. Minimum and maximum usage level of feed, labour and cotton wool were 2.7g, 0.23hrs, 29.02g and 26.79g, 7.03hrs and 85.16g respectively.

Table 2: Descriptive Statistics of variables used in the Study

Variable	Mean	Minimum	Maximum
Feed	9.70±5.56g	2.76g	26.79g
Labour	3.60±0.20hrs	0.23hrs	7.03hrs
Cotton wool	131.76±1.6g	29.02g	234.5g
Output	543. 87±10.2g	103.01g	987.10g

The variables were subjected to stationarity test and the result of Augmented Dickey Fuller test (ADF) revealed that the data was stationary for all the variables tested under

the three significance levels (at 1%,5% and 10%). Due to this, there was no need of performing cointegration test. Since the absolute value of test statistic for all the variables were greater than the critical values, the null hypothesis of existence of unit root (non-stationarity) was rejected (Table 3).

Table 3: Results of Dickey-Fuller Test for Unit Root

Variable	Test statistic	1% Critical value	5% Critical value	10% Critical value
Cotton wool	-6.058	-3.562	-2.920	-2.595
Labour	-6.297	-3.562	-2.920	-2.595
Feed	-7.008	-3.562	-2.920	-2.595

Results from the Jarque-Bera's test revealed a normally distributed data. This test statistic is compared with chi-square distribution with 2 degrees of freedom and normality assumption is rejected if the calculated statistic exceeds a critical value from the chi square distribution.

Factors affecting Technical Efficiency of Cricket Production

The maximum likelihood parameter estimates of the stochastic production function are presented in Table 4. The coefficient of regression represents the elasticities of factors of production used in the experiment. The results revealed feed, cotton wool and labour significantly affected cricket production.

Table 4: Estimates for stochastic production parameters of cricket production

Production factors	Coefficients of regression	Std. Error	P -values
Constant	0.0298	0.0158	0.059
Feed	0.0003	0.0001	0.013**
Cotton wool	-0.0013	0.0005	0.009**
Labour	0.1035	0.0047	0.000***

** (P<0.05), *** (P<0.01) Summarized from STATA output

The sum of the elasticities was 0.1323 implying decreasing returns to scale of the cricket farm. This implies that any increase in input use results in a less than proportionate increase in output under the prevailing technology. Technically, output cannot expand unless there is change in technology. Similar findings were also reported by Bajrami, Wailes, Dixoni, Musliu and Morat, (2017) on technical efficiency of dairy farms in Kosovo.

Labour had the highest elasticity followed by cotton wool and feed respectively (Table 4). Labour had a positive and significant influence on cricket production (P< 0.000). Though the effect of labour on cricket production is inelastic, an hour increase in labour would lead to 0.1035 unit increase in output or productivity of crickets. This implied that productivity would be increased if more hours are allocated to production, further suggesting that labour

would be the most limiting factor of production and possibly the main reason for the decreasing returns to scale experienced in the cricket farm. This finding in agreement with the findings of Girei, Dire,. Iliya and Salihu (2013) on increased food output in Fadama, Nigeria and Obare *et al.*(2010) on production of Irish potato in Nyandarua, Kenya. Management and production activities required at cricket farm are labour intensive pointing towards the development of labour saving technologies for improved productivity. Abdallah and Rahman, (2017) and Ali, Shah, Jan, Jan, Fayaz and Ullah *et al.* (2013) established that productivity was only increased in maize and sugar cane respectively when labour saving technologies were developed or when more labour hours were allocated to labour intensive activities during production processes. However, findings of Yegon *et al.* (2015) on soy bean production in Bomet, Kenya, contradicts on the principle of marginal productivity. In addition, cricket farming is a new enterprise and as such the inexperienced labourers need more time to learn the new production techniques.

Cotton wool was the second most limiting factor of production in cricket production. It had a negative and significant influence on output indicating that a unit increase in cotton wool use led to a 0.0013% reduction in cricket output. Additional use of cotton wool led to decreased marginal cricket productivity may be due to cost. Cotton wool used in the cricket production were processed ones bought from the shops. The cost element might have contributed to the negative effect of this factor. This is in agreement with the findings of Yegon *et al.* (2016) that for labour intensive activities like cricket farming, optimum yield requires high cost inputs and Otitoju and Arene, (2010) who observed that additional use of high cost inputs led to decline in marginal productivity. Cotton wool might also encourage bacterial and fungal growth killing mostly pinheads. When cotton wool is used as an egg collection substrate, it should not be squeezed as this may prevent the pinheads from wriggling out as they hatch. All these in addition to high cost might explain the negative inelastic influence on productivity implying that for optimum productivity to be achieved, the usage of cotton wool should be reduced or usage of a cheap alternative should be encouraged.

Feed experienced increasing marginal returns in the cricket production, an indication that it had a positive significant relationship with cricket output. A one gram increase in feed consumption led to 0.0003 unit increase of output of cricket (grams). Feed is a critical input in the production process as it forms part of what is transformed into body mass. The implication is on the nutrition as better diets increases performance in terms of yields or output. Further still, well established optimum feeding rates feeds for each stage of life of the crickets are still lacking thus underfeeding or feeding wrong feed in terms of nutrient composition might have had effect on productivity. Islam, Tai and Kusairi, (2016) and Barjami *et al.* (2017), reported similar findings with fish cage farming in Peninsular, Malaysia and dairy farming in Kosovo respectively.

