EFFECTS OF HOUSING AND FEED ON GROWTH AND TECHNICAL EFFICIENCY OF PRODUCTION OF *Acheta domesticus (L)* AND *Gryllus bimaculatus* FOR SUSTAINABLE COMMERCIAL CRICKET PRODUCTION IN THE LAKE VICTORIA REGION, KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements for the Award of Doctor of Philosophy in Agribusiness Management of Jaramogi Oginga Odinga University of Science and Technology

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and has not been submitted wholly or in part for any award in this or any other institution of learning.

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DEDICATION

To the late Mary Theresa Oyando and Lamech Okeyo Omondi

ABSTRACT

The Lake Victoria Region has been synonymous with persistent cycle of food insecurity and low income among farmers. This has been mainly attributed to small scale subsistence farming and unsustainable farming methods. To address the problem of food insecurity, low income and unsustainable agriculture, it is necessary that innovative farming methods be sought. Consequently, this study has focused on cricket rearing due to their unique potential to address the three concerns. The aim of the study was to generate knowledge on edible cricket rearing systems for medium and large-scale producers in the Lake Victoria Region. The specific objectives were: to determine the growth performance of crickets fed on different agricultural by-products; to evaluate the performance of crickets under different housing systems for medium production and to determine the technical efficiency of cricket production. Two -way ANOVA was used to analyze the first two objectives while objective three was analyzed through Stochastic Frontier Analysis (SFA). The study investigated growth performance of the crickets under two housing systems: Tunnel house and Prefabricated house. The feed used in the study were: Grower's mash (GM) which was used as a control, Rice bran+ Brewers' spent yeast (RBSY), Rice bran+ bloodmeal (RBBM) and Rice bran +Brewer's spent grain (RBSG). In the third objective, the study further investigated technical efficiency of cricket rearing at the JOOUST insect farm. Housing type did not affect overall growth rate of the two-cricket species significantly ($P>0.05$) but was statistically different between the two-cricket species ($P< 0.000$). *G. bimaculatus* had a higher growth rate than *A. domesticus*. There was also statistically significant difference in growth rate amongst the crickets fed on the four feed types ($P<0.000$). Maximum likelihood estimates revealed that labour ($P<0.000$) and feed ($P<0.000$) had positive significant influence while cotton wool had significant negative ($P<0.005$) effect on cricket output. Change of species from *G. bimaculatus* to *A. domesticus* increased inefficiency while increase in scale of production and experience reduced inefficiency. The sum of elasticities revealed decreasing returns to scale. The results of this study implied that the genetically superior cricket species should be reared in either of the houses and new production technologies should be developed if expansion in production is to be realized. Proper training and scaling up of production would further help in increasing productivity. The new technologies should cover feeding rates, alternative input that is cheaper, and can serve the same purpose as cotton wool and labour saving techniques.

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ANOVA :	Analysis of Variance
CBO :	Community Based Organization
DEA :	Data Envelopment Analysis
DFA :	Distribution Free Approach
FAO :	Food and Agriculture Organization
FDH :	Free Disposal Hull
GM :	Growers' Mash
ICIPE :	International Centre of Insect Physiology and Ecology
JOOUST :	Jaramogi Oginga Odinga University of Science and Technology
KIHBS :	Kenya Integrated Household Budget Survey
NGO :	Non-Governmental Organization
OLS :	Ordinary Least Square
PDR :	Peoples Democratic Republic
RBBM :	Rice bran + Bloodmeal
RBSG :	Rice bran + Spent Grain
RBSY :	Rice bran +Spent Yeast
RH :	Relative Humidity
SFA :	Stochastic Frontier Analysis
TE :	Technical Efficiency
TFA :	Thick Frontier Analysis

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Global population is expected to increase to 9.3 billion by 2050 whereas demand for food is projected to double by 2030 (FAO, 2017). Twenty percent of that increase is attributed to population growth (FAO, 2003; FAO, 2017). Demand for food is steadily increasing worldwide and agricultural productivity can hardly keep pace (FAO, 2003; Tilman, Balzer, Hill and Befort, 2011). It is projected that by 2050, demand for animal protein will have doubled globally. At the same time, the livestock industry is considered to be resource consuming and is unlikely to meet this projected increase in demand (FAO, 2003; Pascucci Dentoni and Mitsopoulus, 2015; Premalatha, Abbasi, Abbasi and Abbasi, 2011; Tilman et al., 2011). Moreover, it has ramifications with regard to green-house emissions (FAO, 2013). The aforementioned scenario calls for creative, innovative, cost effective and environmentally sound and sustainable ways of meeting the global demand for animal protein. It is in this view, that edible insect production should be developed as an alternative source of animal protein. Edible insects constitute a category of food and feed that is greatly underutilized but may contribute significantly to future global nutritional needs (Pascucci et al., 2015). Previous studies (FAO, 2003; Pascucci et al., 2015; Ayieko, Ogola and Ayieko; 2016), have shown that edible insects have the potential to contribute to food security and nutrition in a sustainably sound manner, improving rural livelihoods and income as well as reducing pressure on the environment in feeding the ever-growing world population. Recent studies of the potentiality of large-scale entomophagy (Van Huis, Van Itterbeeck, Klunder, Mertens, Halloran, Muir et al., 2010; Pascucci et al., 2015 suggest that entomophagy as an alternative protein source to animal feed citing possible benefits including greater efficiency, lower resource use, increased food security and environmental as well as economic sustainability.

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; Carrington, 2010; 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 (2010b) 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.

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 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).

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; Saunders, 2008; Premalatha et al., 2011).

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.

Protein Production and Consumption trends

The demand for protein has increased rapidly over the past decade due to increase in population, increasing incomes and rapid urbanization (FAO, 2017). The demand for animal proteins such as meat and milk are projected to increase by 58% and 70% respectively in 2050 compared to the levels in 2010 (FAO, 2011). It is projected that within the developing countries, 60% and 9% of protein will be from cereals and meat respectively by 2024 (Table 1) (FAO, 2017; Tilman et al., 2011). In Sub-saharan Africa, there has been a shift towards livestock protein sources. Consumption of meat has been projected to grow by 5-6% per annum and that of milk and dairy products at 3.4-3.8 percent per annum in the next decade (Thornton, 2010). These increase in consumption will take place amidst constraint production and advocacy for less emission of greenhouse gases. In fact, FAO (2017) reports of a paltry 1% increase in production of meat and fish globally in 2016. Insects have been missing in the global arena as an alternative source of protein but with the numerous benefits now attached to it, it might just be the healthiest and environmentally friendly alternative.

Table 1: Major Sources of Global protein supply

Protein Source	Contribution (%)
Cereals	40.4
Meat	17.8
Milk – Excluding butter	10.1
Fish and seafood	6.4
Vegetables	5.7
Pulses	4.9
Eggs	3.4
Oil crops	3.4
Starchy roots	2.8
Others	5.1

Source: FAO, 2010

Kenya's population has been projected to increase to 63 million by the year 2030 from 38,473,893 in 2010 (Mohajan, 2014). It is reported that presently, 51% of Kenyans are suffering from starvation and it is estimated that over 45 percent of the total population live below the poverty line whereby over 50.5 percent live in rural areas compared to 33.5 percent in urban areas (Mohajan, 2014). At the same time, Kenya's protein intake is estimated at 58 grams/person/day against the global level of 77 grams/person/day, developed countries rate of 103g rams/person/day and sub-Saharan Africa rate of 55g rams/person/day. (FAO, 2010c). All these projections call for a sustainable source of protein with less environmental blue print which, underutilized insects can offer.

1.2 Statement of the Problem

The protein deficiency in the diets of most developing countries and particularly in Sub-Saharan Africa (SSA) is a cause for concern. The increase in population requires a commensurate supply of protein in diets. Most of the conventional sources of animal protein like beef, mutton, poultry and pork are too expensive for the majority of the people. Additionally, protein supply from these sources is decreasing due to several causes, including drought, diseases, high cost of feed, poor animal husbandry techniques and low productivity of indigenous animal breeds. Food security and environmental sustainability remain key challenges within the context of food production. Overall, the situation has generated interest in the introduction and development of new and diversified protein sources. Insects are considered a possible solution to the growing protein demand as well as achieving improved environmental sustainability and conservation of biodiversity. Use of crickets as an innovative source of high protein to both human beings and animals has been studied. Crickets, especially *Acheta domesticus* (House Cricket) and *Gryllus bimaculatus* (Field Cricket), have been found to be adaptable to mass rearing. However, the success of mass rearing of these insects depends on a number of factors of which one main component is the availability of feeds that are efficiently digested and able to provide the required nutrients for optimum growth. Besides suitable feed, it is also important to consider types of housing and efficiency of the entire cricket production system. Availability of suitable cricket feed presents a fundamental challenge to mass cricket production. The current practice has largely depended on poultry feeds which have been found to be expensive and also exposed to competition between the two enterprises. There is, therefore, a need to explore an alternative source of cricket feed. Similarly, to ensure sustainable large-scale production and conservation of biodiversity, suitable rearing conditions in terms of abiotic factors must be in place. Among these requirements is appropriate housing systems which are not only affordable but also adaptable to local conditions. Commercialization of cricket farming cannot be achieved without the economic consideration. Economic efficiency is an indication of the performance of each farming enterprise in terms of maximization of inputs and outputs. Cricket farming being a new enterprise, there should be recommended levels and guidelines on input use that maximizes output and subsequently income. Consequently, production efficiency in harnessing the various inputs is critical to successful mass cricket rearing. This study sought to investigate the effect of feed and housing on growth performance of *Acheta domesticus* and *Gryllus bimaculatus* crickets and subsequently establish optimum production levels in relation to the various amounts of inputs.

1.3 Objectives of the Study

Overall Objective: To generate knowledge on feed, housing system and technical efficiency of cricket production systems for medium and large-scale production.

Specific Objectives

1. To investigate the effects of housing system on growth performance of *Acheta domesticus* and *Gryllus bimaculatus* crickets.
2. To examine the effects of agro byproducts-based feeds on growth performance of *Acheta domesticus* and *Gryllus bimaculatus* crickets.
3. Determine the technical efficiency of medium scale cricket production.

1.4 Hypotheses

1. H_o: = There is no difference in growth performance and survival of *Acheta domesticus* and *Gryllus bimaculatus* reared under different housing systems.
2. H_o: = There is no difference in growth rate of *Acheta domesticus* and *Gryllus bimaculatus* fed on different agricultural by-products.

1.5 Research Question

3. What is the technical efficiency of medium scale cricket production?

1.6 Rationale of the Study

Insects have been a delicacy in the culture of many communities since time immemorial thus with improved sensitization many people are likely to adopt large scale commercial production of crickets for food and feed. Insects have the potential to multiply faster and form large populations, achieving large biomasses, thus they can enhance food production and security. However, this can only be achieved if production is well planned and appropriate technologies and strategies applied. Production and rearing of edible crickets do not require sophisticated machinery or equipment but locally available resources. There are opportunities for skills and experience transfer and as well as market opportunities from other countries such as Thailand which are more advanced in cricket farming. This study has the potential to contribute to the reduction of poverty levels and malnutrition in the project area through improved diet and income. Crickets can also be used as protein source in fish and poultry feeds thus improving income and production. Furthermore, cricket rearing and production can help in mitigating the effects of climate change and enhancing of farmers’ resilience since it is not directly affected by the poor weather conditions which affect other agricultural enterprises. It can also increase employment opportunities especially for the women who are more vulnerable to impacts of climate change.

There is a demand for healthy alternative sources of animal proteins for which crickets have shown potential to deliver. Rearing of crickets at the household levels has shown that it is resource input efficient. It is, therefore, worth determining its market chain development.

1.7 Significance of the Study

The promotion of cricket consumption is envisaged to help combat malnutrition, alleviate food insecurity and generate new sources of income in the region. The research aimed to create new interests in the role of insects as a diet and subsequently stimulate insect consumption nation-wide and promote edible cricket farming. The research will provide valuable lessons for further promotion of entomophagy in Kenya as well as generation of information and education on proper cricket farming practices.

1.8 Scope of the Study

The research was carried out at Jaramogi Oginga Odinga University of Science and Technology (JOOUST). The study specifically focused on medium scale production of edible crickets with potential for large scale production.

1.9 Definition of Terms

Adult weight	:	The point at which there is no more gain in body weight.
Growth rate	:	Changes in body weight per unit of time
Medium scale	:	A production quantity of 100kg of cricket mass per month
Period to maturity	:	The time duration it takes to attain adult weight from the experimental date

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

Insects have been in existence for tens of thousands of years and their contribution to human life cannot be underestimated (Daniella, 2014). Though some species are regarded as pests, majority have beneficial contribution to both humans and nature. Apart from being utilized as food, insects and their products have been used in textile, food, pharmaceutical industries and medical and agricultural sectors (Van Huis et al., 2013). This review seeks to draw on a wide range of scientific research on the contribution that insects make to ecosystems, diets, food security and livelihoods in both developed and developing countries.

2.1 Human Entomophagy

Human Entomophagy, refers to the practice of eating insects and is a universal cultural phenomenon (Rumpold and Schluter, 2013; Van Huis and Oonincx, 2017). Globally, edible insects are an important resource that contributes to livelihoods (Muafor, 2014; Niaba, et al., 2013; Adesina, 2012; Van Huis et al., 2013). However, its manifestation is peculiarly different among ethnic or cultural settings (Alamu, et al., 2013; Van Huis, 2013). Previous studies have reported that of the total entomophagy practised by the world's population, 80% is intentional (Srivastava et al., 2009; Premalatha et al., 2011). It has been further reported that entomophagy only differs in terms of location, type of insect and ethnic group involved (Adegbola et al., 2013).

In Asia, Africa and South America, edible insects have long been used by ethnic groups as a cheap and sustainable source of protein (Wang et al., 2005). Approximately, 1900 species of insects are eaten worldwide and majorly in developing countries, and it is estimated that about 38% of these are consumed in Africa (Adegbola, et al., 2013). Some of the popular insects eaten around the world are crickets, grasshoppers, ants, beetle grubs and caterpillar (FAO, 2013; Adesina, 2012; Braide and Nwaoguikpe, 2011). Consumption of insects can be done at all stages of their development life (Niedermann, 2014). Naturally, insects which are commonly eaten are those that can be gathered speedily in large quantities and consumed raw, cooked or used as part of ingredients (Srivastava et al., 2009).

In Asia, countries such as Thailand, Vietnam and Lao's PDR are reputed for consumption of different species of insects. Literature also reveals that 117 native insect species were traditionally used as food in Japan (Payne, 2015). Not surprisingly, today people can now find insect cuisines in restaurants in some parts of Asia and Europe (Adegbola, et al., 2013).

Entomophagy has also been reported in parts of Europe. For example, cheese maggots are considered a delicacy in Italy (Alamu, et al., 2013). Beetle larvae and grasshoppers have been eaten by Greeks and Romans (Pascucci et al., 2015). It has also been reported that some tribes in Venezuela, Colombia and South Africa prefer eating insects instead of meat (Adegbola, et al., 2013; Braide and Nwaoguikpe, 2011; Banjo et al., 2006).

Africa occupies a special place in entomophagy. It is estimated that of the 1900 edible insect species eaten in the world, 30 species are eaten in Congo, 22 in Madagascar, 36 in South Africa, 62 in the Democratic Republic of Congo, and 32 in Zimbabwe (Van Huis, 2003). In Nigeria, people consider edible insects as a main source of food and further use them for various rituals and medicinal purposes (Banjo et al., 2006). In East Africa, the long-horned grasshopper is a delicacy especially in Uganda (Ayieko, 2010). Banjo et al., (2006) also reported on the consumption of the larvae of many species of the larger beetles, termites, grasshoppers and adult lake flies in Uganda.

Several species of insects are used as food in Kenya (Ayieko, 2007; Ayieko and Oriaro, 2008). These include termites, black-ants and grasshoppers which are celebrated delicacies among the Luo, Luhya and Kisii communities of western Kenya. Available evidence indicates that the practice of eating insects is a wide spread phenomenon amongst the communities of Western Kenya (Kinyuru et al., 2012; Ayieko, 2010). It has been reported further that communities living around Lake Victoria regard termites as being suitable for children and pregnant women (Niaba et al., 2013; Kinyuru et al., 2009). Normally, the termites are considered as part of the diet when in season (Niaba et al., 2013; Kenji et al., 2012; Banjo et al., 2006). In Kenya, the Luo community prefers black ants, *Carabara vidua* (Smith) and lake flies, *Chaoborus and Chironomus spp*, because of their nutrients and belief in their medicinal value (Ayieko and Oriaro, 2008; Ayieko et al., 2012). There are several literature reports about the distribution and consumption of edible insects around Lake Victoria region of Western Kenya as well as evaluation of their nutritional profiles and the possibility to use them as ingredients in conventional food products of the community (Ayieko and Oriaro, 2008; Ayieko et al., 2012). It has been further demonstrated that no insects' eating linked toxicity catastrophe has been reported by communities in Kenya (Kinyuru et al., 2012).

