

**GROWTH PERFORMANCE OF NILE TILAPIA (*Oreochromis niloticus*)
FED ON DIETS CONTAINING CRICKET (*Acheta domesticus*) MEAL
IN KENYA**

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MAY, 2021

DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

I wish to dedicate this thesis to my family; my husband Dr. Benard M. Kinyua, and children Sophie, Lilian and Wisemann and to my parents Mr. Julius Mwangi and my late beloved mother Mrs. Cesia Wairimu (may she rest in eternal peace), for their support, love and encouragement and to my spiritual father Reverend John K. Mburu for his prayers and spiritual guidance.

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TABLE OF CONTENTS

DECLARATION.....	ii
DEDICATION.....	ii
ACKNOWLEDGEMENT.....	iii
TABLE OF CONTENTS	v
LIST OF TABLES.....	viii
LIST OF FIGURES	x
LIST OF APPENDICES	xi
ABBREVIATIONS	xii
ABSTRACT	xiii
CHAPTER ONE: INTRODUCTION.....	1
1.1 Background information.....	1
1.2 Problem statement	4
1.3 Justification.....	5
1.4 Study objectives.....	6
1.4.1 General Objective	6
1.4.2 Specific objectives	6
1.5 Hypotheses.....	6
1.6 Theoretical and conceptual framework	7
1.6.1 Theoretical framework	7
1.6.2 Conceptual framework	8

1.7 Significance of the study	9
CHAPTER TWO: LITERATURE REVIEW	11
2.1 Overview of fish farming globally	11
2.2 Fish farming in Africa	12
2.3. Fish farming in Kenya	13
2.4 Tilapia fish farming	16
2.4.1 Tilapia species and distribution	16
2.4.2. Growth characteristics and nutritional requirement of Nile tilapia	18
2.4.3 Economic significance of Nile tilapia (<i>Oreochromis niloticus</i>)	19
2.5. Nutrition and feeding of <i>Oreochromis niloticus</i>	20
2.6. The status of fish feeds in Kenya.....	21
2.7 Fishmeal as used in the fish feed formulation	23
2.8 Potential of insects in aquaculture diets	24
2.8.1 Potential of house cricket (<i>Acheta domesticus</i>) meal in animal diet	25
2.8.2 Breeding and production of house cricket (<i>Acheta domesticus</i>)	26
2.8.3 Nutritive value and chemical composition of house cricket meal.....	26
2.9 Performance of fish fed on cricket meal.....	27
2.10 Potential risks of using cricket as feed	28
2.11 Economic analysis	29
2.11.1 Fish production using fishmeal and insect meal.....	29

2.12 Summary of literature and gaps identified	33
CHAPTER THREE: MATERIALS AND METHODS	35
3.1 The Study Area	35
3.2 Experimental diets	36
3.3 Experimental procedures and design	38
3.4 Laboratory analysis of feed ingredients and test diet	39
3.5 Fish sampling and growth analysis	40
3.5.1 Performance parameters calculations	41
3.6 Survival of the fish	42
3.7 Water quality analysis.....	42
3.8 Economic analysis	42
3.9 Statistical Analysis	43
3.10 Ethical and Logistical Considerations	44
CHAPTER FOUR: RESULTS AND DISCUSSION.....	45
4.1 Proximate analysis	45
4.2 Growth performance of the <i>Oreochromis niloticus</i>	47
4.3 Effects of various treatments on survival of the fish	53
4.4 Economic analysis	58
CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	64
5.1 Summary of significant findings	64

5.2 Conclusions	65
5.3 Recommendations	66
5.4 Suggestion for further study	66
REFERENCES	67
APPENDICES	90

LIST OF TABLES

Table 2. 1: Chemical constituent in cricket compared to fishmeal.....	27
Table 3. 1: Proportions of ingredients used to formulate the trial diets	38
Table 3. 2: Cost of ingredients used in formulating the trial diets	43
Table 4.1: Proximate analysis (% DM) of feed ingredients used in the feeding trial.....	45
Table 4. 2: Chemical Composition of the five experimental diets	46
Table 4. 3: Performance of <i>Oreochromis niloticus</i> fed on different dietary treatments.....	49
Table 4.4: Range and averages of physical-chemical parameters of the water during the tilapia fish growing period in the hapa nets and their environs.	57
Table 4. 5: Economic analysis for production of Nile tilapia fed diet containing various levels of <i>Acheta domesticus</i> meal	59

LIST OF FIGURES

Figure 1. 1: Conceptual framework	9
Figure 2. 1: Global Aquaculture production by region	12
Figure 2. 2: Aquaculture production in Kenya from 2006 to 2016	14
Figure 2. 3: Current global aquaculture production trends for Nile tilapia (<i>Oreochromis niloticus</i>).....	18
Figure 3.1: Map of study area	36
Figure 4. 1: Growth trends of <i>Oreochromis niloticus</i> over the culture	52
Figure 4.2: Fish survival rate	53
Figure 4.3: Incident cost of five treatments of Cricket meal fed to Nile Tilapia fish	60
Figure 4. 4: Profit index of the five treatments of Cricket meal fed to Nile Tilapia fish.....	61

LIST OF APPENDICES

Appendix I: Table of Compounded Tilapia feeds Specification Kenya Standard 2289- 1 Complete feed	90
Appendix II: Figures of pond liming	91
Appendix III: Mounted Hapa nets in a Pond filled with water	92
Appendix IV: Research Approval from Kenyatta University Graduate School	93

ABBREVIATIONS

CF	Crude fibre
CM	Cricket Meal
CP	Crude Protein
DAP	Di-ammonium phosphate
DM	Dry Matter
EE	Ether Extract
FAO	Food Agricultural Organization
FCR	Feed Conversion Ratio
FM	Fish Meal
MT	Metric Tonnes
NFE	Nitrogen Free Extract
SE	Standard Error