Determinants of Technical Inefficiency

The inefficiency parameters were specified as species, scale of production measured in terms of number of cages or buckets, housing type and experience measured in number of production cycles. A positive coefficient of a variable decreases efficiency in cricket production and vice versa; thus, species and housing type had negative influence on cricket production albeit housing type being non- significant. Scale of production and experience had positive influence on cricket production at 5% and 1% significant level (Table 5).

Table 5: Regression coefficients of determinants of cricket production inefficiency

Inefficiency factors	Parameters	Coefficient of regression	Std. Error	P-values
Species	δ_1	4.3144	1.4569	0.003**
Scale of production (No. of cages)	δ_2	-0.6572	0.2371	0.006**
Housing type	δ_3	0.2710	0.5899	0.646
Experience (cycles)	δ_4	-0.5087	0.1041	0.000***
Diagnostics				
Log Likelihood	245.4946			
Sigma-v		0.0037	0.0007	
Wald chi2(3)	813.77			
Prob.> chi2	0.000			
Lambda	2.1663***			
Gamma	0.6842***			

** (P<0.05), *** (P<0.01) Summarized from STATA output

The log likelihood (245.4946) was different from zero while the chi-square value (813.77) was highly significant at 1% which implied that the explanatory variables used in the model were collectively able to explain the variations in cricket productivity. Lambda (λ) was large and significantly (P<0.01) different from zero (2.1663). Therefore, the null hypothesis of no technical inefficiency in cricket production was rejected. This indicated that production was below the production frontier and did not attain maximum possible output. It also indicated goodness of fit and correctness of the specified normal/half-normal distribution assumption as was reported by Gichimu *et al.* (2013). Sigma squared (δ^2) was also significantly different from zero indicating that the inefficiency effects were random and stochastic. Gamma (γ) was 0.6842, which meant that about 68.42% of the variation in cricket productivity was due to differences in technical efficiency, that is, factors within the farmer's control especially in the use of inputs and general farm management.

Species negatively affected inefficiency (Table 5). Change of species from *G. bimaculatus* to *A. domesticus* decreased efficiency. *G. bimaculatus* species are bigger in size and takes shorter period to reach maturity. Changing to *A. domesticus* which is smaller, weighs less and takes longer to reach maturity would reduce output in grams. For maximization of productivity, farmers will always select species of animals that are superior in production performance in terms of maturity period and body mass. This is in agreement with the findings of Islam *et al.* (2016) that slower growing fish species increased production inefficiency amongst Peninsular farmers in Malaysia.

Scale of production, which was measured in terms of number of cages per production cycle, had a positive relationship with efficiency of cricket production (Table 5). Increased production units lead to decreased cost of production as the cost will be spread amongst several units, thereby achieving a higher technical efficiency. This contradicts the findings of Islam *et al.* (2016) and Bajrami *et al.* (2017) that there was no difference in technical efficiency between small and big farms in production. On the other hand, Ly, Nanseki and Chomei, (2016), Girei *et al.* (2013) is of a different opinion that increased production leads to improved efficiency and productivity.

Experience, which was measured in terms of production cycles, had a positive and significant (P<0.000) impact on efficiency of cricket production, meaning that more production cycles lead to more experience through learning thereby increasing efficiency. It can further lead to specialization which further improves productivity. More experience helps with optimal application of inputs and better managerial skills. Mignouna *et al.* (2012), Obara *et al.* (2010) and Chepnge'tich *et al.* (2015) argued that experience helped in rational decision making leading to efficient allocation of resources. Islam *et al.* (2016) and Ly *et al.* (2016) reported of inefficiency in farming activities due to lack experience and knowledge. This was found to hamper proper selection of suitable technologies. There should be expansion of production scale combined with knowledge transfer to the labourers working in the insect farm. This knowledge acquisition will bring about the experience that was found to increase efficiency.

CONCLUSION AND RECOMMENDATIONS

Stochastic frontier analysis revealed a positive relationship between output and two major inputs; feed and labour. However, cotton wool had a significant negative effect on production. Species, scale of production and experience had significant effect on inefficiency while housing did not. Rearing *G. bimaculatus* improved efficiency of production and thus should be recommended to improve productivity. Similarly, scale of production should also be expanded to provide basis for optimal use of inputs.   The sum of elasticities reported decreasing returns to scale for the

cricket production at the JOOUST farm. The policy implication to stakeholders and researchers is the development of new production technologies to bring about expansion in production. Further research should focus on labour saving technologies as this appeared to the most limiting input from the results. Consequently, optimum productivity will only be achieved if there is sustained and prioritized development of production procedures and technologies in terms of affordable and nutrient rich feed, optimum feeding rates and rearing conditions and suitable rearing inputs. It should be noted, however, that the study only dealt with technical efficiency which does not give comprehensive information on overall efficiency analysis to enable rational decision making by the farmers on profitability of the enterprise. More research should be done on the allocative efficiency so as to permit a complete economic efficiency of the enterprise.

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