2.2 Importance of Insect Farming

The history of civilization has made insect eating be viewed as ‘primitive’ and poor man’s food (Ayieko and Oriaro, 2008). However, in the recent past there has been a dramatic shift in perception, leading to a renewed and heightened interest in entomophagy (Bednarova et al., 2013). This development has been triggered by several issues such as food security, malnutrition, poverty alleviation and environmental conservation (Agbidye and Nongo, 2009; Jiri et al., 2014). 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.

2.2.1 Health and Nutritional Benefits of Insects

Recent studies have shown that insects often contain more protein, fat, and carbohydrates than the same measure of beef or fish, and a higher energy value than soybeans, maize, beef, fish, lentils, or other beans (Adepoju and Omotayo, 2014; Gahukar. 2011; Jiri et al., 2014; Pascucci et al., 2015). Insects contain a high amount of crude protein. Some insects contain more protein than meat does, for instance the house cricket (*Acheta domesticus* L.) and field cricket (*Gryllus testaceus*), have slightly superior protein to soy protein (Pascucci et al., 2015; Rumpold and Schluter, 2013; Wang et al., 2005). Tsvangirayi (2013) pointed out that the Emperor moth (Mopane worm) contains three times the amount of protein as beef. The crude protein value of *Rhynchophorus* spp. is as high as 71.6% (Braide and Nwaoguikpe, 2011). A study of 94 edible insects by Ramos- Elorduy and Pino (1990) found that 50% of the insects have higher caloric values than soya-beans, 63% were superior to beef, and 70% were better than fish and beans. Many insects have been found to contain low cholesterol and fat (Gahukar, 2011; Srivastava et al., 2009). One of the possible ways to counter protein energy malnutrition is to promote the utilization of lesser known and cheaper sources of animal proteins such as those from insects. Adegbola, et al. (2013) postulated that a 10% increase in the world supply of animal protein through the mass production of insects for food can to a large extent, reduce if not eliminate the malnutrition problems of the world as well as decrease the pressure on conventional protein sources. Furthermore, insects are herbivores and have clean eating habits which make them cleaner than chicken, pigs, and many other conventional protein sources; in fact, the grasshopper is one of the cleanest animals (Abbasi and Abassi, 2011). It can therefore be inferred that insects are not only an important source of protein but also a safe one to eat. Insect consumption has been postulated that can help manage hypertension, diabetes and obesity as well as acting as an oxidant thereby improving immunity (Roos and Van Huis, 2017).

2.2.2 Environmental Benefits of Farming Insects

Insects are more environmentally friendly and more adaptable to the climatic change. Insect farming can therefore help in mitigating the effects of climate change and building of farmers' resilience since it is not directly affected by the poor weather conditions which affect other agricultural enterprises (Ayieko, Ndonga and Oriaro, 2010; VanHuis et al., 2013). Quite often than not, most insects consumed, are harvested from the wild hence, they are mostly free from pesticide and other chemical contaminants which proliferate in places where conventional source of protein are found (Durst and Shono, 2010). Insects also convert food much more efficiently than conventional livestock and emit fewer greenhouse gases (Van Huis, 2003; VanHuis and Oonincx, 2017). Further, some insect species can be grown on organic side streams, reducing environmental contamination and transforming waste into high-protein feed that can replace the increasingly more expensive compound feed ingredients, such as fish meal (Van Huis, 2013; Adegbola, et al., 2013; VanHuis and Oonincx, 2017). When insects are generally eaten by most people in the society, especially those of them that are edible, they will not be seen as pest but rather as a conventional source of much needed protein. Consequently, the use of pesticides and other chemicals which have adverse effect on health and the environment would be reduced (Van Huis and Oonincx, 2017).

2.2.3 Economic and Livelihood Benefits of Insects

Another pertinent motivation for insect rearing arises from the fact that it is highly suitable for both rural and poor urban settlements due its small size, low-cost and low capital investment requirement (Barwa, 2009). Insect rearing uses less land and energy than most of the animal species that are conventionally used for food and agriculture (Premalatha et al., 2011). Moreover, insects grow very fast and are prolific; this makes them a potentially reliable supplier of animal protein at short intervals (Niedermann, 2014). Insect farming is posited to reduce poverty levels through creation of other employment and income opportunities for the poor populace (Van Huis et al., 2013). Studies have revealed that 29% of rural dwellers in South Africa generate their income through collection and selling of mopane caterpillars (*Imbrasia belina*), 19% and 64% of Lao PDR insect sellers see it as either a full time or part time income generating activity while in Thailand it is an economic activity for the rural populace (Halloran et al., 2017). Further still, consuming these insects might just be the panacea to the persistent malnutrition and food security especially in Sub-Saharan Africa, thereby improving the livelihoods of these populace.

The particular interest in the house cricket and field cricket is stimulated by several basic facts. First, the insects lend themselves well to mass rearing under controlled conditions and can produce six to seven generations per year (VanHuis and Oonincx, 2017). Second, both crickets are omnivorous, and preliminary studies indicated that they may have the capability of converting poultry manure into a protein-rich feedstuff for poultry on an economically competitive basis (Wang et al., 2005). Third, the crickets are easily adapted to domestic rearing and is an important source of nutrients (Van Huis et al., 2013). Therefore, sustainable management of insect as food should be of interest especially in Sub-Saharan Africa where entomophagy is not inimitable (Van Huis, 2003). Indeed, use of insects as food should be advocated for especially in Sub- Saharan Africa where food reserve shortages are rampant (Niaba et al., 2013). Despite this clear leverage of entomophagy, unsustainable exploitation of the ecosystem now threatens edible insects with extinction (Ayieko et al., 2012). This makes the case for sustainable commercial production of edible insects not only appealing but inevitable.

2.3 Insect Farming and Harvesting

Most edible insects are harvested in the wild often by women (Van Huis, 2003; Van Huis and Oonincx, 2017) and this is mostly practised by cultivators of the forest (Banjo et al., 2006). The techniques of collecting edible insects have majorly depended on insects' behaviour. For example, inactivity at low temperatures enables easy catching of locusts and grasshoppers in the morning. Night flyers such as termites and some grasshoppers can be lured into traps by light. Some insects like palm weevils can be attracted to artificially created breeding sites. Interestingly, crickets and cicadas can be located by the sound they make. Traditionally a number of tools have been used to facilitate capturing, namely; glue sticks, nets and baskets (Van Huis, 2003; Ayieko, 2010).

There have been developments in procuring edible insects world over. In Peru termites are either harvested from prickly pear plants growing in the wild or planted as live fences around houses. In Mexico cochineal are grown in environmentally controlled micro-tunnels made of transparent plastic. The most prominent examples of this can be seen in the harvesting of edible eggs of aquatic *hemipterans* from artificial oviposition sites in lakes in Mexico. In Sub-Saharan Africa deliberate cutting of palm trees in the tropics to trigger egg laying by palm weevils (*Rhynchophorus* spp.) and the subsequent harvesting of larvae has been reported. Also, manipulating host tree distribution and abundance, shifting cultivation, implementing fire regimes, managing host tree preservation, and manually introducing caterpillars to a designated area to promote the abundance of arboreal, foliage-consuming caterpillars is not uncommon. In Kenya, there has been development and testing of a modern trap for harvesting winged termites as a way of improving indigenous knowledge (Kinyuru et al., 2012). All these environmental manipulations to procure edible insects could be considered as semi-cultivation.

In more recent past, a number of edible insects have been commercially farmed for human consumption especially in Thailand (Hanboonsong et al., 2003). These include the House Cricket (*Acheta domesticus*), the Palm Weevil (*Rhynchophorus ferrugineus*) and the Giant Water Bug (*Lethocerusindicus*). Water beetles have also been farmed in China (Hanboonsong et al., 2003). However, when promoting insects as food and feed, procedures for large-scale rearing remain a challenge and hence need to be developed. This is a challenge for industries specialized in the mass rearing of insects for bio-control, sterile insect technique, and pet feed. The major issues in mass rearing are quality, reliability, and cost-effectiveness (Van Huis, 2013). Since collection and harvesting of edible insects is anchored on indigenous knowledge, interested stakeholders have raised interest on merging these knowledge and new technology to ensure reliability, sustainability and good farming practices (Ayieko et al., 2012).

Advances in extensive production systems are just emerging in many countries and rearing of edible insects is now up-and-coming as an integral component of animal husbandry and more so as one that resonates with the environment. However, insect farming has largely remained a family-going concern. Mostly, insects such as mealworms, crickets and grasshoppers are reared in large quantities, mainly as pets or for zoos in temperate areas. In recent times firms have begun to commercialize insects as food and feed. However, the fraction of production intended for direct human consumption is still negligible. In countries such as Thailand, Vietnam and Lao People's Democratic Republic, rearing of crickets for human consumption is usually done by collecting the insects from wild habitats or farming by small-scale farmers**.** Though small-scale, such activities have led to generation of significant income and employment opportunities for rural households (Hanboonsong et al., 2003).

In order to address the problem of food security, it is imperative that insect farming adopts environmentally sustainable methods. Insects ought to be made consistently available throughout the year if they are to provide the needed substitute to animal protein. This can only be achieved by developing improved conservation methods as well as by large scale insect farming, a sort of minilivestock. Given the economic, nutritional and ecological advantages of entomophagy, its promotion deserves an ever-greater attention by national institutions and assistance programmes (Van Huis, 2003). Consequently, some of the insect species, especially those with high nutritional content, should be cultivated with contemporary techniques to increase their commercial value and availability (Banjo et al., 2006).

2.4 Crickets

Crickets are cold blooded nocturnal insects of the order *Orthoptera* and fall in the family of *Gryllidae* (true cricket) (Borror, 1989). The *Orthoptera* are a large group of “jumpers” including crickets, locusts, grasshoppers, katydids and ground hoppers that can be found in most habitats. Morphologically, crickets are recognized by their jumping hind legs, three tarsal segments, and long tactile cerci bearing clumps of knobbed hairs, mandibulate mouthparts and a large prothorax (Borror, 1989; El-Damanhouri, 2011). There are several species of crickets but *Acheta domesticus* (House Cricket) and *Gryllus bimaculatus* (Field Cricket) are the most popular. These two undergo incomplete metamorphosis (Fig. 1), meaning they do not enter into a pupal stage, but hatch from the egg looking like adult crickets and live in moist or damp places under logs or rocks (JOOUST Cricket manual, 2013). Cricket nymphs undergo 10 different stages of growth called instars before reaching adulthood. Characteristically, their pair of wings is held over flat body. The female cricket has a long needle like protrusion (ovipositor) used for laying eggs in addition to two cerci and can lay up to 200 eggs at a time.

The male crickets only have two cerci at the end of their abdomen. They are omnivorous scavengers that feed on both animal and plant matter (Klassey, 2012). They occasionally exhibit or display predatory behaviour upon the crippled or weak crickets or when food source is irregular (Borror, 1989). Crickets have a sexual reproduction and males make chirping sounds by rubbing their wings to attract females during the mating season (JOOUST Cricket manual, 2013; Klassey, 2012; El-Damanhouri, 2011; Borror, 1989).

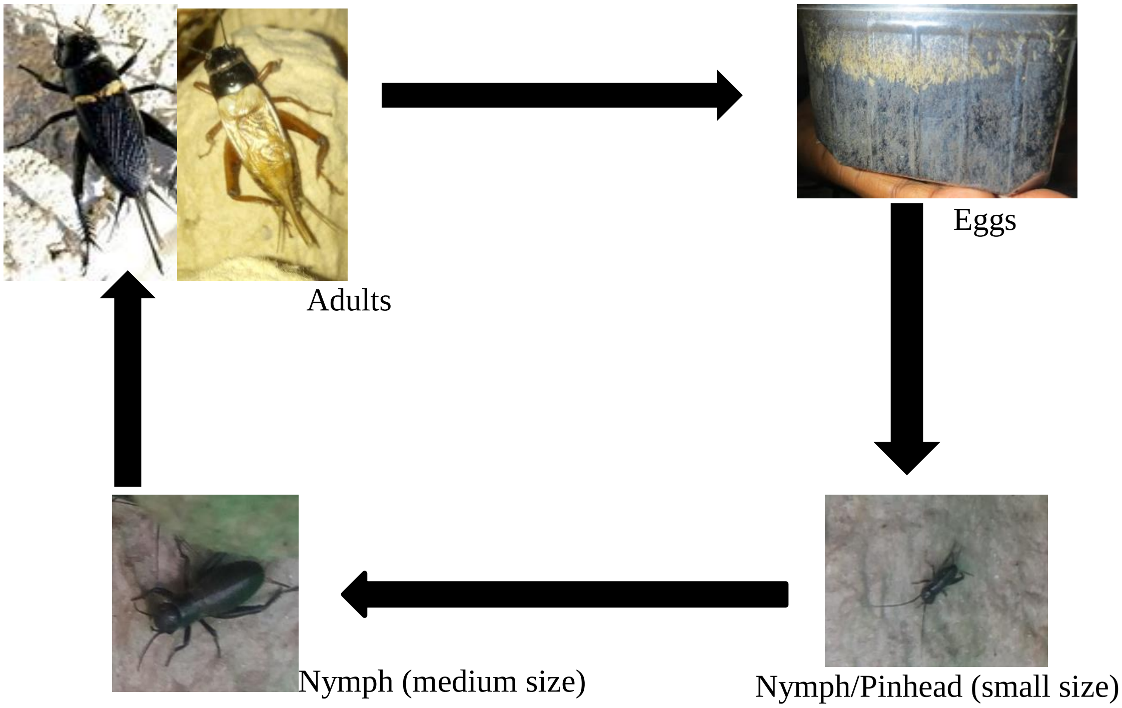

Figure 1: Cricket Life Cycle

2.5 Crickets: Rearing and Entomophagy

Crickets especially *Acheta domesticus* (House Cricket) and *Gryllus bimaculatus* (Field Cricket) have been found to be adaptable to mass rearing and produce faster due to shorter life cycle under favourable conditions (JOOUST cricket manual, 2013; Van Huis and Oonincx, 2017). Relevant stakeholders have shown interest on sustainable commercial production of edible crickets due to the aforementioned benefits. Some of the Asian countries have commercialized cricket production which now serves as a source of income and food to small and medium scale farmers; for instance, Thailand alone registered about 20,000 small scale cricket farmers in the past two decades (Hanboonsong et al., 2003). The mono Indians have used crickets' flour to bake their bread and cake while ground crickets have long shelf life and play the same role as sugar used in baking (Srivastava et al., 2009). Use of crickets as food has been investigated as an innovative source of high protein to both human beings and animals (Ayieko et al., 2012; Kinyuru et al., 2012).

Most edible insects are harvested in the wild and the practice of farming insects for food and feed is relatively new (Hanboonsong et al., 2003; FAO, 2013). The mere traditional collection from the wild habitat is seasonal and unreliable, raising the concern of sustainability (Ayieko et al., 2010). As such rearing procedures and housing for large scale production need to be developed for the cosmopolitan species, the house cricket and field cricket, considering their nutritional value, taste, ease of rearing and less greenhouse gas emissions.

The deliberate farming of edible insects for food and feed is partly the answer to the issues of sustainability. Large scale production systems have been introduced recently in many countries and rearing of edible insects is now growing (Riggi, et al., 2013). Currently, there is an emerging trend to commercialize this system of insect production (Van Huis, 2013). In Thailand and China, insects such as crickets, silkworm and cicadas are now being bred under full domestication where they are in captivity or partial domestication where their natural habitats are manipulated (Feng, Chen, Zhao, He, Sun, Wang et al., 2017). The success of such commercialization rests on the sustainability of production, a challenge that requires an appropriate housing system that is suitable for large scale insect production.

Crickets' growth and development, depends on abiotic factors; rainfall, light, relative humidity and temperature (Ogah et al., 2012; Holmes, 2010; Verbitsky and Verbitskaya, 2011) and suitability of any housing system is in its ability to maintain optimum levels of these abiotic factors specifically, temperature and relative humidity. Temperatures and relative humidity have been known to have effect on behaviour, reproductive status, survival, fecundity and physiology of poikilotherms (Tochen, Woltz, Dalton, Lee, Wiman, and Walton, 2016; Tamiru, Getu, Jembere and Bruce, 2012). However, these effects are rationally investigated by the objective on housing system. It is against this background that this study was conceived with this particular objective: To investigate the effects of housing on growth performance of common house cricket (*A. domesticus*) and field cricket (*G. bimaculatus*).

2.5.1 Temperature as a Factor in Cricket Housing

Optimum development of insects usually occurs within a range of temperatures. Most insects have a minimum and a maximum developmental temperature, below and above which, respectively, insect development ceases. Temperature as one of the abiotic factors, affect almost all metabolic and physiological processes of organisms. These include and not limited to growth, survival, reproduction, body size and population size (Kuyucu and Çağlar, 2016; Sangle, Satpute, Khan and Rode, 2015; Niehaus et al., 2011). Khalid et al. (2014); Kollberg et al. (2013) and Neven, (2000) have also reported on the dependency of development time, flight, dispersal rate and final weight on temperature. In fact, temperature more often affects organism's development than growth as observed by Forster et al. (2011); Forster and Hirst, (2012); Astuti et al. (2013).