ABSTRACT

Aquaculture sector continues to grow leading to increased demand for fishmeal (FM). The most preferred and nutritionally superior but costly protein source of fish diets. An affordable and readily available protein source is desirable to reduce the over-reliance on FM, and insects have been proposed to be a good alternative. A six months experiment was conducted to determine the effect of replacing FM with cricket meal (CM) on the growth performance, survival and economic performance of Nile tilapia (*Oreochromis niloticus*). Five (5) iso-nitrogenous diets (35% CP) were formulated with various substitution levels of CM for FM; T1 (0%), T2 (25%), T3 (50%), T4 (75%) and T5 (100%). Four hundred and fifty (450) male Nile tilapia fingerlings weighing 30 ± 5 g were randomly distributed into 5 groups each with 30 fingerlings per hapa in 3 replicates in a completely randomised design (CRD). The fingerlings were initially fed at 8% body weight (BW) and at 3% BW after they attained an average of 50g BW. Feeding was at 0900hrs and 1500hrs daily with biweekly measurements of weights for 22 weeks. Mortality was also recorded. Data was recorded in Microsoft excel[®] before being subjected to ANOVA using SPSS 23.0 and significant means separated using LSD at $P < 0.05$. Average weight gain, feed conversion ratio (FCR) and survival rates (SR) were determined. Fish fed on T2 were larger (199.97 g) ($p < 0.05$) than those on T1 (169.86 g), T3 (164.64 g), T4 (151.60 g) and T5 (147.56 g). Feed Conversion Rate was better in fish fed on T2 (2.07) compared with other treatments (T1=2.70, T3=2.72, T4=2.84, T5=2.77). There was high SR of the fish in all treatments (T1=96.7%, T2=97.8%, T3=97.8%, T4=96.7%, and T5=97.8%), indicating that CM in fish diets had no adverse effect on fish survival. Replacing FM with 25% CM gave the lowest Incidence Cost (IC) of 169.0 compared with the other treatments and also had the highest Profit Index (PI) of 1.77. To conclude, CM can replace FM as an alternative protein source profitably without any nutritional defect and therefore can be used at 25% in formulation of Nile tilapia fish diets.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Aquaculture development at the global level has been viewed as a means to enhance food security and supplementing income for rural families (FAO, 2012). There is an increasing demand for fish and fish protein globally, which in 2017 represented about 17% animal protein supply and 7% of all protein consumed globally resulting to wide spread fishing (FAO, 2020). The growth of global aquaculture has been sporadic over the last fifty years with almost comparable global production capabilities of culture and capture fisheries. This is attributed to technological advancements in fish production such as hybridization, genetic engineering, formulated diets and biofloc technology used in ponds, cages, tanks, and recirculation system (FAO, 2012).

Production of fish globally is estimated to have reached 179 million tonnes in 2018 valued at USD 401 billion out of which 82 million tonnes (46%) valued at USD 250 billion was from aquaculture production. From the overall total, 20.5 kg per capita annually was estimated from the 156 million tonnes (52%) used for human consumption (FAO, 2020). Production of fishmeal and fish oils took the balance of 22 million tonnes. Currently it has been reported that inland aquaculture produced 51.3 million tonnes of aquatic animals representing 62.5% of the world farmed fish production (FAO, 2020). In 2018, China remaining the major fish producer contributed 35% of global fish production, Asia, excluding China, contributed a significant share of 34%

while America, Europe, Africa and Oceania contributed 14%, 10%, 7% and 1% respectively (FAO, 2020).

African continent had a poor start, maybe as a result of high incidences of poverty, malnutrition and unemployment (Hecht, 2000) and lagged behind other continents in fish production, contributing only 1.8% (Bostock *et al.*, 2010; El Sayed, 2006; FAO, 2010a). In the last decade, African fish production showed an exciting phase of growth contributing to 7% of total fish produced globally where 17.9% of total fish produced in Africa was from aquaculture (FAO, 2020).

In Kenya aquaculture started in 1920s and since then has been on a slow growth until 2014 when it picked at 24,096Mt. However there was a drastic reduction in following years up to 2016 when the records showed 14952MT (KNBS, 2017). Aquaculture is mainly for subsistence, with little surplus production being sold in the rural market (Ngugi *et al.*, 2018).

The major constraints to aquaculture development in Africa especially Kenya is lack of adequate supply of quality fish feeds, high feed cost and lack of scientific data on fish especially tilapia's optimal feeding levels for optimized production of different classes and stages of fish (FAO, 2013; Munguti *et al.*, 2012; White, 2013).

Fish feeds industries mainly depend on fishmeal, which is preferred because of its superior amino and fatty acids profiles as well as its high palatability and digestibility (Chapman, 2006). Increased cost of production in fish farming sector is as a result of increased demand and unstable fishmeal

production (Jabir *et al.*, 2012). Most of the commercially manufactured feeds are made of grain, fishmeal and fish oil. These ingredients are rich in energy, protein, fat and other essential nutrients that various species of farmed fish require. However, these feedstuffs are scarce and expensive especially fishmeal and oils which forms the major ingredients of fish feeds. The Kenyan government economic stimulus package in 2009 to boost fish industry resulted in high demand of fish feed which could not be met due to limited supply of fishmeal. To meet the raising demand of fish feeds the market was flooded with poor quality feeds by some unscrupulous businessmen. Consequently, high prices of the fish feeds increased the cost of production and reduced the profit margins for the farmer (Charo- Karisa and Gichuri, 2010; Munguti *et al.*, 2014b).

According to Shepherd and Jackson (2013), fish feed constitutes 80% of production costs in aquaculture, protein being the key nutrient that influences market price of fish feed. Due to the increased production cost, researchers have been compelled to seek new alternatives for protein source which will provide similar nutritive value for optimal growth and development of fish at reasonable cost compared with fishmeal. In light of this, insect meals are being tested for their potential use as fishmeal replacements. Studies have shown that locust and variegated grasshopper meal can replace up to 25% fishmeal in fish feeds (Alegbeleye *et al.*, 2012; Balogun *et al.*, 2011). Good growth performance and nutrient utilization has been reported in African catfish fed with housefly maggot at 25-30% inclusion rate (Adewolu *et al.*, 2010; Sogbesan *et al.*, 2006).

Cricket meal (CM) not only has high crude protein level ranging from 55 to 73% but also has enough essential amino acids for the fish (Barroso *et al.*, 2014; Finke, 2002). However, cricket has a considerable amount of chitin; 8.7% dry matter, (Wang *et al.*, 2005), a nitrogenous substance (long-chain polymer of N-acetylglucosamine) in their exoskeleton (Chaudhari, *et al.*, 2011). This may inhibit nutrient digestion and absorption thus affecting production performance in monogastric animals (Karlsen *et al.*, 2017; Agboola *et al.*, 2005). It has been reported that CM can replace up to 100% of fishmeal and produce better growth performance than the control diet which contained fishmeal as the only source of protein in African catfish nutrition (Taufek *et al.*, 2013). This study therefore evaluated the potential use of the house cricket (*Acheta domesticus*) meal in the diet of Nile tilapia as an alternative source of protein to address the problem of the expensive and inadequate fishmeal in Kenya.