Ectotherms, have employed different physiological and behavioral mechanisms of responding to temperature stochasticity (Kuyucu and Çağlar, 2016; Niehaus et al., 2011). Some of the behavioral mechanisms employed by insects include induction of diapauses or dormancy in insects if temperature goes beyond or below the developmental threshold (Hance, van Baaren, Vernon, and Boivin, 2007); some insects aestivate during periods of high temperatures but hibernate when temperatures are low but later resume activity when conditions are favorable (Holmes, 2010; Kuyucu and Çağlar, 2016). Crickets, as ectotherms, either respond to internal changes in temperatures behaviorally since they lack the complex neural and physiological mechanisms required to maintain a constant body temperature against changes in external temperature or adapt to environments suitable to their physiological structures (Holmes, 2010; Jaworski and Hilszczański, 2013**;** Niehaus et al., 2011; Ogah et al., 2012). Crickets may thermo-regulate by moving to microenvironments that allow them to maintain their preferred body temperature. Previous studies Neven (2000) and Niehaus et al. (2011), observed that if body temperature exceeds the limits of the cricket's enzymatic capacity, then the enzymes denature and the cricket eventually dies.

Temperatures have been reported to have effect on cricket's chirping rate which is critical in reproduction (Jang and Gerhadt, 2007), laying rate and hatching rate (Khalid *et al.*, 2014; Jaworski and Hilszczański, 2013), feeding (Adamo and Lovett, 2011; Camp *et al.,* 2015) and growth rate (Mirth and Riddiford, 2007; Niehaus et al., 2011). Though, crickets are known to adapt to diverse temperature levels, a suitable housing system should be able to maintain near optimum levels.

2.5.2 Relative Humidity as a Factor in Cricket Housing

Relative humidity has been reported to have diverse effects on different physiological processes of insects (Astuti, Mudjiono, Rasminah and Rahardjo, 2013). These effects range from desiccation, weight loss of eggs, young larvae and adults (Holmes, 2010), increased or decreased lifespan (Holmes, 2010; Tomberlin and Sheppard, 2002), increased or decreased hatching duration and laying rate (Astuti et al., 2013), feeding rate (Ogah et al., 2012), reproduction and growth rate (Tochen et al., 2016). Lu and Wu (2011) reported of significant effect of humidity on insects' survival, fecundity and development. He further observed that high relative humidity was beneficial for immature survival, adult longevity and fecundity, and population growth of *A. lucorum.* A study on the populations of African Rice Gall Midge (AfRGM) found that high relative humidity had a positive correlation with populations of African Rice Gall Midge (AfRGM) (Ogah et al., 2012). However, high humidity can also lead to high mortality due to infection by entomopathogen**s** (Li, Liu, Wang, Zhou and Si, 2014; Tochen et al., 2016). According to Child (2007), Orthoptera compensates for water loss by increasing intake of food but at the same time withstands starvation when water is in abundance. Different authors have reported different humidity levels suitable for cricket growth. While JOOUST Cricket Manual, (2013) suggests a relative humidity (RH) ranging from 60-70%, Miech et al. (2016) reported of RH of 50% with a temperature range of 29°C - 35°C.

2.5.3 Light as a Factor in Cricket Housing

Light intensity has been shown to affect insects' growth and development (Nakamura, 2003), and as such, they display different behavioral effects of light such as positive phototaxis (attraction), negative phototaxis (repulsion) and light adaption (Shimoda and Honda, 2013). Durrant et al. (2015) obseved about negative effects of constant light on the behavior and physiology of both vertebrates and invertebrates. Furthermore, changes in photoperiod have been found to influence behaviors of insects (Bertram and Bellani, 2002;) resulting into changes in growth curve, development time, adult size and to some extent interfering with life history and physiological traits of some organisms (Hammerschmidt et al., 2012; Nakamura, 2003). A high light illumination especially at night interferes with normal activities such as breeding, egg laying, male stridulation period and feeding of nocturnal insects impacting negatively on their growth curve (Bertram and Bellani, 2002; Adamo and Lovett, 2013). It further exposes them to predators (White and Shardlow, 2011). Crickets, being nocturnal insects, are expected to show negative photo-taxis i.e. show highest activity at night. Due to their nocturnal nature, the insects were provided with hide outs in this study to provide dark places or shelters during day time especially the females.

Under favourable conditions, crickets especially *Acheta domesticus* (House Cricket) and *Gryllus bimaculatus* (Field Cricket) are adaptable to mass rearing and bourgeon faster due to their shorter life cycle (FAO 2013; Van Huis,2013; Hanboonsong et al., 2003). However, when promoting insects as food and feed, efficient systems for large-scale production remain a major challenge (Grenier, 2009). An important component of large-scale insect production is a suitable housing system that can address the major issues in mass rearing such as quality, reliability, and cost-effectiveness (Van Huis, 2013). While existing literature largely focus on rearing containers/pens (Hanboonsong et al., 2003), information on housing systems is still scanty. This study, therefore, sought to investigate the effect of housing on growth performance of *Acheta domesticus* and *Gryllus bimaculatus* reared under two housing systems; tunnel unit and prefabricated house.

2.6 Cricket Feed

The need for sustainable large-scale commercial production of insects has stimulated interest in the development of artificial diets including agro-byproducts (Nation, 2002). Studies have sought to use organic side-streams in formulation of insect feed as a deliberate effort to help in waste management (Van Huis, 2013). Insects reared on various diets do not have similar growth rates and differ in developmental periods (Maklakov, Simpson, Zajitschek, Hall, Dessman, Clissold et al., 2008; Tawes, 2014). Previous studies have confirmed that feed quality in terms physical attributes such as shape, colour, smell, hardness and allelochemical influences the insect capacity to consume and digest feed substrates (El-Damanhuri, 2011 and Leblanc, 2012; Lemoine and Shantz, 2016).

Previous studies on the effects of feed on growth performance of insects and specifically crickets have yielded different results. El-Damanhouri (2011), Zajitschek et al., (2009) and Zillion, (2012) observed that crickets fed on a high proteinous feed took a shorter period to reach adulthood as compared to the ones fed on a low proteinous feed. Similarly, El-Damanhuri (2011) found out that *G. bimaculatus* took a shorter period to reach adulthood when fed on a high protein food. However, optimization of weight gain, reproductive performance and life span of adult field crickets, *G. veletis*, on diets with different combinations of protein to carbohydrates ratios, revealed preference for diets with low protein-carbohydrate ratios as they seemed to maximize on both life span and reproductive performance (Harrison, Reubenheimer, Simpson, Godin, and Bertram, 2014). Megido, Alabi, Nieus, Blecker, Danthine, Bogart, Haubrugea and Francisa (2016) observed that carbohydrate and fat rich diets produced heavier insects compared to the protein rich-low carbohydrate diets that were sub- optimal for cricket growth. El-Damanhuri (2011) and LeBlanc (2012) observed that crickets fed on high or too low-fat feed for a long period had reduced body weight due to oxidative stress and failure to compensate for the inadequate nutrients. Lundy and Parrella (2015) reported up to 99% mortality in crickets reared on diets containing purely grain straw. However, diets high in yeast-derived protein have been reported to shorten larval development time, reduce mortality and increase weight gain when fed to edible mealworms (Broekhoven et al., 2015). The findings from these studies underscore the critical role of feed type and quality in cricket growth and development.

Cricket feeding is an important component of the production process especially for the caged crickets and that insects reared on various diets do not grow at equal rates and differ in developmental periods (El-Damanhouri, 2011). Further still, growth, mortality, development, and reproduction of insects depend on the food quality (Lyn et al., 2010; zillion, 2012; Stahlschmidt and Adamo, 2015; Lundy and Parrella, 2015; Zajitschek et al., 2009). The omnivorous nature of crickets enables it to select feed from both animal and plant sources (Tawes, 2014; El-Damanhouri, 2011; Klassey, 2012. Key components of the cricket feed should be calcium, which is essential due to moulting, protein which provide amino acids that are assembled into structural tissues and enzymes and carbohydrates as source of energy (Klassey, 2012). Crickets should be fed on adequate and high nutritious foods to enable them survive and breed and will continue to unremittingly eat until their daily protein requirements are met (Hallet, 1995). Crickets are generally fed on a watery or fresh source of food as well as on high protein food such as chicken mash (Megido et al., 2016), however, it is costly (JOOUST manual, 2013 and Hansboong et al., 2003) and this calls for identification of locally available, nutritious and less costly cricket feed.
It is against this background that the study was conceived to identify locally available, nutritious and less costly cricket feed. The study specifically sought to evaluate the growth performance of Common house cricket (*Acheta domesticus*) and Field cricket (*Gryllus bimaculatus*) fed on different agro-byproducts.

2.6.1 Requirements for Specific Nutrients

Proteins

Proteins are important part of the insect diet as they provide amino acids that are assembled into structural tissues and enzymes (El-Damanhouri, 2011), enhances growth and longevity, reduces nymphal mortality, maturation of ovaries and eggs (Nation, 2002). The requirement of optimal protein in the diet, differs with age, sex and physiological stress.

Carbohydrates

Carbohydrate is a major source of energy, though insects do not require it in absolute for growth since it can be synthesized from amino acids and lipids (Nation, 2002). The carbohydrate composition of the haemolymph (blood sugar), trehalose, is greatly influenced by the diet **(**El-Damanhouri, 2011). It is stored in the fat body mainly in the form of glycogen, which can be rapidly hydrolyzed into a readily useable form of energy, trehalose. Utilization of carbohydrates as source of energy is mostly during metamorphosis due to metabolic interconversions (El-Damanhouri, 2011), flight in *Hymenoptera, Diptera* and *Blattoidea*, egg maturation especially in cockroach, *Leucophaea maderae* (Nation, 2002) and male stridulation in crickets (Maklakov et al., 2008; Harrison et al., 2014).

Lipids

Lipids, especially the neutral lipids are important sources of energy for insects (Nation, 2002; El-Damanhouri, 2011). The amount and the composition of lipids in an insect vary considerably between developmental stages and tissues, and are influenced by several factors, including starvation, sex, hormones, and nutrition (Nation, 2002; Tawes, 2014). They play key roles in insect biochemistry as sources of energy, structural components and as hormones. Insects utilize lipids efficiently for development and growth, reproduction and flight. The most critical lipid required in the insect diet is sterol that is useful in moulting and as a component of cell membranes (Nation,2002). Some insects such as *A. domesticus* and American cockroach *Periplanea americana* are able to synthesize polysaturated fatty acids. Although lipids are a requirement in the diet of insects, most of the lipids can be synthesized from carbohydrates and stored in the fatty body tissues.

Vitamins

Studies of insect vitamin requirements have yielded diverse and conflicting results. Some studies have shown that insects require thiamine, riboflavin, folic acid, choline, biotin and pantothenic acid (Nation, 2002). Studies have shown that water soluble vitamins such as ascorbic acid is a requirement for growth and development in some insects particularly the phytophagous insects, vitamin A is required by house flies, *Musca domestica*, and tobacco hornworms, *Manduca sexta*, for normal structure of the eye and *Schistocerca gregaria* for normal body pigmentation (Nation, 2002). While vitamin B12 is necessary for egg viability in *Blattella germanica*; vitamin E is an important element in spermatogenesis in male *A. domesticus* and maturation and ovipositioning of eggs in female *Cryptolaemus montrousieri*. Vitamin K has been reported to have some positive effect on crickets, a part from acting as phagostimulant in honey bees (Nation, 2002; McDonald et al., 2011). The requirements of vitamins in the diet of insects are not limited to growth, viability of eggs, normal pigmentation and eye functioning, adult maturity, ovipositioning of eggs and spermatogenesis, but they also act as phagostimulant.

2.6.2 Evaluating the Nutritional Quality of a Diet

Different criteria have been postulated for evaluating quality and suitability of diets of insects be it in immature or adult stages (Nation, 2002). From previous studies, measurement of growth rate has been frequently used to evaluate nutritional quality of diets by majority of the researchers (Nation, 2002; Megido et al., 2016; Lundy and Parrella, 2015). However, it should be augmented by measurement of weight gains (Megido et al., 2016), time between molts or to pupation, time to adult emergence, percent successful pupation or hatched eggs, number of eggs laid, longevity of adults (Lyn et al., 2010) and time to sexual maturity which are all influenced by nutrition (Nation, 2002).

2.6.3 Use of Agro-byproducts as Cricket Feed

Agro-by products form part of waste products from the agricultural industrial activities. The interest on proper waste disposal has triggered research on their alternative uses (Oonincx et al., 2015). Though they have been useful as feed in macro livestock enterprises, their suitability as insect feed has not been sufficiently studied.

Brewery by-products can be potentially valuable resources for agriculture. Spent barley grain, hops and surplus yeast are the major by products. Spent grain has the most value because of its high levels of sugars and proteins (Ben-Hamed, Seddighi and Thomas, 2011; Levic, Djuragic, Sredanovic, 2010). As these are by products rather than waste products, they can be recycled and reused in the food and agricultural industries (Aliyu and Bala, 2011). Wet Brewery spent grain (WBSG) is the material that remains after grains have been mashed to extract starch and sugars during the beer making process. These materials are always fed to cattle in the wet or dried form (Levic, Djuragic, Sredanovic, 2010). Traditionally spent grain is a valuable supplement to existing feed due to its high protein content. It is also a good source of dietary fiber, though this leads to low digestibility in Orthoptera (Ben-Hamed, Seddighi and Thomas, 2011). Presently, use of brewers' yeast is relatively limited to feed as it is very palatable and offers a good source of protein (Levic et al., 2010). Brewers’ yeast characteristically contains increased or high crude protein concentrations. In a study by Kim, Kim, Lee, Yoo and Kim, (2016), wheat bran with 30% and 50% brewer’s waste was found to be a good potential as a feed supplement for rearing mealworms and had positive effects on larval growth of mealworm because of its high nutrient contents for feed formulations.

Rice bran is a by-product of rice milling industry. This material is obtained from the outer layers of the rice caryopsis and consists of fine particles of pericarp, seed coat, nucleus, embryo, aleurone layer and part of sub-aleurone layer of the starchy endosperm obtained from the polishing of brown rice (Shaheen, Ahmad, Anjum, Syed and Saeed, 2015). It is a good source of metabolizable energy, fat, vitamin B (Rezaei, 2006) and lysine and methionine and can be an effective material to supplement the lysine and methionine deficient foods such as wheat, maize and sorghum (Shaheen, et al., 2015). The major carbohydrates of rice bran are cellulose and hemi-celluloses. These types of carbohydrates are indigestible by some insects (Miech et al., 2016; Aliyu and Bala, 2011; Levic et al., 2010; Cruz et al., 2005). In addition, starch is also present due to breakage of endosperm during milling but the quantity of starch varies according to the amount of breakage and degree of milling (Shaheen, et al., 2015).

Bloodmeal is a by-product of slaughter house and it is used as a source of protein in the diets of most animals both ruminants and non-ruminants (Makinde and Sonaiya, 2011). It is very rich in lysine, arginine, methionine, leucine, cystine but poor in isoleucine and glycine (Makinde and Sonaiya, 2011; Khawaja, Khan and Ansari, 2007; Seifdavati et al., 2008). It can compensate for lysine and methionine deficiencies in vegetable protein diets, however, its characteristic smell deters intake (Seifdavati et al., 2008).

All these qualities of agro by products such as high protein contents, being cheaper than traditional feed ingredients make them suitable and economically alternative source for consideration as feed. This suitability can only be economical and sustainable if their conversion in biomass of the insects is efficient, an element that will be explored in this study.

2.6.4 Feed Intake and Utilization

Food utilization efficiency is the standard by which insects can be assessed for physiological responses to food consumption (Nation, 2002)**.** Understanding feed conversion efficiency is an important aspect in insect production due to increasing costs of large or mass rearing (Nation, 2002). It demonstrates both the economic feasibility and the environmental impact of rearing insects (Van Huis and Oonincx, 2017). It further helps identify the reasons for changes in growth rate and developmental time, such as those related to changes in nutritional quality of food. This is helpful to farmers in selecting insect species that maximizes weight gain per unit of food consumed (Spang, 2013). It further still expounds on the quality of the ingested food which translates to nutritional components of the insect (Kulma, Plachý, Kouřimská, Vrabec, Bubová, & Adámková et al., 2016), because even though the digestibility of a particular food may be good, it may not be readily converted to body mass or substance due to imbalance in nutrients

Quantification of food utilization in insects can either be arithmetic or geometric approach. Arithmetic approach calculates mean insect weight while geometric multiplies the initial and final weights and then computes the square root of the product (Nation, 2002). Several experimental measurements and procedures for measuring food utilization efficiency by insects have been postulated and developed by researchers. The most commonly used procedures are: Feed Conversion Ratio (FCR), Approximate digestibility (AD), Efficiency of conversion of digested food (ECD), and efficiency of conversion of ingested food (ECI). FCR shows the efficiency with which the insect is capable of transforming feed consumed in body mass. The higher the FCR, the poorer the conversion. ECI is a direct measure of body mass gained relative to the amount of food ingested (total consumption) and is expressed on dry matter basis, whereas ECD ignores food that passes through the insect undigested, though it measures the amount of food energy devoted for physiological maintenance (Nation,2002). Approximate digestibility is ability of the insect to digest feed and is expressed as a percentage as follows (Shntibala,Nonita andSingh, 2002).

$$\text{Approximate Digestibility (AD)} = \left(\frac{(\text{Dry weight of food ingested} - \text{Dry weight of feces})}{\text{Dry weight of food ingested}}\right) * 100$$

$$\text{Efficiency of Conversion of Ingested food (ECI)} = \left(\frac{\text{Weight gained}}{\text{Dry weight of food ingested}}\right) * 100$$

Efficiency of conversion of digested food (ECD) is calculated as;

$$\left(\frac{Weight\ gained}{Dry\ weight\ of\ food\ ingested - Dry\ weight\ of\ feced}\right) * 100$$

All these measurements are dependent on food type, age, gender and developmental stage of the insect. They may reach high values towards ecdysis or in younger insects due to pressure of survival.

2.7 Growth Measurement in Insects

Growth is the consistent and ongoing transformation of acquired resources and energy from the environment by the insects in to biomass. Crickets experience determinate growth due to their exoskeleton meaning, moulting and increases in biomass stops at adulthood (Maino and Kearney, 2015). Several methods have been suggested to measure this increase in size or biomass so as to determine growth rate. One method is using linear measures such as the head capsule width or body length. This is only suitable when weighing directly is not possible or technically undesirable (Costa and Gomes-Filho, 2002). Though technically feasible, this method was not suitable for our study because it either required that the insects be immobilized or killed. Further still, measuring of growth as a body length depends on the body part being measured, however, these body parts can either go through isometric or allometric growth. This might create discrepancies and inconclusive measurements.

The other method is measuring growth as an increase in biomass. This can be done by weighing the insects either singly or in groups over a specified time interval and then calculating weight increase per time interval. The study used the last method in calculating growth rates as it seemed to give consistent results and is widely and universally used.

2.8 Efficiency of Production

Efficiency is the measurement of how efficient an organization uses its resources to produce outputs (Asmare and Begashaw, 2018). It can further be defined as 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 (Baten and Hossain, 2014; Hepelwa, 2013; Yegon, Kibet and and Lagat, 2015). It is the relationship between or ratio of output to input used (Coelli et al., 2005) and can be assessed in terms of technical and allocative efficiency. Attainment of efficiency depends on the necessary and sufficient conditions that must be met by the firm or the economic agent under consideration. The necessary condition is only achieved if there is no any other way of 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; Mignouna, Manyong, Mutabazi, Senkondo and Oleke, 2012).

2.8.1 Technical Efficiency

The technical efficiency (TE) is defined as the ratio of the firm or the farmer actual production to the optimal output. It occurs when farmers are obtaining the maximum output given certain inputs of production (Baten and Hossain, 2014; Hepelwa, 2013). 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 output is less than optimal output or the frontier output (Muhammad, 2016). Technical efficiency, a structural transformation of the production function by use of new inputs and techniques of production, can either be output oriented or input oriented (Hassan, Kamil, Mustafa and Baten, 2012; Taru, Lawal and Tizhe, 2011). A technically efficient firm should be operating on the boundary of its production possibilities frontier.

2.8.2 Technical Efficiency Measurement

Measuring efficiency is of paramount importance as it leads to resource savings which have impacts on farm management and policy formulation (Taru, Lawal and Tizhe, 2011). Resource-use efficiency measures are important indicators of the competitiveness and viability of any agricultural activity and hence the economic performance of any technology and producer (Otieno, Hubbard and Ruto, 2014). The efficiency levels can be used to select the most cost-effective input use options and to determine the magnitude of gains that could be obtained by improving efficiency of the existing production technologies (Yegon et al., 2015; Otieno et al., 2014). The process of measurement attempts to identify those factors that are farm specific which hinder production along the frontier (Muhammad, 2016; Mignouna et al., 2012). It also indicates the extent to which the small holder farmers use their available potential and inputs in agricultural activities (Ilembo and Kuzilwa, 2014). It further helps raise productivity by improving the efficiency of the available resources and technology particularly in the economies where resources are scarce and the modern technologies are difficult to apply (Muhammed, 2016).

A number of methodologies have been developed in order to empirically apply the concept of technical efficiency. This can be through non-parametric or parametric approaches (Hassan et al. 2012). Non-parametric approaches include Data envelopment analysis (DEA) and Free Disposal Hull (FDH). DEA is the popular approach and was originally used to measure efficiency performance in non- government organizations, however its application has now been extended to other sectors (Coelli etal., 2005; Bezat, 2009). It applies the weighted sums of input to outputs to measure the technical efficiency (Galluzo, 2018). The most common technique has been to compare the behaviour of the best practice firms with other firms which is non-parametric. This, essentially, entails the use of linear programming to estimate a frontier production function of the most productive firms (Nyekanyeka, 2011; Chepngetich, Nyamwaro, Bett and Kizito, 2015; Zamanian et al., 2013; Coelli et al., 2005). Therefore, the relative technical efficiency of other firms can then be determined by comparing their performance to that of the best practice firms. The problem with this is reliance on outlier firm for computation of frontier function which may not reflect the true efficiency of the other firms (Djokoto, 2012; Zamanian et al., 2013). Secondly, a part from its ability to measure efficiency of several inputs and outputs of economic agents with less restrictive assumptions, it reports statistical noise as inefficiency thus lowering technical efficiency (Hassan et al., 2012; Plastina and Lence, 2018).

The other approach of estimating technical efficiency is a parametric approach which might take the form of Stochastic Frontier Analysis (SFA), Distribution Free Approach (DFA) and Thick Frontier Approach (TFA) (Hassan et al., 2012). In all the three, the frontier is defined by a set of explanatory variables, a statistical noise and inefficiency. DFA is mostly applicable in panel data, TFA does impose any distributional assumption on the error term but assumes that inefficiency is variable between the highest and lowest ranks or quantiles (Skevas, Emvalomatis and Brummer, 2017). SFA is the most used approach because of its potential of separating the effects of error from the effects of inefficiency and confound the effects of misspecification of functional form with inefficiency, but still generate acceptable results only for a single output as against multiple inputs (Hasan, Kamil, Mustafa and Baten, 2012; Mburu, Ogutu and Mulwa, 2014; Orea and Wall, 2017; Cillero, Thorne, Wallace, Breen and Hennessy, 2018). It has been used in the analysis of inefficiency of agricultural systems because agricultural production is associated with uncertainties and prone to exogenous shocks (Gichimu, Macharia and Mwangi, 2013; Mailena, Shamsudin, Radam and Mohammed, 2014; Orea and Wall, 2017; Cillero et al., 2018). It uses both Ordinary Least Squares (OLS) production function and deterministic production frontiers. OLS fits data through the centre of the data and assumes all firms are efficient while deterministic fits frontier over the data and assumes there is no data noise or all errors are to be due to technical inefficiency. This study therefore, used stochastic frontier analysis in determining the technical inefficiency of cricket production due to the aforementioned advantages.

Increase in agricultural productivity which is seen as a solution to the persistent food insecurity especially in Sub Saharan Africa (Muhammad, 2016), can only be sustained if the smallholder farmers are utilizing their available scarce resources efficiently (Obare, Nyagaka, Nguyo and Mwakubo, 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).

2.8.3 Conceptual Framework

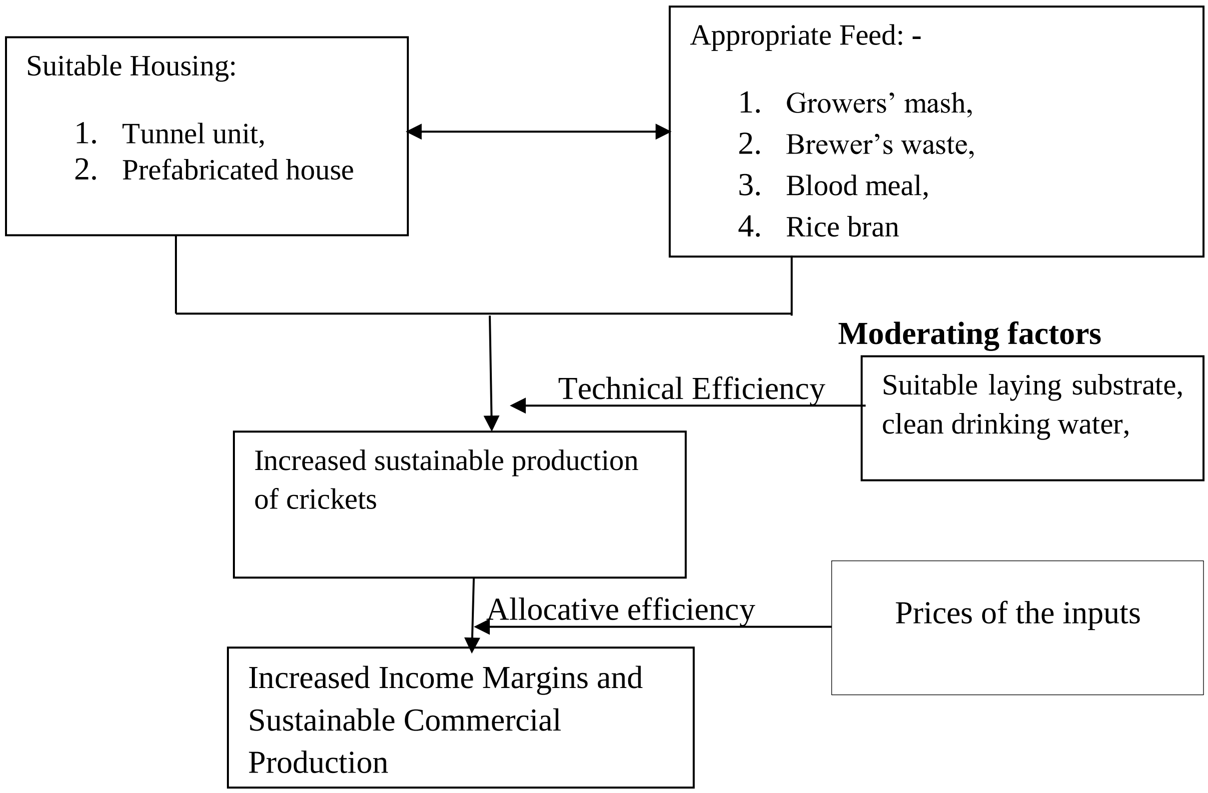

Figure 2: Conceptual Framework

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

The relationship between increased production of crickets, suitable cage and appropriate feed can be conceptualized at a fairly general level, as depicted in the Figure 2. A series of relationships emerge in this consequential development. It is postulated that suitable house will interact with appropriate feed as two sets of causal factors that will lead to increased production of crickets. It is however, recognized that interaction between feed and house is likely to be influenced by modifying factors such as suitable laying substrate and clean drinking water. It is envisioned that increased production of crickets will only be sustainable if the production is economically efficient. It is, however, hoped that increased production will translate to increased income margins for the farmers leading to continued rearing of the crickets.

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CHAPTER THREE: METHODOLOGY

3.1 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 22.5ºC and evaporation varies between 2000 mm and 2200 mm annually (DEAP, 2007).

3.2 Material*s*

3.2.1 Cricket Species

Fourteen-day old crickets of *Gryllus bimaculatus* and *Acheta domesticus* were obtained from the Edible Crickets' Project at Jaramogi Oginga Odinga University of Science and Technology (JOOUST) to ensure strain purity. The choice of the species was prompted by their availability within the study area.

3.2.2 Cricket Feed

Four different agro-byproduct feeds used were obtained locally. Grower's mash and dried bloodmeal were procured from the local agro-vet shops, brewer's spent yeast and grain were sourced from the Kenya Breweries Company and rice bran was obtained from the Dominion Farms Limited.

3.2.3 Housing

Two housing types were used in the experiment: a tunnel house (Fig. 3), measuring 8m x 15m and a prefabricated house (Fig.4) measuring, 7m x 7m x 5m, and completed with netting material and iron sheets on the sides and ordinary iron sheets on the roof. The crickets were reared under the prevailing climatic conditions, that is, there was no control of temperature and relative humidity.

Figure 3: Tunnel house **Figure 4: Prefabricated house**

3.3 Effects of Housing on Growth Performance of Common House Cricket (*Acheta domesticus)* and Field Cricket *(Gryllus bimaculatus)*

3.3.1 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. The experiment was carried out for ten and twelve weeks for *Gryllus bimaculatus* in the tunnel house and the prefabricated house respectively, and sixteen weeks in both housing types for *Acheta domesticus* due to its slow growth. Temperature and relative humidity profiles were recorded by HOBO data loggers (U12-012 RH/TEMP; Onset Computer Corp., USA) which were placed in both housing units.

3.3.2 Data Collection

Samples of 50 insects were randomly taken from each bucket and weighed using electronic scale, Model Kern (PFB), capacity of 200grams, on a weekly basis. Two parameters, the period to maturity and weight at adult stage, were also recorded. The period to maturity was the time taken to attained the mature body weight whereas mature weight was the point at which the crickets were not gaining any more weight. Growth rate was defined as change in weight associated with unit change in time and was computed as

$$\text{Growth rate} = \frac{\text{Weight at maturity(g)}}{\text{Time (weeks)}}$$

3.3.3 Statistical Model and Analysis

Shapiro-Wilk test and Levene's test were used to check for normality of data and homogeneity of variance respectively. Results from the two tests were both non- significant indicating normality and homogeneity of the data and variance. A two-way ANOVA was used to analyze the effects of housing and species on growth rate of the crickets. The following statistical model was used:

$$Y_{ijk} = \mu + S_i + H_j + (SH)_{ij} + \varepsilon_{ijk} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where,

μ is the overall mean.

Y_{ijk} is the growth rate of the k^{th} insect of the i^{th} genetic group from the j^{th} housing unit.

S_i is the effect of the i^{th} genetic group

H_j is the effect of the j^{th} housing unit.

$(SH)_{ij}$ is the interaction between genetic group and housing unit.

ε_{ijk} is the random error

3.4 Growth Performance of Common House Cricket (*Acheta domesticus*) and Field Cricket (*Gryllus bimaculatus*) Fed on Agro-byproducts.

3.4.1 Experimental Design

The crickets were reared in 100L plastic buckets which were housed in a tunnel unit of size 8m x 15m in a Randomized Complete Block Design (RCBD). Each of the two species were given the four different types of feed. The experiment comprised of four treatments namely; rice bran +blood meal (RBBM), rice bran+ spent grain (RBSG), rice bran +spent yeast (RBSG) and grower's mash (GM) as the control. Each bucket was stocked with 200 crickets. The buckets were covered with a mosquito net to prevent entry of predators and 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 three days. To prevent anxiety, egg trays (29cm x 29.5cm) were placed vertically in the buckets to act as hide-outs. 100g of each feed was placed in the buckets. The feed was provided *ad-libitum* for a week. The experimental diets were fed singly and not as a ration.

The crickets were left to self-select between the two feed types within each experimental unit. Data on amount of feed consumed was recorded weekly and unconsumed feed was replaced. The experiment which was replicated three times, was carried out for ten weeks for *G. bimaculatus* and seventeen weeks for *A. domesticus* due to difference in growth rates. Temperature and relative humidity profiles were recorded by a HOBO data logger (U12-012 RH/TEMP; Onset Computer Corp., USA) which was placed in the tunnel unit.

3.4.2 Data Collection

A batch of 50 crickets were randomly sampled and weighed using Model Kern (PFB, capacity of 200 grams) weighing scale on a weekly basis until the crickets attained adulthood, when there were no increases in bodyweight. The measures of growth were growth rate and adult weight (weight at maturity). The growth rate data was generated by the formula below:

$$\text{Growth rate } = \frac{\text{Weight at maturity(g)}}{\text{Time (weeks)}}$$

3.4.3 Statistical Model and Analysis

Shapiro-Wilk test and Levene’s test were used to check for normality of data and homogeneity of variance respectively. Both results from the two tests were non- significant indicating normality and homogeneity of the data and variance. Analysis of variance (ANOVA) was used to determine whether there were significant differences in the mean growth rates of the four groups. Tukey HSD was subsequently used to separate the means. The following linear statistical model was used:

$$Y_{ijk\,=}\ \mu + S_i + F_j + (SF)_{ij} + \varepsilon_{ijk}\text{--}(2)$$

where,

μ is the overall mean.