1.2 Problem statement

Aquaculture has great potential in Kenya due to increasing per capita fish consumption. Nile tilapia is the most farmed fish in the country due to its increased customer preference and recognized as lucrative start up fish farming enterprise. However, one of the most pressing challenges in its production is the lack of efficient and inexpensive fish feeds for different stages of fish development. Protein is the most expensive macro-nutrient in fish feeds production.

Most commercial fish feed production relies on fishmeal as the main source of protein which is expensive and its availability often unreliable because of diminishing marine capture resulting from overfishing. No other alternative, cheap source of protein for Nile tilapia feed has been validated and documented in Kenya. Substitution of fishmeal therefore with a more reliable, inexpensive insect meal such as *Acheta domesticus* which has comparable nutritional value to fishmeal is desirable.

1.3 Justification

Nile tilapia (*Oreochromis niloticus*) is among the common fresh water fish species that have a high demand in Kenyan market and is reared by many farmers who practice commercial aquaculture. The expansion and growth of the sector has been hindered by high cost of fish feeds which is as a result of costly fishmeal and oils which are the major components of fish feeds (Shitote *et al.*, 2001). Other sources of protein like soya beans have been exploited though their intensive use in fish feeds and other animal feeds has resulted in increased prices.

Insect meals have potential to be an alternative source of protein to fishmeal in fish diets. To date, numerous studies on insect meals as animal feeds have been done with good results in catfish production. However, no reliable evidence on the use of house cricket (*Acheta domesticus*) as an alternative source of protein to fishmeal for Nile tilapia diets has been documented in Kenya. This research will therefore aim at assessing the growth performance, optimal inclusion levels and survival rates of Nile tilapia

(*Oreochromis niloticus*) fed house cricket (*Acheta domesticus*) based meal as an alternative protein source for a cost effective and easily produced fish feeds.

1.4 Study objectives

1.4.1 General Objective

The general objective of the study was to assess the growth performance of Nile Tilapia (*Oreochromis niloticus*) fed on diets containing cricket meal (*Acheta domesticus*) at varying inclusion levels.

1.4.2 Specific objectives

- i) To determine the growth rate and feed conversion ratio of Nile tilapia fish fed house cricket (*Acheta domesticus*) based feed at varying inclusion levels.
- ii) To assess the survival rates of Nile tilapia fish fed house cricket (*Acheta domesticus*) based feed at varying rates.
- iii) To evaluate the cost benefit ratio of using house cricket (*Acheta domesticus*) based feed as a substitute to fishmeal at varying rates.

1.5 Hypotheses

To meet the objectives of the study, the following Null hypotheses were postulated;

- i) Growth rate and feed conversion rates of fish fed commercially prepared feed pellets containing fishmeal and the diet containing house cricket (*Acheta domesticus*) meal has no significant difference.

- ii) Inclusion of house cricket (*Acheta domesticus*) meal in Nile tilapia feeds does not significantly affect the survival of the fish.
- iii) The cost of feeding Nile tilapia using feed containing house cricket (*Acheta domesticus*) and that containing fishmeal is not significantly different.

1.6 Theoretical and conceptual framework

1.6.1 Theoretical framework

In any production system, various factors are involved in determining the kind of outcome one will get. In this research the theory of constraints (TOC) was applied (Bushong, *et al.*, 1999). The theory aims at optimising profit and the use of resources. Various factors were looked at to determine and to ensure the expected outcomes are not adversely affected. The variables considered to affect the outcome of the experiment included the animal factors and environmental factors.

Animal factors considered included the sex of the fingerling where male mono sex fingerlings were selected to ensure that breeding stress did not affect the growth of the fish during the experiment. Weight and size of the fingerlings at selection was also taken care of by selecting fingerlings with less than 40g (30g to 35g).

Environmental factors considered include the salinity of the pond water where liming of the pond was done prior to filling with water to stabilize the pH and also to kill any microorganism which could cause diseases to the fish affecting the results. To ensure water remained fresh and at expected levels of

water throughout the experiment, water was added to the ponds on a weekly basis. Water loss due to seepage and evaporation could affect the water levels. This also helped in aerating the water to maintain oxygen levels at optimum.

1.6.2 Conceptual framework

This defines the variables of research and how the independent variables influence the dependent variables. Production performance depends on several factors such as feeding, environmental and animal factors. Profitability in fish farming is greatly influenced by independent, dependent, and intervening variables (Figure 1.1).