Y_{ijk} is the growth rate of the kth insect of the ith genetic group fed on the jth feed type.

$S_i$is the effect of the ith genetic group

F_j is the effect of the jth feed type.

$(SH)_{ij}$ is the interaction between genetic group (species) and feed.

ε_{ijk} is the random error

3.5 Analysis of Technical Efficiency of Cricket Production

3.5.1 Data Types and Collection

The endogenous and exogenous data used in the study 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 2015-2016. The exogenous variables were inputs used in the production: feed, cotton wool and labour (Table 2).

Table 2: 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 -
Cottonwool	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 unit	Two units, 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 –

3.5.2 Empirical Modelling

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

$$q = f(x_1, x_2, \ldots, x_N) + v \tag{3}$$

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: $$\mathbf{Y}_i = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1\mathbf{x}_i + \mathbf{v}_i \tag{4}$$

Deterministic: $$\mathbf{Y}_i = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1\mathbf{x}_i - \mathbf{u}_i \tag{5}$$

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

SFA: $$\mathbf{Y}i = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1\mathbf{x}_i + (\mathbf{v}i - \mathbf{u}_i) \tag{6}$$

Where;

Yi= output of the i^th^ firm

$\boldsymbol{\beta}_0$ = is the constant

$\boldsymbol{\beta}_{1=}$vector of unknown parameters

$\mathbf{x}_{i=}$ vector containing the logarithms of inputs

$\mathbf{v}_\mathbf{i}$ = “noise” error term – symmetric (normal distribution). It represents changes in technical efficiency estimates unaccounted for by changes in the independent variables.
$\boldsymbol{u}_\mathbf{i}$ = “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 $\boldsymbol{v_i}$**.** The $\boldsymbol{u}_\mathbf{i}$’s are identically and independently distributed non-negative random variables. Lastly, it was assumed that $\boldsymbol{v_i}$ and $\boldsymbol{u_i}$ 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 numbers 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;

$Y_i = \exp^{(\beta 0 + \beta 1lnx1i + \beta 2lnx2i + ...\beta nlnxni)} \exp^{(vi)} \exp^{(- ui)}$-----------------------------------(7)

This can be log-linearized by taking the natural loge of both sides, resulting into equation 8.

or $\ln Yi = \ln\beta_0 + \beta_{1ln}x_{1i} + \beta_{2ln}x_{2i} + ...\beta_{nln}x_{ni} + vi - u_i$-----------------------------------(8)

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

$\ln Yi = \ln\beta_0 + \beta_{1ln}x_{1i} + \beta_{2ln}x_{2i} + ...\beta_{nln}x_{ni} + \varepsilon_i$--(9)

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; Djokoto, 2012).

Variables that affected technical efficiency of cricket production was estimated by the inefficiency model specified by Battesse and Tessema (1992) and Coelli et al. (2005) as shown in equation 10;

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

$$\mathrm{TEi} = \frac{\exp(\beta 0\ +\ \beta 1\mathrm{lnx1i}\ + \beta 2\mathrm{lnx2i}\ + \cdots . \beta \mathrm{nlnxni}\ +\ \mathrm{vi}\ -\ \mathrm{ui})}{\exp(\beta 0\ +\ \beta 1\mathrm{lnx1i}\ + \beta 2\mathrm{lnx2i}\ + \cdots . \beta \mathrm{nlnxni}\ +\ \mathrm{vi})}$$

$TE_i = \exp(-u_i)$ -- (10)

This measure of efficiency is between zero and one. If $u_i = 1$ 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 $u_i <1$ 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 11 below.

$$-u = \sum_{i=1}^{n} \alpha izi + wi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

where -μ was the inefficiency component, zi is a vector of non-farm-variables affecting inefficiency which were: species, scale of operation, housing type and experience, αi is the parameters 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.

3.5.3 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 of 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 was necessary for the efficiency and consistency of the estimates.

CHAPTER FOUR: EFFECTS OF HOUSING ON GROWTH OF COMMON HOUSE CRICKET (*Acheta domesticus*) AND FIELD CRICKET (*Gryllus bimaculatus*)

4.1 RESULTS OF THE ANALYSIS

4.1.1 Summary Statistics of Relative Humidity and Temperature by Housing Type

Relative Humidity (RH%) and temperature profiles of both housing systems are shown in Table 3. Highest Relative Humidity and temperature readings were recorded in prefabricated house and tunnel unit respectively. Mean RH% and temperatures were 60.27% and 27.61°C and 62.79% and 25.94°C in a tunnel house and prefabricated house respectively.

Table 3: Relative humidity and temperature profiles by housing type

Parameters	Tunnel House	Prefabricated House
Relative Humidity (%)		
Maximum	88.50	96.19
Minimum	13.508	15.92
Average	60.27	62.79
Standard Deviation (SD)	17.62	22.40
Temperature (°C)		
Maximum	51.50	43.70
Minim um	16.77	17.11
Average	27.61	25.94
Standard Deviation (SD)	8.65	5.92

An independent t-test carried out to determine if there were significant statistical differences in temperature and humidity profiles between the two housing types showed that the mean temperature and humidity profiles were statistically different between the two housing types. Prefabricated house recorded a significantly lower mean temperature (25.94°C) than tunnel house (27.61°C), *t*, (21125) = 16.36, P<0.000). At the same time, tunnel house recorded lower mean relative humidity (60.27%) than the prefabricated house (62.79%), *t*, (21125) = -9.08, P<0.000).

4.1.2 Mean Feed Intake and Body Weights by Housing Type

A higher feed intake was recorded in a tunnel house than the prefabricated house for both species (Table 4). *G. bimaculatus* consistently consumed more feed than *A. domesticus* within the two housing systems.

Table 4: *G. bimaculatus* and *A. domesticus* mean feed intake per house

Housing type	Species	Mean Feed intake	P-value
Tunnel House	*G. bimaculatus*	24.86±2.4 g	0.0000
	A. domesticus	7.51± 0.7g	
Prefabricated house	*G. bimaculatus*	15.62±1.1 g	0.0000
	A. domesticus	5.61±0.5g	

Mean adult weight of *G. bimaculatus* in the tunnel and prefabricated houses was 0.746±0.05g and 0.629±0.05g and of *A. domesticus* was 0.271±0.03g and 0.322±0.03g respectively. Higher weight gains were recorded in the tunnel house by *G. bimaculatus* and prefabricated house by *A. domesticus*.

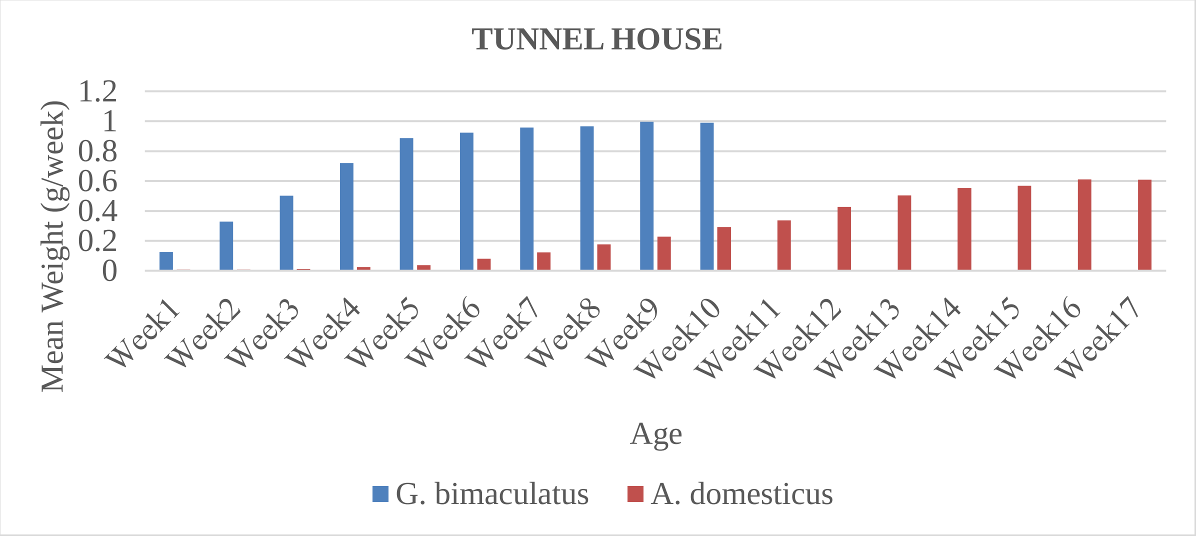


Figure 5: Trends of growth by age (weeks) in a tunnel house

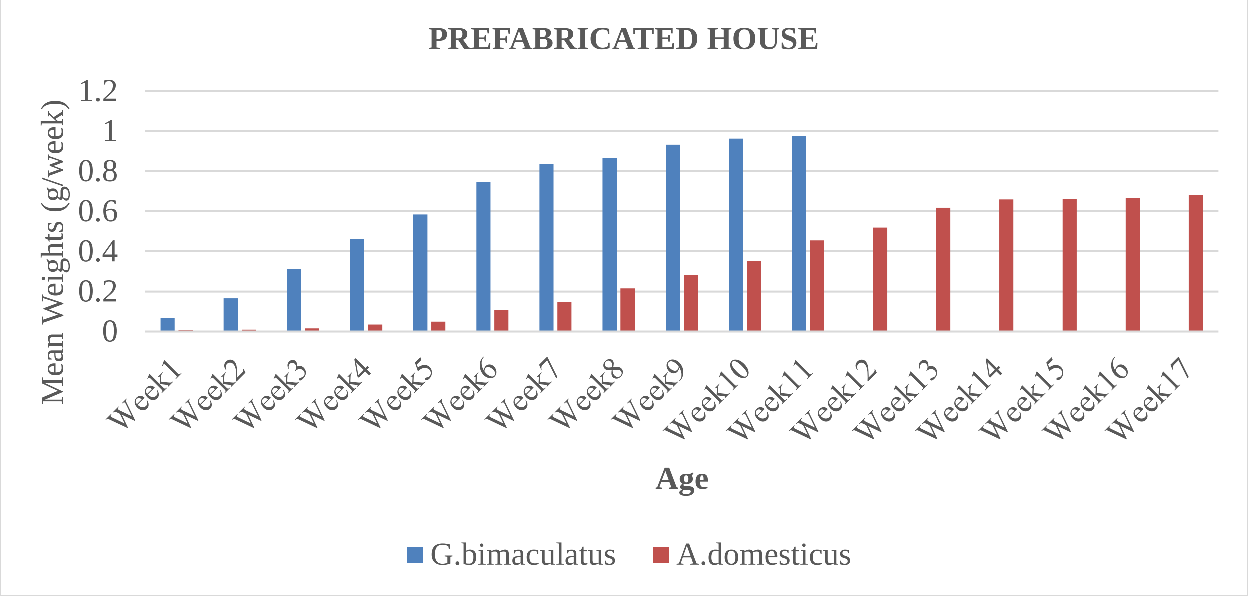


Figure 6: Trends of growth by age (week) in a prefabricated house

Body weight gain by week in each house is set out in Figures 5 and 6. The peak weight gain in the tunnel house was recorded in week 9 and 16 for *G. bimaculatus* and *A. domesticus* respectively, while in the prefabricated house, peak weight gains were recorded in week 11 and 16 for the two species correspondingly. *A. domesticus* had the same developmental time (16 weeks) within the two types of houses though a higher growth rate was recorded in the tunnel house (Fig.7 and 8).

On the other hand, *G. bimaculatus* had a shorter developmental time to maturity (10 weeks) in the tunnel house compared to the prefabricated house. *G. bimaculatus's* growth rate peaked in week 3 in the tunnel unit and week 5 in the prefabricated house (Fig. 7 and 8).

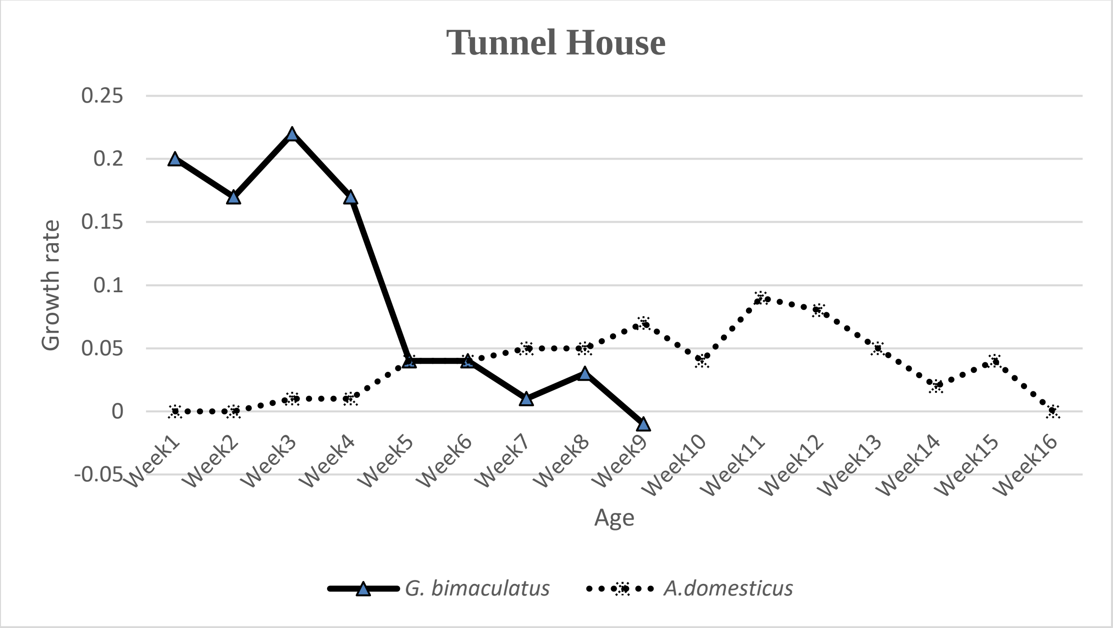


Figure 7: Growth rate trends by age (weeks) in a tunnel house

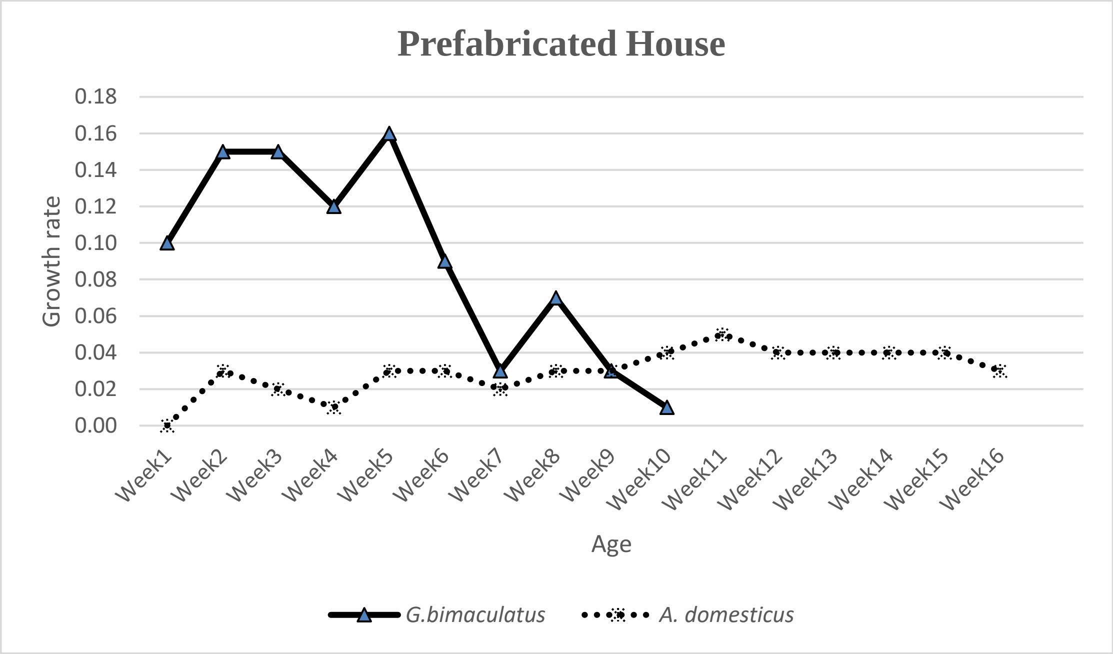


Figure 8: Growth rate trends by age (weeks) in a prefabricated house

4.1.3 Stages of Growth and Development by Species and Housing Type

Other indicators of growth are as presented in Table 5. In the tunnel house, sex notification was recorded in week 2 and week 6 while wing formation was noticed in week 3 and week 8 for *G.*

bimaculatus and *A. domesticus* respectively (Table 5). Adult emergence and start of chirping was recorded in week 4 and week 10, start of laying was observed in week 5 and week 11 respectively**.**

The prefabricated house recorded sex notification in week 2 for *G. bimaculatus* and week 7 for *A. domesticus*. Wing formation was observed in week 3 and week 9 for the two species correspondingly. Adult emergence was noticed in weeks 5 and 11, while laying started in weeks 6 and 12 for *G. bimaculatus* and *A. domesticus* respectively.