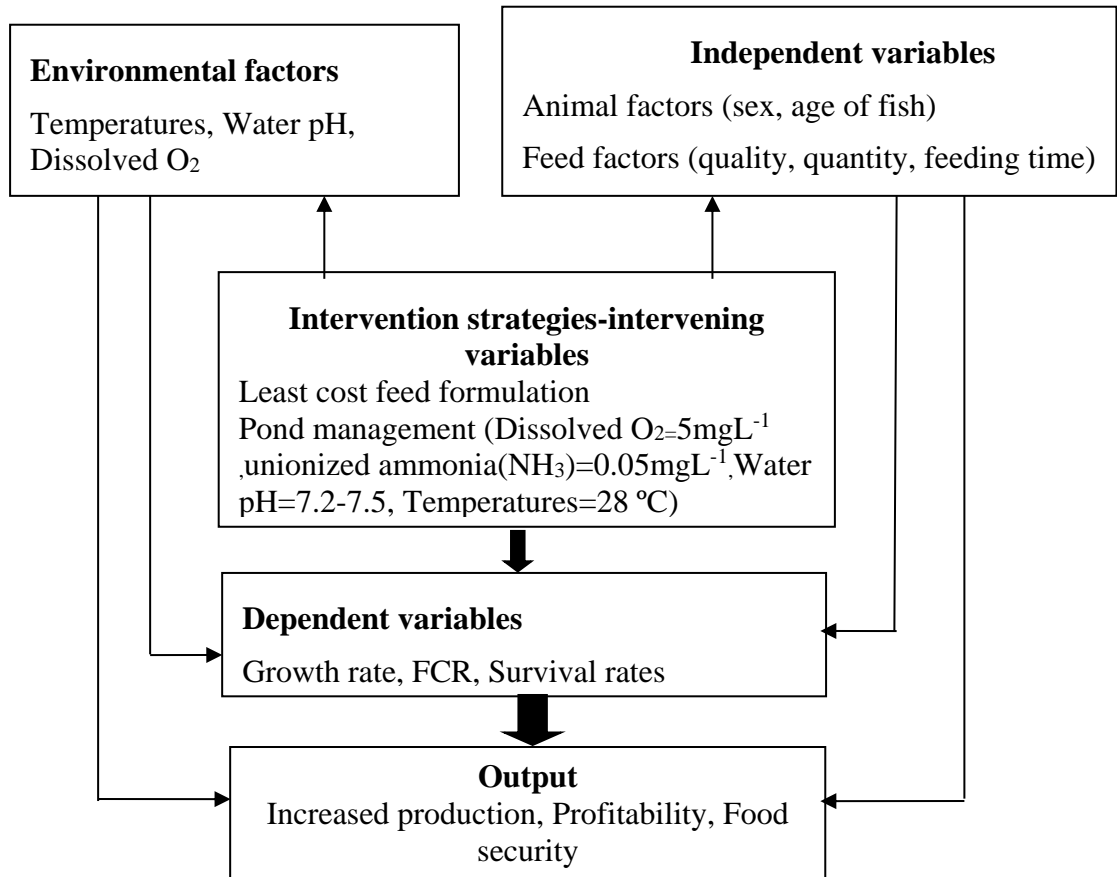


Figure 1.1: Conceptual framework (Adapted from Boyd, 2008)

1.7 Significance of the study

The current study established and documented the optimal inclusion levels of cricket meal in Nile Tilapia fish diets for a most cost effective fish production system. The continuous fluctuation in supply and increased price of fishmeal has indirectly increased the cost of production of farmed fish (Hardy, 2010) thus reducing the profit margin to farmers. Cricket meal offers an alternative source of protein in fish feeds which if validated would reduce overreliance on fishmeal. Realisation of use of insects as animal feeds and

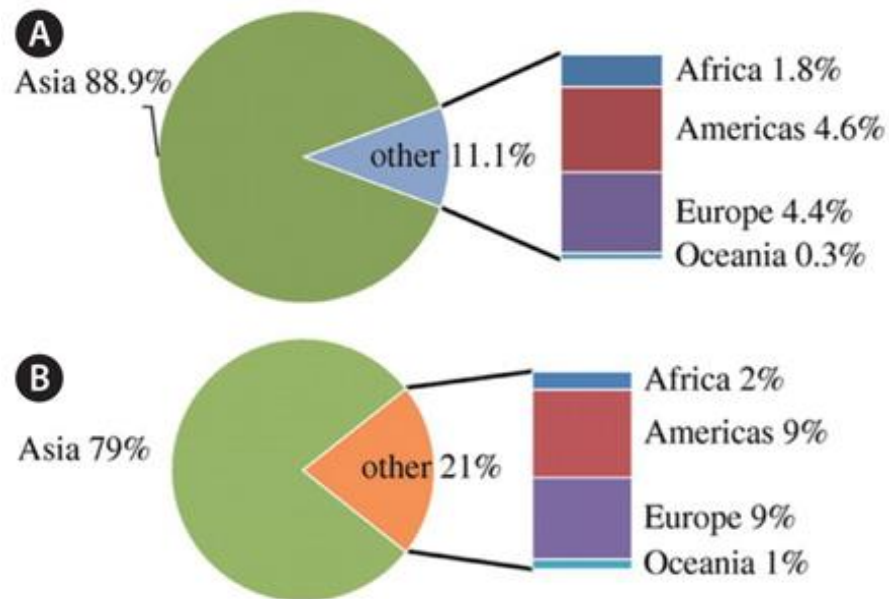
specifically as fish feeds that can produce better performance is an added advantage to the local farmers. The problem of over dependency on fishmeal which currently is the preferred source of protein by farmers can be solved by embracing the finding of this research that insects can be a better alternative.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of fish farming globally

Globally, growth of aquaculture industry over the last five decades has been sporadic with culture and capture fisheries production capability being comparable (FAO, 2012). Fish farming is the world's fastest growing sector of food production which up to 2016-2018 accounted for nearly 50% of world food fish (FAO, 2020). Hybridization, genetic engineering, diet formulation and biofloc technology used in ponds, cages, tanks and recirculation systems are some of the advanced technologies in fish production which have contributed to the sporadic growth coupled with increasing demand for the fish protein as food and feed (FAO, 2012). Nevertheless, the growth of global aquaculture has differed across the continents, Asia being the giant in aquaculture production compared to the other continents and projected to account for more than 90% of production by 2030 (FAO, 2020).

On global scale, Africa up to year 2008 was yet to realize any significant amount of aquaculture despite having huge natural resources (FAO, 2010a) where it contributed only 1.8 % of total aquaculture production (FAO, 2016) while America, Europe and Oceania produced 4.6%, 4.4% and 0.3% respectively (Figure 2.1). The growth has since then been on an upwards trajectory reaching 14%, 10%, 7% and 1% in America, Europe, Africa and Oceania in 2018 with Asia remaining the major fish producer contributed over 65% of global fish production (FAO, 2020).



(A) Aquaculture by quantity 2008 (excluding aquatic plants).

(B) Aquaculture by value 2008 (excluding aquatic plants)

Figure 2. 1: Global Aquaculture production by region (FAO, 2016)

2.2 Fish farming in Africa

The African continent has great potential for fish farming with 37% of its surface area suitable for artisanal fish farming and 43% for commercial fish production (Aguilar-Manjarrez and Nath, 1998). Though having great potential in terms of huge natural resources, the continent up to year 2008 was yet to realize any significant growth in aquaculture, maybe as a result of high incidences of poverty, malnutrition and unemployment (Hecht, 2000). The continent lagged behind other areas in fish production, contributing only 1.8% (Bostock *et al.*, 2010; El Sayed, 2006; FAO, 2010a). In the last decade, African fish production showed an exciting phase of growth

contributing to only 2196 million tonnes (2.67%) of fish on global scale of aquaculture production (Halwart, 2020). Currently, the production has risen to 7% of total fish produced globally where 17.9% of total fish produced in Africa was from aquaculture (FAO, 2020).

2.3. Fish farming in Kenya

In Kenya, fish farming was first practiced by the colonists in the early 1900s through introduction of trout in rivers for sport fishing (Ngugi *et al.*, 2007). According to Maar *et al.* (2007) this sport fishing progressed to static pond culture of species such as tilapia, common carp and catfish in the 1920s. The beginning of small scale rural fish farming in Kenya started as a result of establishment of Sagana and Kiganjo fish farms for production of warm and cold water seed fish in 1948 which later become popular in 1960s (Ngugi *et al.*, 2007; Ngugi and Manyala, 2004; Nyonje *et al.*, 2011).