Table 5: Stages of growth and development by species and house type

	Tunnel House	Prefabricated House
G. bimaculatus		
Sex notification	Week 2	Week 2
Wing formation	Week 3	Week 3
Adult emergence	Week 4	Week 5
Start of laying	Week 5	Week 6
A. domesticus		
Sex notification	Week 6	Week 7
Wing formation	Week 8	Week 9
Adult emergence	Week 10	Week 11
Start of laying	Week 11	Week 12

4.1.4 ANOVA Results on the Effects of Housing and Species on Growth Rate

From the two-way ANOVA (Table 6), a significant interaction between housing and species on cricket growth rate was observed (P< 0.0155).

Table 6: Analysis of Variance of effects of housing and cricket species on growth rate

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Housing	1	0.0002	0.0002	0.847	0.3610
Species	1	0.0222	0.0222	113.263	0.0000 ***
Housing:Species	1	0.0012	0.0012	6.208	0.0155 *
Residuals	60	0.012	0.0002		

Significance codes: 0 '****' 0.001 '***' 0.01 '**' 0.05 '**' 0.1 '* ' 1

A Tukey post-hoc analysis (Table 7) showed that mean growth rate was statistically different between the two species and that the growth rate of *Acheta domesticus* was found to be

0.037gm/week **(**P<0.000), lower than that of *Gryllus bimaculatus.* Overall, growth rate for the crickets was 0.003gm/week (P< 0.38, Table 7), lower in the prefabricated house than in the tunnel house. However, this difference was statistically non-significant.

Table 7: Comparison of treatment means

	Difference	Std. Err	t-value	P>|t|
Housing				
Prefabricated -Tunnel	-0.003	0.032	-0.95	0.380
Species				
A. domesticus -G. bimaculatus	-0.037	0.032	-11.66	0.000

4.1.5 Nutritional Profiles Showing Major Food Nutrient Content of the Crickets by Type of Housing

The proximate profile for both species records high levels of dry matter but varied levels of other parameters (Table 8). In both species, high levels of crude protein and dry matter were reported in the prefabricated house and tunnel house correspondingly. Both species performed better in prefabricated house in terms of converting feeds in to protein contents. At the same time, high fat levels were recorded in both species within the two housing systems except in *G. bimaculatus* reared in prefabricated house.

Table 8: Nutritional profiles showing major food components of *G. bimaculatus* and *A. domesticus* by type of housing

Housing Type	Species	DM%	ASH%	FAT%	CP%	P%
Tunnel House	*G. bimaculatus*	95.18	3.27	27.46	61.68	1.09
	A. domesticus	94.35	3.66	29.58	62.41	1.32
Prefabricated House	*G. bimaculatus*	88.46	3.86	16.18	69.48	1.25
	A. domesticus	94.26	3.97	25.51	62.98	0.98

DM-Dry matter, CP- Crude Protein, P -Phosphorous

4.2 DISCUSSION OF THE RESULTS

4.2.1 Effects of Housing on Growth Rate of the Crickets

In this study, temperature and humidity were the key functional factors in the housing units that were expected to influence growth performance of the crickets. It was therefore anticipated that fluctuations in humidity and temperature within the respective housing units would impact on growth which would have been consistent with earlier findings of (Niehaus et al., 2011; Verbitsky and Verbitskaya, 2011; Jaworski and Hilszczański, 2013; Adamo and Lovett, 2011; Camp et al., 2014). However, this was not the case in this study as the unit of housing system did not influence growth rate of crickets between 2 weeks of age and adulthood. Nonetheless these findings concurred with Lachenicht, Clusella-Trullas, Boardman, Le Roux and Terblanche (2010) and Schuller, Cooper, Storm, Sears and Angilleta, (2011) who observed that *A. domesticus* can tolerate both low and high temperatures. The non-significant effect of housing type in this study could be attributed to the fact that crickets are cold blooded organisms whose internal body temperatures depend on the temperatures of the surrounding and, therefore, adapted easily to the fluctuating environmental conditions within the two housing systems. This adaptation to fluctuating temperatures and humidity profiles within the two housing systems by both species was an indication of their physiological and biological response to the environment.

While the type of housing system did not have significant influence on growth rate, it was, however, noted that development period in *Gryllus bimaculatus* was one week shorter in the tunnel house. The shorter development period may be attributed to slightly higher temperatures and humidity which accelerated metabolism and molting rate of crickets, leading to enhanced feed intake and growth (Ogah et al., 2012; Astuti et al., 2013; Lemoine and Shantz, 2016). At high temperatures, ectotherms take a shorter period to complete a developmental stage due to increased enzymatic activities and the opposite is true for the lower temperature (Sangle et al., 2015). The increased metabolism triggers increase in feed intake due to cellular energy requirements (Anderson, Hessen, Boersma, Urabe and Mayor, 2017) which translates into increased biomass explaining the higher growth rate in the tunnel (0.003gm/week, Table 7) though it was not statistically significant. This may further explain the consistent high feed intake in the tunnel house by the two species (Table 4). These findings are consistent with those of Holmes (2010), who observed that warmth was a vital factor in growth and development of ectotherms and that an increase in heat increases their metabolism thereby increasing growth. Ogah, et al., (2012) and Khaliq et al. (2014) found that high temperature and relative humidity increased the rates of metabolism, growth and development and other physiological processes of African Rice Gall Midge, *Orseolia oryzivora,* thereby increasing their populations and the same finding was also reported by Benelli, Leather, Francati, Marchetti and Dindo, (2015) and Kollberg, et al. (2013) on the accelerated metabolic rates of *H. axyridis.* This observation, however, contradicts the findings of Mirth and Riddiford (2007) and Miller, Clissold, Mayntz and Simpson, (2009) who observed that high temperature retarded growth.

On the other hand, lower temperatures and relative humidity resulted in lower growth rates as was observed in the prefabricated house. This is in agreement with the findings of Hance et al. (2007) who reported on decreased growth rate on organisms reared under lower than normal temperatures and Holmes, (2010) who observed that Black Soldier Flies (*Hermetia illucens*) reared below the temperature and humidity thresholds had poor growth rates. Crickets have been reported to grow faster in a temperature range of 29°C - 35°C and in a relative humidity of 50%, Miech et al. (2016) which was close to the levels observed in this study in the two housing systems (Table 3), and may further explain the non-significant growth rate recorded between the two housing systems in our study.

4.2.2 Effect of Housing on Nutritional Composition of the Insect Body

Temperatures have been found to interact with diets thereby affecting the performance of insects (Miller et al., 2009). Relative variability was recorded regarding dry matter (DM), (88.46-95.18%), ASH (3.27-3.97%) and phosphorous (P) (0.98-1.32%) in both houses. Nonetheless, considerable variability was observed in crude protein and fat. These variations are indications of interactive effects of housing condition and diet on the body composition of crickets. Relative low crude protein and high crude fat amounts were recorded in the tunnel house respectively, for both species (Table 8). Higher temperatures have been found to induce protein limitation by reducing nitrogen digestion efficiency and might explain the low crude protein content recorded in the tunnel house. Lemoine and Shantz, (2016) and Miller et al. (2009) reported of inefficiencies in feed utilizations by insects reared at temperatures of above 32°C. This was attributed to high maintenance requirements at high temperature. This is probably because proteins denature more rapidly at higher temperatures, which, in turn, requires greater rates of protein synthesis and repair to maintain basic cellular function (Nation, 2002). Increased maintenance requirements at high temperatures may occupy a greater fraction of available nitrogen, a crucial and often limiting component of protein synthesis in insects.

4.2.3 Effect of Species on the Growth Rate of the Crickets

It was observed from this study that the species had a significant influence on the growth rate of the crickets. This finding concurred with results from Mogbo, Okeke, Ufele and Nwosu, (2013), that species confers a genetic potential for growth in organisms. It would appear that the two species had inherent differential genetic capacity for growth. *G. bimaculatus* consistently exhibited a higher mean growth rate than *A. domesticus* under the two housing systems (Table 6), indicating that it was the suitable genotype for both types of housing. This species is generally known to be a ferocious eater as was demonstrated by the higher mean feed intake (Table 3). Further still, the superior growth performance might also be an indication of its ease of adaptability to various environmental conditions. The performance of any animal depends on the inherent genetic make-up and the environment in which it has been raised (Mogbo et al., 2013; Silfver, Rousi, Oksanen and Roininen, 2014) and different species would perform differently within the same environment given their genetic make-up (Silfver et al., 2014).

CHAPTER FIVE: GROWTH PERFORMANCE OF COMMON HOUSE CRICKET (*Acheta domesticus*) AND FIELD CRICKET (*Gryllus bimaculatus*) FED ON AGRO-BYPRODUCTS

5.1. RESULTS OF THE ANALYSIS

5.1.1 Proximate Analysis of Experimental Cricket Feeds

The nutrient composition of feeds used as obtained from proximate analyses are set out in Table 9. Bloodmeal and brewer's spent yeast had the highest crude protein, while brewer's spent grain, grower's mash and rice bran had the least amount of crude protein.

Table 9: Composition of experimental feeds

Feed Type	DM% (105)	ASH%	FAT%	CP%	CF%	NFE%
Rice bran	92.16	13.68	18.62	19.22	13.81	34.72
Brewer's spent grain	92.26	3.07	7.90	27.13	21.22	38.68
Brewer's spent yeast	93.45	11.06	1.57	49.71	0.85	36.71
Grower's mash	92.47	8.82	7.59	15.89	9.78	57.92
Bloodmeal	91.37	5.82	1.49	87.46	1.94	3.28

DM-Dry Matter, CP – Crude Protein, CF -Crude Fibre, NFE -Nitrogen Free Extracts

Rice bran had the highest fat content followed by brewer's spent grain, grower's mash; while spent yeast and bloodmeal had the lowest. The other nutrient components showed various trends across the four feed types, however, of importance was the high levels of crude fibre in spent brewer's grain and rice bran.

5.1.2 Comparative Feed Selection by *A. domesticus* and *G. bimaculatus* Crickets

The crickets were left to self-select optimum feed combination amongst the experimental diets and the selection pattern is as shown in Table 10.

Table 10: Diet selection by *A. domesticus* and *G. bimaculatus*

Species	Experimental diets		
	RB:SY	**RB:BM**	**RB:SG**
G. bimaculatus	52.20:47.80	80.56:19.44	47.86:52.14
A. domesticus	31.89:68.11	70.79:29.21	41.83:58.17

RB-Rice bran, SY-Spent yeast, BM-Bloodmeal, SG- Spent grain

Both species consistently consumed more of rice bran over bloodmeal in experimental diet 3, (RBBM) albeit the high level of crude protein Table 9. Apart from the noticeable preference for spent yeast over rice bran by *A. domesticus*, all other feed preferences almost had a selection ratio of 1:1.

5.1.3 Mean Feed Intake and Body Weights Trends of *A. domesticus* and *G. bimaculatus* Fed on Agro-by products

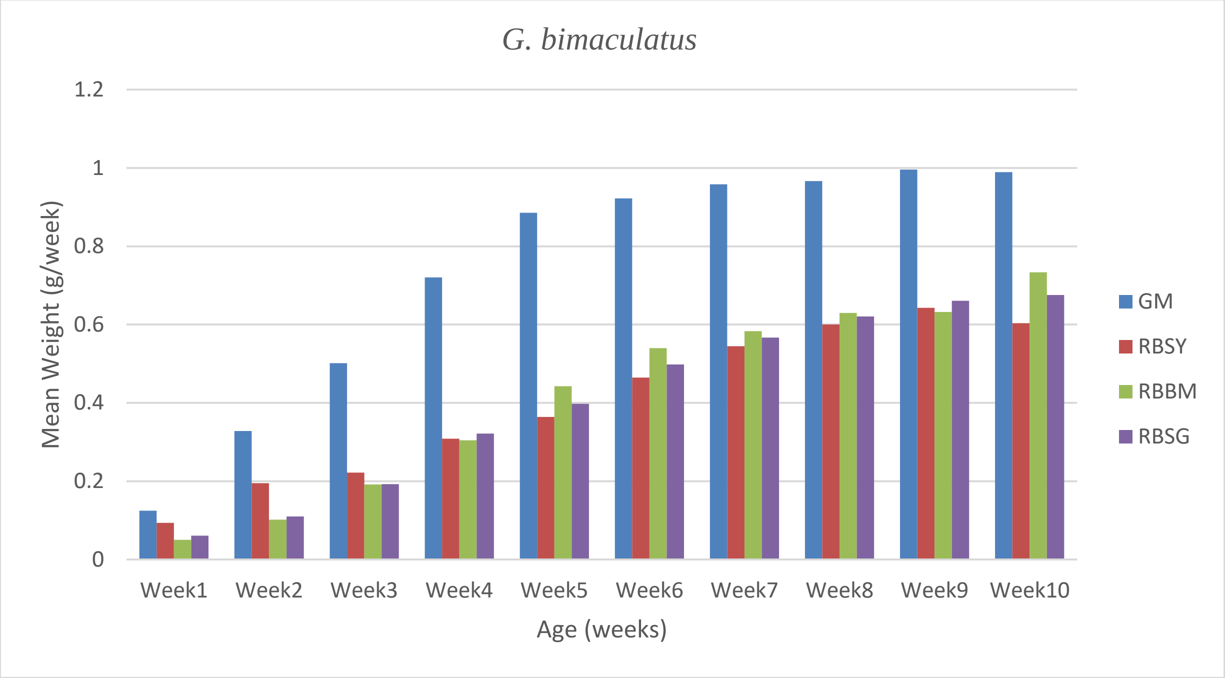
Mean adult weight of *G. bimaculatus* were 0.746±0.05g, 0.404±0.03g, 0.425±0.04g and 0.412±0.04g for cohorts fed on GM, RBSY, RBBM and RBSG respectively. Mean adult weights of *A. domesticus* were 0.271±0.03g, 0.155±0.02g, 0.135±0.02g and 0.181±0.02g for cohorts fed on GM, RBSY, RBBM and RBSG respectively (Table 11).

Table 11: Summary of mean adult body weight and feed intake of crickets (*A. domesticus* and *G. bimaculatus*)

Species	**Parameters**	**Feed Types**			
		GM	RBSY	RBBM	RBSG
G. bimaculatus	Mean body weight	0.746±0.05g	0.404±0.03g	0.425±0.04g	0.412±0.04g
	Mean Feed intake	24.86±2.4g	8.59±0.42g	14.71±1.13g	13.44±0.94g
A. domesticus	Mean body weight	0.271±0.03g	0.155±0.02g	0.135±0.02g	0.181±0.02g
	Mean Feed intake	7.51±0.67g	3.58±0.22g	3.38±0.26g	6.14±0.54g

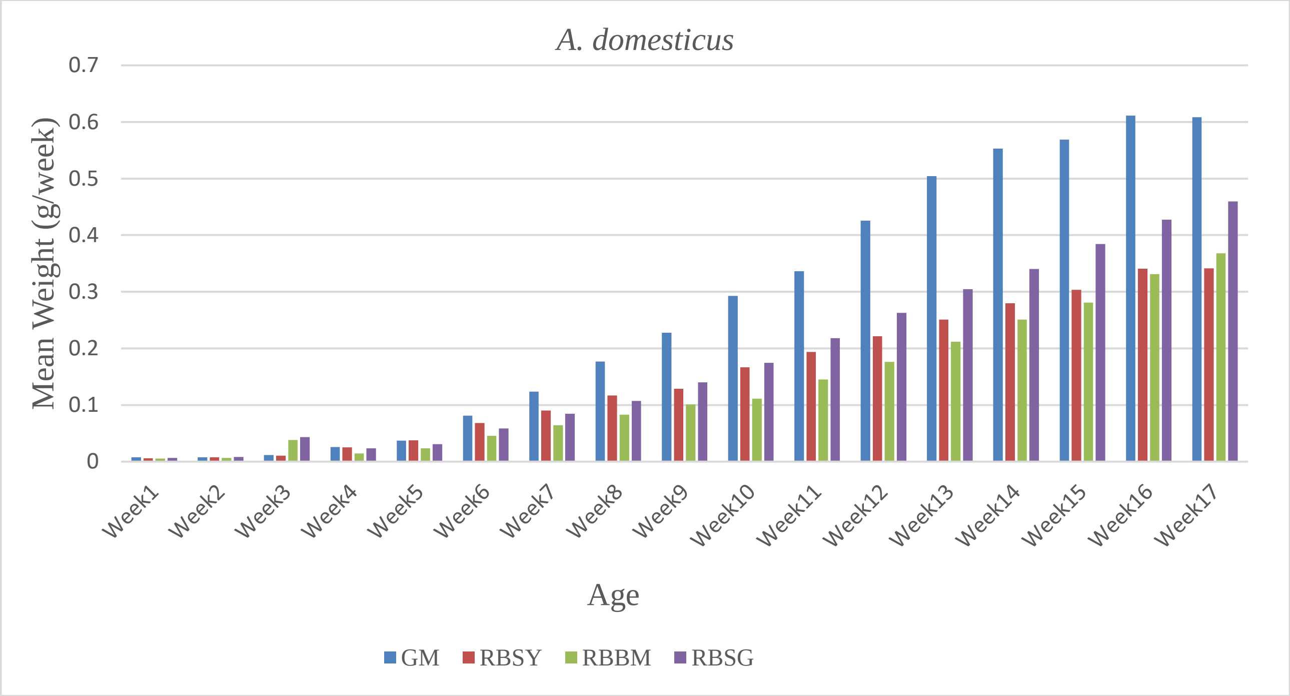
GM-Grower's mash, RBSY- Rice bran +Spent yeast, RBBM- Rice bran +Bloodmeal, RBSG-Rice bran + Spent grain

Highest body weights were recorded in cricket cohorts fed grower's mash for both species while other experimental diets recorded variable body weights. Highest feed intake was observed in *G. bimaculatus.* Grower's mash was the most preferred while experimental diet 2 (RBSY) was the least consumed by both species.



GM – Grower’s mash, RBSY – Rice bran +Spent Yeast, RBBM – Rice bran +Bloodmeal and RBSG – Rice bran + Spent Grain

Figure 9: Weekly Mean body weight of *G. bimaculatus*



GM – Grower’s mash, RBSY – Rice bran +Spent Yeast, RBBM – Rice bran +Bloodmeal and RBSG – Rice bran + Spent Grain

Figure 10: Weekly Mean body weights of *A. domesticus*

5.1.4 Physiological and Developmental Growth Trends by Feed Type

Table 12 shows different physiological and developmental processes of different cohorts of the two species fed on different feed types. A Shorter developmental period was recorded in cohorts fed on growers' mash (control diet) in both species. Sex notification for *G. bimaculatus* and *A. domesticus* fed on growers' mash and rice bran + spent yeast was observed in week 2 and 6 respectively and in week 4 and 9 in the cohort fed on rice bran + bloodmeal and in week 4 and 7 for cohorts fed on rice bran + spent grain respectively.

Table 12: Physiological and developmental growth trends of *G. bimaculatus* and *A. domesticus* by feed type

	GM	**RBSY**	**RBBM**	**RBSG**
G. bimaculatus				
Sex notification	Week 2	Week 2	Week 4	Week 4
Adult emergence	Week 4	Week 6	Week 6	Week 6
Start of laying	Week 5	Week 7	Week 8	Week 7
A. domesticus				
Sex notification	Week 6	Week 6	Week 9	Week 7
Adult emergence	Week 10	Week 10	Week 13	Week 11
Start of laying	Week 11	Week 13	Week 15	Week 14

GM- Growers' mash, RBSY-Rice bran+ Spent yeast, RBBM- Rice bran +Bloodmeal, RBSG - Rice bran +Spent grain

In *G. bimaculatus,* peak growth rate was recorded in week 3 for the cohorts fed on growers' mash while cohorts fed on a combination of rice bran and spent grain registered their peak growth rate in week 5. As for the cohorts fed on rice bran and spent yeast, the peak growth rate was noted in week 3 and the cohorts fed on rice bran and bloodmeal had their peak growth rate in week 4 (Fig 12).

In *A .domesticus,* peak growth rate was recorded in weeks 11,9 and 15 for the cohorts fed on growers' mash and rice bran + spent grain, rice bran + spent yeast, and rice bran+ bloodmeal respectively (Fig 13).

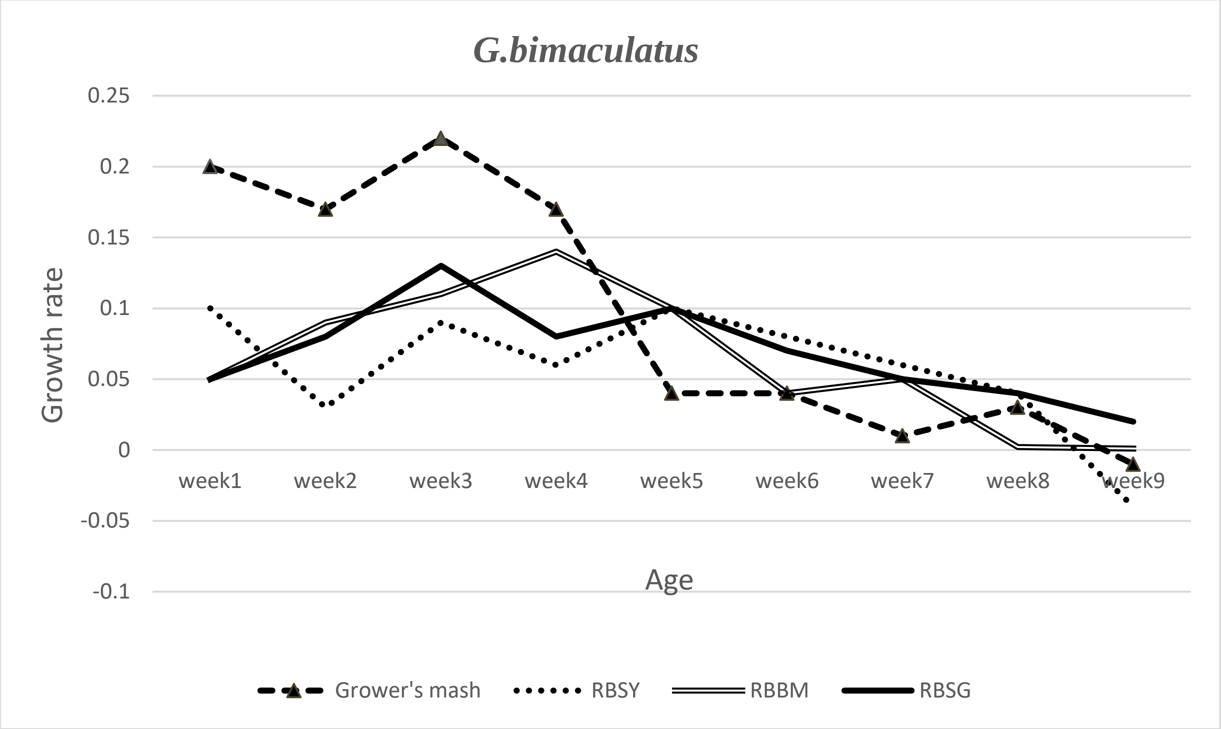


Figure 11: Growth patterns of *G. bimaculatus* fed on different agro-byproducts

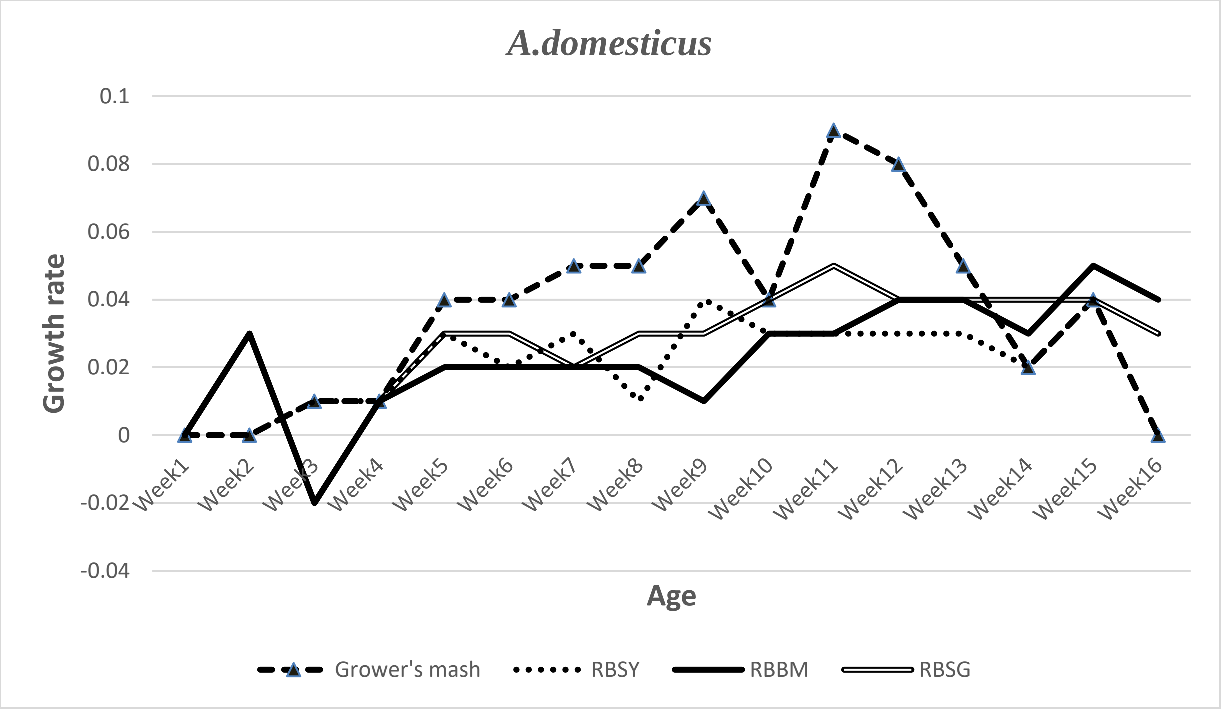


Figure 12: Growth patterns of *A. domesticus* fed on different agro-byproducts

5.1.5 ANOVA Results on Effect of Species and Treatment on Growth Rate

Growth rate was significantly affected by species and treatment (P<0.000) and the interaction between species and feed (P<0.05) (Table 13).

Table 13: Analysis of Variance of effect of species and treatment on growth rate of Cricket

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Species	1	0.277	0.277	143.02	0.0000***
Treatment	3	0.087	0.029	15.04	0.0000 ***
Treatment:Species	3	0.022	0.007	3.71	0.0115**
Residuals	842	1.629	0.0002		

Significance codes: 0 '****' 0.001 '***' 0.01 '**' 0.05 '**' 0.1 '* ' 1

The control diet consistently exhibited higher growth rate than the experimental diets while the mean difference between the experimental diets were not statistically different from each other (Table 14).

Overall growth rate of *G. bimaculatus's* was found to be 0.037gm/week (Table 14), higher than *A. domesticus.* The mean growth rate of cohorts fed on RBSY, RBBM and RBSG were found to be 0.028gm/week, 0.021gm/week and 0.021gm/week significantly (P<0.000) lower than control diet, respectively. The other mean growth rates were not statistically different from each other (Table 14).

Table 14: Comparison of cricket feed treatment means

	Difference	Std. Err	t-value	P>|t|
Species				
A. domesticus -G. bimaculatus	-0.037	0.031	-11.96	0.000
Treatments				
RBSY- GM	-0.028	0.004	-6.33	0.000
RBBM- GM	-0.021	0.004	-4.70	0.000
RBSG – GM	-0.021	0.004	-4.81	0.000
RBBM – RBSY	0.007	0.004	1.64	0.354
RBSG – RBSY	0.007	0.004	1.54	0.414
RBSG – RBBM	-0.0005	0.004	-0.10	1.000

GM- Growers' mash, RBSY-Rice bran+ Spent yeast, RBBM- Rice bran +Bloodmeal, RBSG - Rice bran +Spent grain

5.1.6 Nutritional Profiles of the Crickets per Type of Feed Treatment

Table 15 shows the nutritional composition of the different cricket cohorts obtained from proximate analysis. High dry matter content was observed in the four diets with the highest proportion in RBBM diet for both species and lowest in RBSY diet in *G. bimaculatus* and GM in *A. domesticus*. Cohorts fed on the experimental diets had higher protein levels than those fed on the control diet except in RBBM in *G. bimaculatus*. The protein levels of crickets fed on RBSY diet were particularly high for both *G. bimaculatus* (70.1%) and *A. domesticus* (71.09%) on dry matter basis even though they had the least body weight.

Table 15: Nutritional composition of the insect body

	DM%	ASH%	FAT%	CP%	P%
Gryllus bimaculatus					
Poultry Growers' Mash	95.18	3.27	27.46	61.68	1.09
Rice bran + Spent brewer's yeast	92	4.57	14.93	70.1	1.23
Rice bran + Bloodmeal	95.99	3.5	33.44	57.49	1.26
Rice bran + Spent brewer's grain	94.59	4.43	27.4	62.11	1.36
Acheta domesticus					
Poultry Growers' Mash	94.35	3.66	29.58	62.41	1.32
Rice bran + Spent brewer's yeast	94.85	4.74	19.2	71.09	1.31
Rice bran + Bloodmeal	95.34	3.58	25.61	66.26	1.33
Rice bran + Spent brewer's grain	95.01	4.36	24.33	66.63	1.41

DM -Dry Matter, CP – Crude Protein, P- Phosphorous

5.2 DISCUSSION OF RESULTS

5.2.1 Diet Selection by *A. domesticus* and *G. bimaculatus*

In this study, both cricket species were left to self-select between two feed types in each experimental unit. Rice bran was used as basal diet and source of carbohydrate amongst the three experimental diets: Rice bran + Spent yeast (RBSY), Rice bran + Bloodmeal (RBBM) and Rice bran + Spent grain (RBSG). Results indicated that *G. bimaculatus* consumed RBSY, RBBM and RBSG in the ratio of 52.20: 47.80, 80.56:19.44 and 47.86:52.14 correspondingly. Similarly, *A. domesticus* showed preference for yeast over rice bran in RBSY diet (31.89: 68.11), rice bran over bloodmeal in RBBM diet (70.79:29.21) and spent grain over rice bran in RBSG diet (41.83:58.17).

Insects have been reported to have the ability to self-select among multiple choices of artificial diet formulations to compensate for single-diet deficiencies (Magowski *et al.*, 2003; Coyle *et al.*, 2011). This self-selection has been attributed to both associative learning and non-associative learning (Nation, 2002; Magowski *et al.*, 2003; Coyle *et al.*, 2011). Associative learning is whereby a specific stimulus or chemical component of food is associated with reward such as growth, while non-associative learning refers to cases in which an organism's behavior toward a stimulus changes in the absence of any apparent associated stimulus (Nation, 2002; Larson, 1987).

From the study it was apparent that bloodmeal was the least preferred by both species though it had high crude protein content from the proximate analysis. Researches have established that feed preference is largely affected by sensory components such as taste, smell and colour (Coyle *et al.*, 2011; Panizzi & Parra, 2012) as well as palatability and acceptability (Chagneau *et al.*, 2007). A part from having imbalanced amino acids and pungent smell, bloodmeal has been known to be less palatable which might have been the probable explanation for the least consumption by the crickets. It was however observed that *G. bimaculatus* preference in RBSY and RBSG diets and *A. domesticus* preference in RBSG diet was almost in a ratio of 50:50 (Table 10). Proximate analysis of these feed types (Table 9) revealed comparatively the same amount of nitrogen free extracts (NFE), which acted as source of metabolizable energy for growth. This might probably explain the indifferent selection and consumption of almost the same amount of these feeds, in addition to the likely indication of their acceptability and palatability. The findings from this study compares with the findings of Lyn et al. (2011) who observed that a confused flour beetle (*Tribolium confusum),* chose a combination of feed that provided a protein to carbohydrate ratio of 57:43 close to the optimum of 50:50 for the immature beetle when given a mixture of 1:1:1: of germ, bran and endosperm and Nation (2002) where the Corn earworms (*Helicoverpa zea)* insects were found to self-select portions from defined diets providing protein to carbohydrate ratio of 79:21, a ratio close to 80:20 of protein to carbohydrates considered to be optimal for growth of tobacco hornworm larvae (*Manduca sexta).*

These findings indicate that the two cricket species have shown positive mixed preference for the different feed types which indicates the potential for formulation of feed from the agro byproducts as well as lay ground for future investigation into the bioavailability of nutrients ingested by the crickets. There is also need to calculate the food conversion ratios to establish the biological efficiency of using these feeds.

5.2.2 Effects of Agro-byproducts Based Feeds on Growth of Crickets

The significant effects of species and agro byproducts-based feeds in this study concur with the earlier findings of EL-Damanhouri (2011), LeBlanc (2012) and Megido et al. (2016) who found that developmental period and growth rates of insects depended on the kind of diet they were fed. Control diet (GM) constantly recorded higher growth than experimental diets. Post-hoc analysis of the means revealed a significant lower growth rates of 0.028gm/week, 0.021gm/week and 0.021gm/week in RBSY, RBBM and RBSG, respectively, relative to control diet (Table 14). This might be explained by the fact that growers' mash provided a more balanced diet as well as high presence of the nitrogen free extracts (NFE; 57.92%), which provided readily available source of energy or utilizable glucose for different physiological functions. These nitrogen free extracts could be easily converted into body mass translating into high growth. Similar conclusion was made by Mcdonald, et al. (2011), that diets high in nitrogen free extracts act as building blocks for other nutrients which aids in growth. This is further supported by Oonincx et al. (2016) and Patton (1978) findings that a diet of about 20% - 30% crude protein (CP) ensured high survival and shorter development period in *A. domesticus* crickets, leading to optimal growth.