In recognition of aquaculture as a viable option for revamping the country's food sector, Kenyan government initiated the ambitious fish farming and productivity programme funded under Economic stimulus project (ESP) in 2008 to stimulate economic development, foster economic recovery, alleviate poverty and spur regional development (Nyonje *et al.*, 2011). The project was implemented within the 2008 and 2012 financial year, leading to an increase in fish pond area from 220 ha in 2008 to 468 ha in 2009 and a total gross land for aquaculture from 728 ha in 2008 to 825 ha in 2009 (Obwanga *et al.*, 2017). This presented a lucrative opportunity for aquaculture development in the feed

sector, however the basic problem of scarcity of fishmeal as preferred protein source still persist.

Despite the initial gains in growth in aquaculture realised due to ESP, the sector has faced setbacks with reduced production from 24,096 MT in 2014 to 14,952 MT in 2016 (Figure 2.2), (FAO, 2016a; Obwanga *et al.*, 2017; KNBS, 2017).

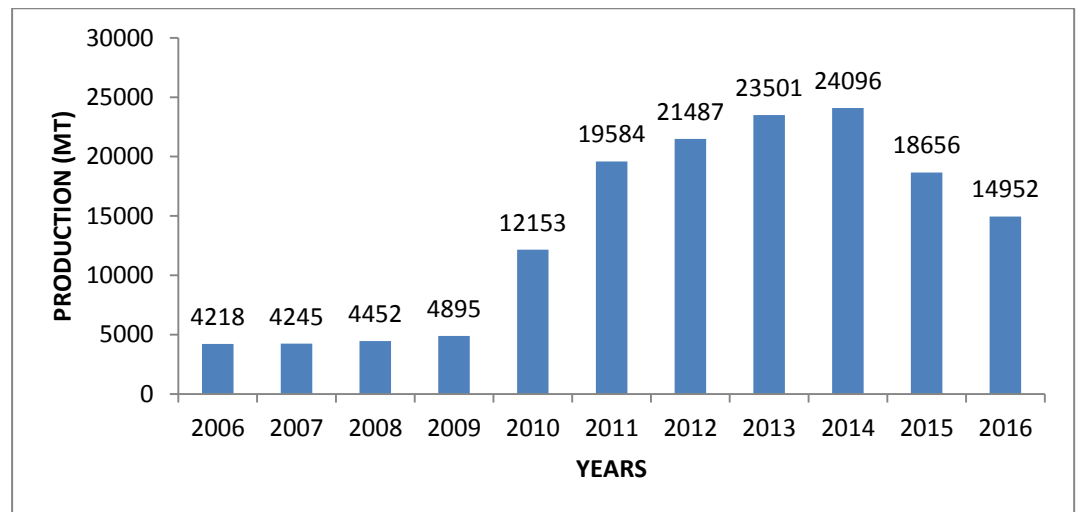


Figure 2. 2: Aquaculture production in Kenya from 2006 to 2016 (FAO, 2016a; Obwanga *et al.*, 2017)

Similarly, the number of operational fishponds reduced from 69,194 in 2013 to 60,277 in 2015, shrinking the operational area from 2,105 to 1,873 ha in 2013 and in 2015 respectively (Ogello and Munguti, 2016; SDF, 2016). Fish production continues to decline this being attributed to low quality and quantity of fish farm inputs, especially fish feeds.

Most parts of Kenya are suitable for aquaculture; However fish farming is practiced on small scale mostly in parts of former Central, Nyanza, Coastal

and Rift Valley provinces (Ngugi *et al.*, 2007; Nyonje *et al.*, 2011). These regions accounts for only 0.014% of the 1.4 million ha of potential aquaculture sites (Otieno, 2011). Other parts of the country have great potential for pond-based aquaculture of Nile tilapia and African catfish (Rothuis *et al.*, 2011).

There are several designated aquaculture development, training and research facilities found in various parts of the country that also serve as sources of fingerlings and feed for fish farmers. They include the National Aquaculture Research Development & Training Centre (NARDTC) in Sagana, Kisii Fish Farm Training Centre, Kiganjo Trout Farm, Ndaragua Trout Farm, Chwele Fish Farm, Lake Basin Development Authority (LBDA) in Kisumu, Wakhungu Fish Farm in Busia, Sangoro Research Station, Kegati Research Station, and Kabonyo and Ngomeni Fish Farms (Anonymous, 2016; Censkowsky and Altena, 2013). The Government of Kenya (GoK), the private sector and a number of Non-Governmental Organizations (NGOs) have also been supporting aquaculture development in Kenya (Rothuis *et al.*, 2011).

Aquaculture provides communities with improved nutrition through the provision of valuable fish protein (FAO, 2012). The average per capita annual fish consumption in 2010 was 5 kg person⁻¹ year⁻¹ which is below the FAO recommended average of 20 kg person⁻¹ year⁻¹ (Rothuis *et al.*, 2011) and the contribution of fish to overall animal protein intake in Kenya is still very low (5.7%) (FAO, 2016a). Freshwater fish consumption in 2014 was estimated at 195,206 tonnes. The demand is expected to reach 270,000 tonnes of fish per

year to maintain per capita fish consumption by the year 2030 when the human population is estimated to reach 67 million (FAO, 2019).

Aquaculture also creates employment for under privileged groups, such as women and young people (Hino, 2011; Hishamunda and Ridler, 2006; Jagger and Pender, 2001). In Kenya, men are heavily involved in fishing activities and women predominate in fish processing and marketing. However, it would be desirable if all players are integrated in all aspects of fish production (Hino, 2011; Jagger and Pender, 2001; Weeratunge *et al.*, 2010). In addition, combining aquaculture with other activities such as rice farming proved to increase the profit to fish farmers by double in Thailand (Aiga *et al.*, 2009; Kawarazuka and Bene, 2010). This can also be tried in Kenyan rice farms.