High fibre in rice bran and spent grain in treatments RBSY, RBBM and RBSG could explain the low growth rate observed in this study. The mean growth rates among the feeds were not statistically different from each other. However, cricket cohorts fed on RBSY diet had slightly higher growth rates (0.007gm/week) than the cohorts fed on RBBM and RBSG diets (Table 14). The high complex structures of the fibre contained in both rice bran and spent grain (lignin, cellulose and hemicellulose) might have been indigestible for the crickets. Earlier studies by Miech et al. (2016), Aliyu and Bala, (2011), Levic et al. (2010) and Cruz et al. (2005) reported on the indigestibility of these fibres by Orthoptera hence could explain the lower growth rates of crickets fed on rice bran and spent grain. High mortality rate (>99%), reported by Lundy and Parrella (2015) for crickets reared on diets that contained straw further supports the indigestibility of the grain fibres in rice bran and spent grain by crickets, which might further explain the lower growth rate observed in this study.

Crickets fed on rice bran+ bloodmeal took longer to reach adulthood. Post hoc analysis by Tukey HSD revealed a statistically significant lower mean growth rate of 0.021gm /week (P <0.000; Table 14) compared to cohorts fed on control diet (GM). From the nutritional analysis of this diet

(Table 9), bloodmeal contained the highest amount of crude protein and lowest nitrogen free extract while rice bran had comparatively higher levels of crude fat and fibre. This nutrient combination appeared be unsuitable for optimum growth rate albeit the high protein content. Seifdavati et al. (2008) observed non-palatability and reported that blood meal imbalanced amino acid and characteristic smell reduced feed intake and digestibility in poultry. Similarly, Lundy and Parrella (2015) observed that proteins contained in bloodmeal and bone marrow were inadequate for cricket's optimum growth. Alternatively, according to Megido et al. (2016), oxidative stress due to high fat in diets constrained growth of Cambodian crickets, *Telegryllus spp*. These factors coupled, with low nitrogen free extract and high crude fibre and fat in the rice bran obtained from this study, might explain the poor performance in this study though more research need to be done to establish bloodmeal digestibility in insects. It was observed that the cricket cohorts fed on this diet, took longer to achieve their peak mean weight. This was interpreted as an adaptation and survival strategy of crickets in response to poor or inadequate diet. This agrees with the findings of Harrison et al. (2014) that in the face of poor diet, insects take longer to reach maturity not only because of inadequate nutritional requirements, but also as a way of maximizing life span and reproductive performance. This trade- off between growth (increasing biomass) and development is a survival strategy employed by most insects.

Diets containing spent yeast have been reported to have optimal performance in growth and development of insects as it acts as a feeding stimulant and contains growth factors for specific insect species like yellow mealworms (Oonincx et al., 2016). Broekhaven et al. (2017) and Oonincx et al. (2016) both reported a shortened development time and higher biomass in edible mealworms fed on yeast-based diet, which contradicts the findings from this study in terms of body mass. Apart from the lower body mass (0.155±0.02g for *A. domesticus* and 0.404±0.03g for *G. bimaculatus*), it was also observed that cricket cohorts fed RBSY diet reached maturity at slightly smaller size than other cricket cohorts. Proximate analysis of brewers' spent yeast used in this diet revealed a high protein content (49.71%) and relatively high nitrogen free extracts. This combination was anticipated to perform better in terms of growth rate but the findings were contrary to the expectation. Previous studies have established that monogastric organisms such as crickets expend a lot of energy in excreting excess protein in form of uric acid (Oonincx et al., 2016; Ferreira et al., 2010). This stressful and wasteful process might explain the lower growth rate and lower body mass in this cohort of crickets. Further, Nakagaki and Deforliat (1991) recommended that spent yeast should be fed in dissolved form but in our study, it was fed in dry powdery form. It is thought that this form might have further made it hard for the crickets to ingest limiting the availability of the required nutrient for their growth.

Both species and its interaction with feeds significantly ($P<0.011$) affected growth rate of the insects. *G. bimaculatus* had a higher mean growth rate (0.037gm/week; Table 14) in comparison to *A. domesticus.* This implies that both species are genetically different and respond to the feeds differently.

5.2.3 Effect of Agro by product- based Feeds on Nutritional Composition of the Insect Body

Dietary composition has been reported to have effects on the nutrient composition of organisms (Oonincx et al., 2016; El-Damanhouri, 2011; Megido et al., 2016). Slight variability was observed regarding dry matter (DM), (92-95.99%), ASH (3.27-4.74%) and P (1.09-1.41%) in both species. However, substantial variability was recorded in crude protein and crude fat across the two species (Table 15). These variations assert the dietary effects on the body composition of the crickets. In both species, RBSY diet produced the highest crude protein but least weight. Nonetheless, the crude protein recorded (57.49- 71.09%; Table 15) across the four diets used in this study were higher than the contents of other conventional sources such as, lamb, chicken, and fish (7.5–23%); milk and milk products (3–26%); whole eggs (13%); beans and soy beans ~38% (Musundire, Zvidzai, Chidewe, Samende and Chemura, 2015; Kouřimská and Adámková, 2016; Ssepuuya, Mukisa and Nakimbugwe, 2017). The crude protein values observed in this experiment were relatively higher than 47.1% reported by Ayieko, Ogola and Ayieko (2016) on *A. domesticus* fed on commercial growers' mash, 35.06% by Amadi and Kiin-Kabari, (2016) on *Brachytrupes membranaceus* collected from the wild.

Large variations were also observed in crude fat contents across the four diets used in the experiment (14.93-33.44%; Table 12). These values were comparable with *R. nitidula* (41–43%) collected from wild in Uganda (Ssepuuya et al., 2017), and winged termites (44-47%) collected from Western Kenya, but were higher than those of grasshopper species, *Zonocerus variegatus,* (3.8%), from western Nigeria (Kenis, Kone, Chrysostome, Devic, Koko, Clottey et al., 2014).

While rearing crickets for food, there is need to establish their digestibility to permit informed comparison with the conventional sources of protein.

CHAPTER SIX: ANALYSIS OF TECHNICAL EFFICIENCY OF CRICKET PRODUCTION

6.1 RESULTS OF THE ANALYSIS

6.1.2 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 16. 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, 29.0 2g and 26.79g, 7.03hrs and 85.16g respectively.

Table 16: 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	85.16g
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 17).

Table 17: 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.

6.1.2 Factors Affecting Technical Efficiency of Cricket Production

The maximum likelihood parameter estimates of the stochastic production function are presented in Table 18. 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 18: 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 17). 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. 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.

6.1.3 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 18).

Table 19: 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 19). 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 19). 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.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

This study investigated the effects of housing conditions and feed on growth performance of two cricket species; *G. bimaculatus* and *A. domesticus* and further analyzed technical efficiency of the cricket farm at JOOUST using the time series production data collected from the farm. Temperature and relative humidity were the two vital variables that were expected to influence cricket growth within the two housing systems. Agro by product -based feeds, rice bran, brewer's spent yeast, brewer's spent grain and bloodmeal were investigated as potential cricket feed. A two- way ANOVA was used to analyze the effects of both housing and feed on growth performance of crickets. Technical efficiency was analyzed by econometric technique using a two-stage Cobb-Douglas stochastic frontier model.

It was found that species of a cricket had significant effect on its growth performance, while housing type did not. The two species of cricket showed wide adaptability to the fluctuations of temperature and relative humidity within the two housing types. Choice of the housing system would then depend on the affordability rather than suitability in terms of rearing conditions due to its non- significant effect. Further research should be done on the optimum humidity and temperature levels suitable for rearing crickets.

G. bimaculatus performed better in terms of growth than *A. domesticus* but the latter had more nutrients especially crude protein. All these differences were attributed to their genetic make-up. In this case, choice of species to produce will depend with the production objective. *G. bimaculatus* would be suitable for those farmers who are after high production turn overs with heavy weights while for nutritionist who are after alleviating protein deficiency, *A. domesticus* would be the most preferable species.

Feed was found to be critical in the production as it significantly affected growth and consequently output. The suitability of feed was found to be affected by its nutrient composition. Crickets performed poorly in certain protein- rich diets such as bloodmeal and brewer's spent yeast and feeds with high lignin which was indigestible by crickets. Further research should be done on these feeds to establish their amino acids profiles or composition, presence of anti-nutrients and digestibility and consequently, their feed conversion ratios. The choice of feed type will depend on the production objective, availability and cost, hence the need for economic efficiency analysis. For farmers who are after heavier weights, grower’s mash would be preferred while for nutritionist, the feed type with yeast component would be suitable one.

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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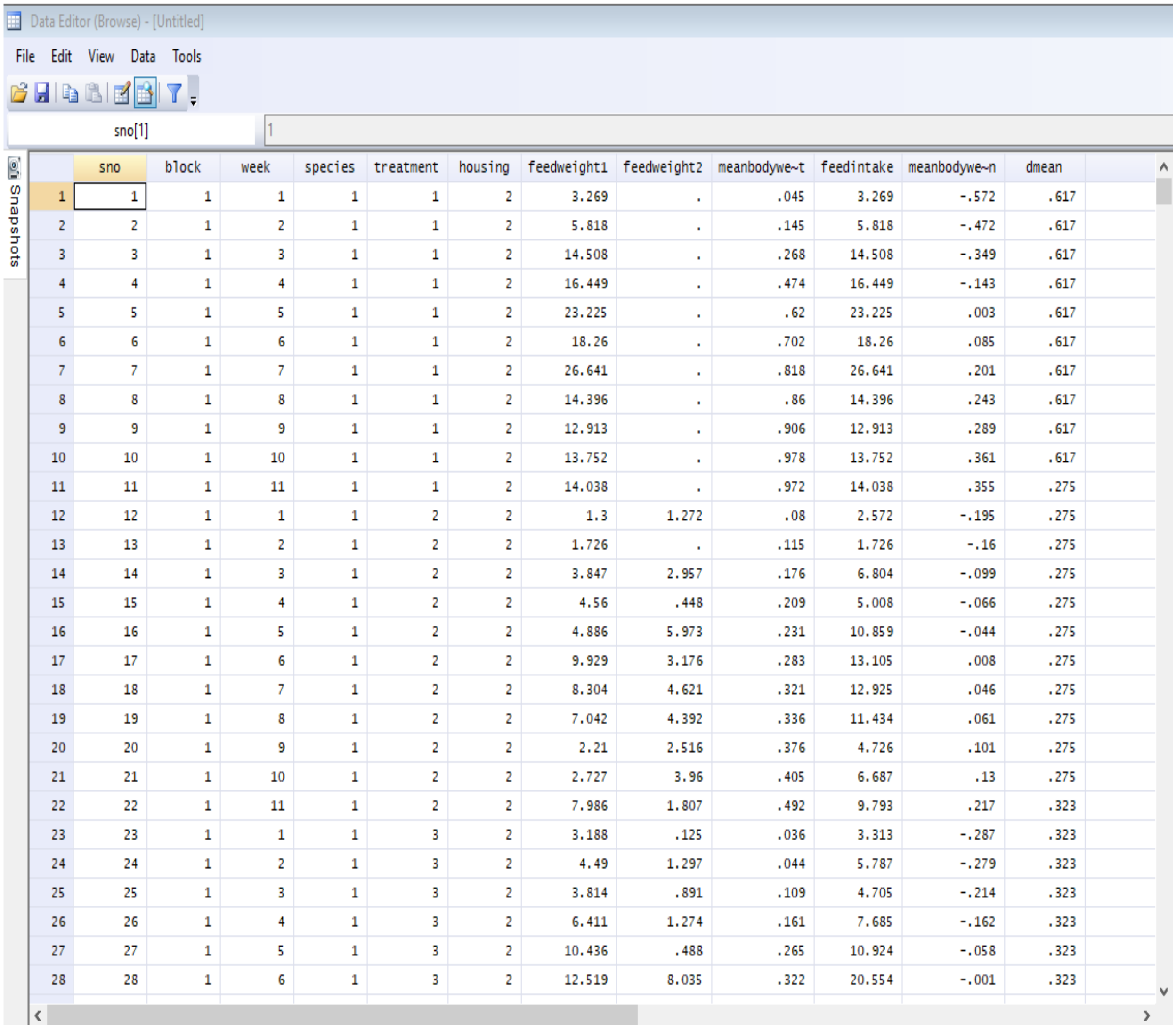
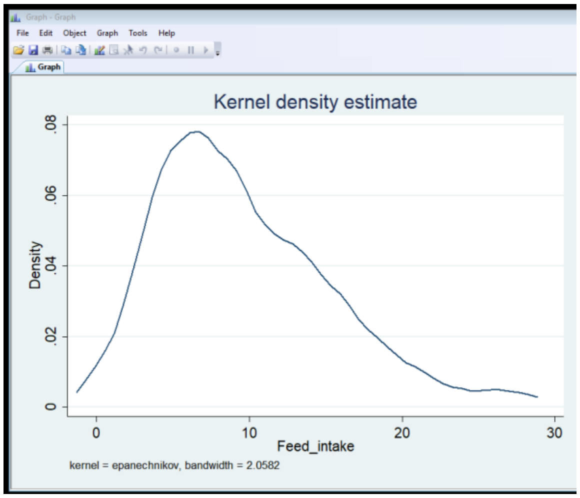
APPENDICES

Screenshot of part of data used in the analysis



	sno	block	week	species	treatment	housing	feedweight1	feedweight2	meanbodywe~t	feedintake	meanbodywe~n	dmean
1	1	1	1	1	1	2	3.269	.	.045	3.269	-.572	.617
2	2	1	2	1	1	2	5.818	.	.145	5.818	-.472	.617
3	3	1	3	1	1	2	14.508	.	.268	14.508	-.349	.617
4	4	1	4	1	1	2	16.449	.	.474	16.449	-.143	.617
5	5	1	5	1	1	2	23.225	.	.62	23.225	.003	.617
6	6	1	6	1	1	2	18.26	.	.702	18.26	.085	.617
7	7	1	7	1	1	2	26.641	.	.818	26.641	.201	.617
8	8	1	8	1	1	2	14.396	.	.86	14.396	.243	.617
9	9	1	9	1	1	2	12.913	.	.906	12.913	.289	.617
10	10	1	10	1	1	2	13.752	.	.978	13.752	.361	.617
11	11	1	11	1	1	2	14.038	.	.972	14.038	.355	.275
12	12	1	1	1	2	2	1.3	1.272	.08	2.572	-.195	.275
13	13	1	2	1	2	2	1.726	.	.115	1.726	-.16	.275
14	14	1	3	1	2	2	3.847	2.957	.176	6.804	-.099	.275
15	15	1	4	1	2	2	4.56	.448	.209	5.008	-.066	.275
16	16	1	5	1	2	2	4.886	5.973	.231	10.859	-.044	.275
17	17	1	6	1	2	2	9.929	3.176	.283	13.105	.008	.275
18	18	1	7	1	2	2	8.304	4.621	.321	12.925	.046	.275
19	19	1	8	1	2	2	7.042	4.392	.336	11.434	.061	.275
20	20	1	9	1	2	2	2.21	2.516	.376	4.726	.101	.275
21	21	1	10	1	2	2	2.727	3.96	.405	6.687	.13	.275
22	22	1	11	1	2	2	7.986	1.807	.492	9.793	.217	.323
23	23	1	1	1	3	2	3.188	.125	.036	3.313	-.287	.323
24	24	1	2	1	3	2	4.49	1.297	.044	5.787	-.279	.323
25	25	1	3	1	3	2	3.814	.891	.109	4.705	-.214	.323
26	26	1	4	1	3	2	6.411	1.274	.161	7.685	-.162	.323
27	27	1	5	1	3	2	10.436	.488	.265	10.924	-.058	.323
28	28	1	6	1	3	2	12.519	8.035	.322	20.554	-.001	.323



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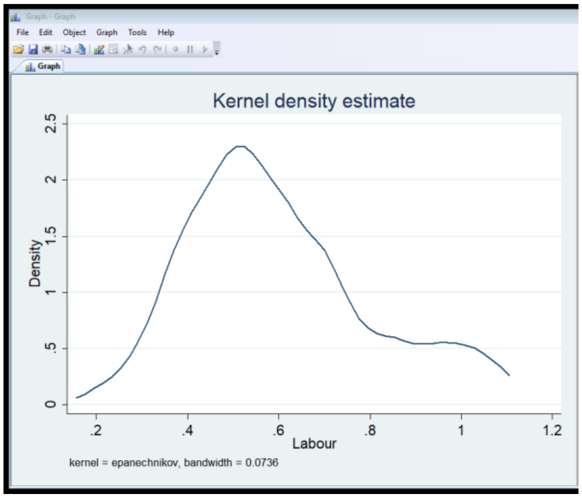

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