2.4 Tilapia fish farming

2.4.1 Tilapia species and distribution

Tilapia is a common name given to three genera of fish in the family Cichlidae namely *Oreochromis*, *Sarotherodon* and *Tilapia* (Santiago and Laron, 2002). The principle species of the genus *Oreochromis* include Nile tilapia (*Oreochromis niloticus*), Mozambique tilapia (*Oreochromis mossambicus*) and blue tilapia (*Oreochromis aureus*). Tilapia is the most preferred cultured fish in East Africa though the second most important cultured fish in the world after carps (Dan and Little, 2000; El-Sayed, 2006). *Oreochromis niloticus* constitute 90% of all tilapia cultured in Africa (Lorenzen *et al.*, 2001; Popma and Masser, 1999).

According to Chimitis, 1957, culturing of tilapia started in 2000 – 2500 BC and since then there has been a steady increase in the global trends of cultured *O. niloticus* (Figure 2.3); (FAO, 2016b). The growth was attributed to high resistance to diseases, ability to survive in low oxygen tensions and ability to feed on wide range of foods. This species of fish is a mouth brooder and also occurs in diverse habitats, with different environmental conditions (Pullin and Lowe-McConnell, 1982).

The species mostly inhabits freshwater and thrives within temperature range of between 25°C and 31°C (Huet, 1972). They can tolerate extreme environmental conditions, such as hypoxic conditions of 1.0 to 1.5 mg L⁻¹ of dissolved oxygen and very low temperatures, as low as 8 to 10°C, and high temperatures up to 42°C, but stops growing at 16°C (Yashouv, 1960) and according to Bowen, 1982, it can tolerate salinities of up to 35 mg L⁻¹.

The geographical distribution for this species is quite diverse. The species is native to Africa and Israel (Chervinski, 1982). Lagler *et al.*, 1977 noted that the species is present and widely distributed in Palestine, Central America, Southern India and Sri Lanka.

In Africa, the species is absent only in the northern Atlas and South West Africa. It is widely distributed in East and South Africa in coastal rivers, lakes, lagoons and estuaries from southern Kenya to the Eastern Cape in South Africa (Philipart and Ruwet, 1982). Moreover, because of its value as culture fish, the species has been introduced into many parts of Africa as well as Madagascar, North and South America, Europe, Asia, Australia and in the Pacific Islands. Thus the species are distributed all over the world not by

geographical barriers, but rather by ecological behavioural barriers such as temperature, dissolved oxygen, food and feeding habit (Philippart and Ruwet, 1982).

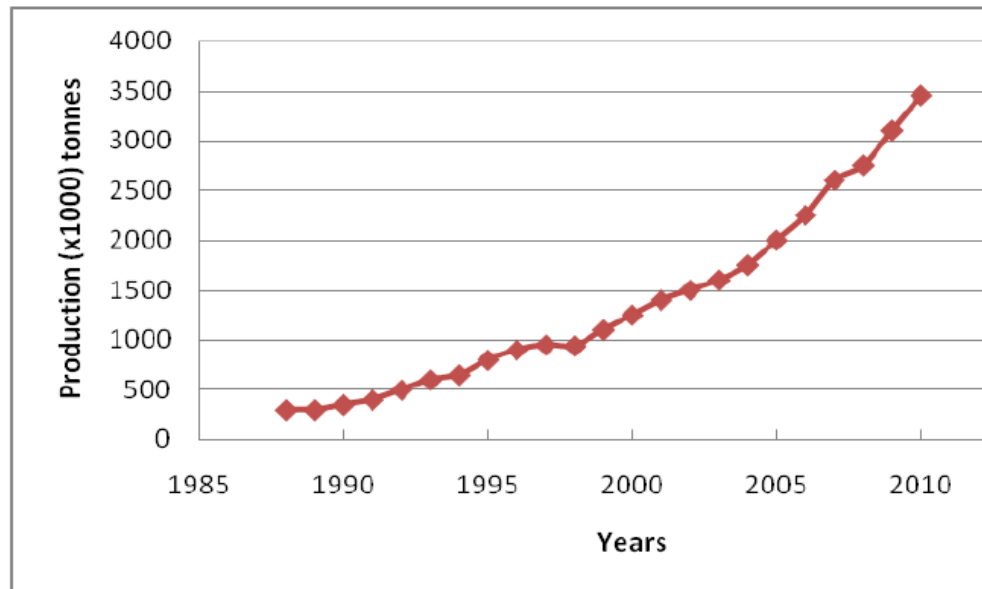


Figure 2. 3: Current global aquaculture production trends for Nile tilapia (*Oreochromis niloticus*), (FAO, 2016b)

2.4.2. Growth characteristics and nutritional requirement of Nile tilapia

The nutritional requirements of *Oreochromis niloticus* reviewed by Stickney (1993) and Bowen (1982) shows the adult of the species can be considered both herbivorous and detritivorous. The young of the species feed largely on phytoplankton and detritus; hence, the species undergoes ontogenic feeding niche shifts (Zagnini *et al.*, 2012). Dempster *et al.* (1995) further determined that *O. niloticus* are particularly adept at assimilating energy from algal chlorophyll and other plant sources. According to this author, the ability is related to the low pH generated in their stomach (pH of 1.0 to 1.25) as

compared to moderate values in other animals (pH of 2.0 to 2.2). The species also has a long intestine, which may be 7 to 10 times the fish length (Moriarty and Moriarty, 1973). Both of these adaptations make *O. niloticus* particularly good at extracting energy from plant matter and allow inexpensive supplemental feeds to be useful in its culture. Therefore, *O. niloticus* is capable of growing on relatively low quality foods, such as benthic detritus aggregates (Dempster *et al.*, 1995).

2.4.3 Economic significance of Nile tilapia (*Oreochromis niloticus*)

Oreochromis niloticus is quite an important species in the aquaculture industry. It contributes to 51.7% of the world tilapine production (FAO, 1993), which was estimated to be between 390 and 821 metric tonnes. *Oreochromis niloticus* has a wide distribution in the world and is an important aquaculture fish species especially in the tropical and sub-tropical countries (Dagne *et al.*, 2013; El-Sayed, 2006). This species is considered to be one of the most productive and internationally traded food fish globally (Chakraborty and Benerjee, 2012; Hernandez *et al.*, 2013; Siddik *et al.*, 2014). It has become a lucrative start up agricultural activity and established fish farmers expanding their production scale as a result of increased consumption across the world (Fitzsimmons, 2005; Ogello *et al.*, 2014).

In Kenya, *O. niloticus* has become very popular among the fish farming communities, a delicacy in rural and urban dwellers and because of its good taste, ease of cooking and health benefits, it is preferred in many hotels and restaurants (Githukia *et al.*, 2014; Kyule *et al.*, 2014). *Oreochromis niloticus*

are easy to culture because they grow in wide range of environmental conditions with low trophic levels for feeding and tolerant to handling stress and poor water quality (Dagne *et al.*, 2013; Liti *et al.*, 2005; Tsadik and Bart, 2007). They also grow very fast under relatively high stocking densities and are highly productive. However, the species exhibits precocious sexual maturity, which results in large numbers of stunted, and sometimes unmarketable sizes, a factor that has for long presented a problem to aquaculturists due to losses (Chakraborty *et al.* 2011; Roderick, 1997). Balarin (1979), also reported that the species attains first sexual maturity when they reach a size of about 15 cm or even less generally at about six months old and thereafter, they spawn every six weeks. This presents a major problem in culture, as they have a tendency to rapidly overpopulate ponds especially in the absence of predators. This therefore calls for more improved culture methods, where cage culture has proved worthwhile (Chakraborty and Benerjee, 2012). Also to curb the challenges, monosex populations of *O. niloticus* are used which have increased production potential and management requirements are low (Beardmore *et al.*, 2001; El-Sayed, 2006).

2.5. Nutrition and feeding of *Oreochromis niloticus*

Good nutrition in animal production systems is essential to economically produce a healthy, high quality product (Ali and Jauncey, 2004; De-Silva *et al.*, 2007). Fish feeds can be categorized as either natural or artificial. Natural feed are organisms that fish find and exploit in their surroundings and may include worms, planktons, insects and many others.

Artificial feed are processed in factories mainly in pelletized form and are made of grain, fishmeal and fish oil which have high proportion of protein and fat. However the rising prices of these products has led to their reduction in fish feeds (Shitote *et al.*, 2001).

Complete diets supply all the ingredients (protein, carbohydrates, fats, vitamins, and minerals) necessary for the optimal growth and health of the fish. Most commercial fish farmers use complete diets, those containing all the required protein (18-50%), lipid (10-25%), carbohydrate (15-20%), ash (< 8.5%), phosphorus (< 1.5%), water (< 10%), and trace amounts of vitamins, and minerals (Steven, 2017).

2.6. The status of fish feeds in Kenya

In any fish farming venture fish feeds is a key component since it accounts for 40-50% of total variable production cost on the enterprise (Craig and Helfrich, 2002; Munguti and Charo- Karisa, 2011). According to Munguti *et al.*, (2011), one of the most pressing challenges in Kenyan aquaculture is the lack of efficient and inexpensive farm-made feeds for different stages of fish development. Protein is the most expensive macro-nutrient in fish feeds as well as the main limiting factor in fish feed production (Shitote *et al.*, 2001).

In Kenya, most cultured fish are reared in fish ponds and fed with locally available and low cost agricultural by product materials such as rice bran, wheat bran, cassava meal and corn meal which are used to produce farm-made feeds. However, most farmers are often unaware of the nutrient requirements of their farmed fish species (White, 2013). In addition, these by

product materials are deficient in macro and micro-nutrients while the high content of crude fibre in some bran reduces the digestibility and palatability leading to low fish yields (Liti *et al.*, 2006).

In established grow-out fish farms, fish are fed twice a day (morning and evening) with between 26 - 30% CP diets while fingerlings are fed at least 2 times a day at 3% body weight with 30 - 40% CP diet. The feeding is done at the same time and place daily through hand feeding method (FAO, 2005; Nunoo *et al.*, 2012).

In 2009, the GoK through the Economic Stimulus Programme (ESP) initiative promoted commercialization of the Nile tilapia and African catfish production which led to increased demand for fish and many farmers engaged in aquaculture (FAO, 2013; Hino, 2011; Manyala, 2011). As a result of the government initiative through the ESP, fish production increased from 1,012 metric tons (MT) produced in 2003 to 21,487 MT in 2016 and more farmers were engaged in fish farming (Munguti *et al.*, 2014a). This led the Kenyan fish feed sector to experience a shortage of 14,000 MT/year of fish feeds (Charo-Karisa and Gichuri, 2010). Since then the demand has been increasing over the years leading to unscrupulous dealers taking advantage to compromise the quality of fish feed which led to the establishment of fish feed standards as shown in Appendix I which are currently being used in the country (ESP, 2012/2013 aquaculture working group). This initiative led to the ESP nutrition team together with other aquaculture stakeholders to establish a vetting process for fish feeds manufacturers. Until 2014, fifteen fish feeds firms were

approved (ESP aquaculture working group 2012/2013). This initiative assisted in ensuring that quality of ingredients for formulating fish feed, proper handling and storage conditions were observed, which in turn significantly improves the feed and affects the performance of the fish (Awity, 2013; Munguti *et al.*, 2014b; Tacon *et al.*, 2013).

2.7 Fishmeal as used in the fish feed formulation

According to FAO (2002), fish feed is the major cost in any aquaculture production taking about 60-70% of total cost of production with the most limiting factor being protein which tends to influence the market prices for fish feeds. Nguyen and Dang (2009) and Phen *et al.*, (2009), also reported that fish feeds are of two types, pelleted feeds and farm-made feeds, where farm made feeds include trash fish and other animals, constituting 50 to 70% of the overall feed formulation. The pelleted feeds on the other hand contain the fishmeal as the main protein source and are prepared according to the fish nutritional requirements. These sources are expensive especially to the small scale farmers and therefore further studies for a cheaper alternative to replace these protein sources are required.

Fishmeal is highly utilized in the fish feeds formulation due to its rich nutrient properties and also due to the current laws restricting the use of most meat meals due to food security which has led to use of fishmeal as the most preferred source of protein in animal feeds manufacturing (Sanchez-Muros *et al.*, 2014). This has led to continued price increase of fishmeal (omona) used in fish feed formulation.

2.8 Potential of insects in aquaculture diets

Utilization of insect meals as animal feed has been given a lot of emphasis in recent years and numerous studies conducted to find alternative sources of protein to cater for the unstable fishmeal production. Howe *et al.*, (2014) reported that since insects are well known for their part in the natural feed for freshwater and marine fish, they can be a good alternative source of protein in the fish diets. Apart from being a sustainable resource, their nutritive value can be maximized by rearing them under different environmental conditions (Premalatha *et al.*, 2011).

Due to their high protein contents, sufficient amino acids and potential to reduce carbon footprint, insects are considered as prospect replacements for fishmeal in fish diets (Henry *et al.*, 2015). Various insects have shown comparably good nutritional profiles; house cricket (*Acheta domesticus*) which was tested in walking cat fish had 8.5 % of ether extract and 57.3% CP (Emehinaiye, 2012; Johri *et al.*, 2011; Van Huis *et al.*, 2013) and Black soldier fly (*Hermetia illucens*) which was tested on channel cat fish and rainbow trout was reported by various researchers to have 15% of ether extract and 40.7% CP (Bondari and Sheppard, 1981; Kroeckel *et al.*, 2012; Lock *et al.*, 2014; Sealey *et al.*, 2011).

To sustain the demand and production of sufficient amounts of fish feeds, these insects could be cultured in mass production, cost effectively by feeding them on agricultural by products especially the vegetables and this

optimizes economics and environmental expenses (Makkar *et al.*, 2014; Tran *et al.*, 2015; Van Huis *et al.*, 2013).

Rearing of insects is highly efficient as they require less maintenance, less energy to maintain their high body temperatures and be reared in little space and with less water giving them a very prominent advantage over crops (Rumpold and Schluter, 2013). Insects can feed on waste biomass, for example vegetable and fruit wastes, and can transform this into high value protein, in turn potentially replacing soya meal or fishmeal in livestock and aquaculture feeds (Ayieko *et al.*, 2016).

2.8.1 Potential of house cricket (*Acheta domesticus*) meal in animal diet

House cricket (*Acheta domesticus*) is one of the most important species used as pet trade and has been domesticated by the Chinese as a pet since the 12th century to be used in cricket fights and is also the most abundant species in pet stores, supplied as fish bait or supplemental feed for ornamental fish and reptiles (Suga, 2006).

Additionally, Mormon cricket (*Anabrus simplex*) has been studied as poultry feed and according to Lorch *et al.* (2005), it is widely distributed in North America in the rangelands. It can replace fishmeal and soybean in broiler diets without affecting growth (Ramos-Elorduy, 2008).

Gryllus testaceus is another cricket species studied in China in poultry feedstuffs, where no adverse effect on growth of broilers fed up to 15% of *G. testaceus* was recorded (Wang *et al.*, 2004). Although crickets are found widespread all over the world, studies to investigate their potential as fish feeds

in animal feeds industry are limited. However, Taufek *et al.* (2013) has shown that CM can replace up to 100% of fishmeal and produce better growth performance than the control diet which contained fishmeal as the only source of protein in African catfish nutrition.

2.8.2 Breeding and production of house cricket (*Acheta domesticus*)

House crickets (*Acheta domesticus*) are omnivorous and can feed on a wide range of organic materials like any other insect (Galloway, 1998). They are easy to farm producing 6 to 7 generations a year and do well in temperatures ranging from 28 to 30°C with a stocking density of 2000 per m² (Walker, 2014). Population control is by cannibalism among themselves (Hardouin *et al.*, 2003).

During mating time, the male will chirp loudly to attract the female mate. After mating, the females lay their eggs in moist sand or soil (Clifford and Woodring, 1990). Mass production is done under controlled conditions (Taufek *et al.*, 2013) and the eggs should be kept moist and at temperatures above 20° C (Sharon, 2016). House cricket (*Acheta domesticus*) and other species of cricket like the field cricket (*Gryllus bimaculatus*) are edible and a common human food in South East Asia, particularly in Thailand (Van Huis *et al.*, 2013).

2.8.3 Nutritive value and chemical composition of house cricket meal

The digestibility of insect proteins and their utilization *in vivo* have been reported to be good, ranging between 75% and 95% (NRC, 1993). Research has shown that cricket meals have crude protein ranging between 50% and

82% and crude lipids (CL) of 8% to 35 % (Gasco *et al.*, 2016; Rumpold and Schluter, 2013). The CP and CL profiles of house cricket meal and fishmeal are incomparable (Table 2.1) (Taufek *et al.* (2013). Every essential amino acid required for the fish, including the limiting amino acid; methionine and lysine in CM are within the acceptable standards (Makkar *et al.*, 2014; Taufek *et al.*, 2013). However, cricket has a considerable amount of chitin; 8.7% dry matter, (Wang *et al.*, 2005), a nitrogenous substance (long-chain polymer of N-acetylglucosamine) in their exoskeleton (Chaudhari, *et al.*, 2011). This may inhibit nutrient digestion and absorption thus affecting production performance in monogastric animals (Karlsen *et al.*, 2017; Agboola *et al.*, 2005)

Table 2. 1: Chemical constituent in cricket compared to fishmeal (Taufek *et al.* (2013).

Component	Fish meal (omena)	Cricket meal
Dry matter (%)	85.5	95.2
Crude protein (%)	53.6	57.0
Crude lipid (%)	1.4	25.8
Crude ash (%)	19.2	4.8

2.9 Performance of fish fed on cricket meal

Over the years, researchers have studied insects as substitute for fishmeal. Common insect meals include; maggot meals, flies, silkworms in poultry and fish feed. Cricket meal (CM) can reduce the cost of production in

fish farming as it has potential in replacing fishmeal whose availability is very volatile and expensive (Taufek *et al.*, 2013). However, information about house cricket (*Acheta domesticus*) meal as protein source for Nile tilapia fish feed is scarce (Wang *et al.*, 2005). A recent study on growth rate and inclusion levels of CM in cat fish (*Claris gariepinus*) have shown favourable results where 100% CM inclusion level was considered as optimal. However, growth reduction was observed in diet containing CM at inclusion levels lower than 100% compared with 100% inclusion (Taufek *et al.*, 2013).

Further studies on CM in Nile tilapia (*O. niloticus*) are necessary in order to document its capacity to replace fishmeal and hence reducing production cost as compared with fishmeal whose availability is expected to diminish over time.

2.10 Potential risks of using cricket as feed

House cricket (*Acheta domesticus*) is known to be affected by a densovirus and this may greatly affect the production of this insect (Weissman *et al.*, 2012). Food Agriculture Organization, (2013) recommended that a parental line of the insect should always be preserved for mass rearing.

Crickets, like other insects, can also bio-accumulate heavy metals such as lead and selenium if fed on organic matter from soils with these metals and although this accumulation of metals may not kill the insects, it can be toxic to fish (Vijver *et al.*, 2003). Rearing insects therefore should not be done on substrate originating from areas with high levels of heavy metals.

However, the main risks are food substrates and the handling, storage of farmed insects and contamination from the environment rather than the insect species themselves (Ayieko *et al.*, 2016). In view of this, hygienic conditions in the rearing of insects are important and need to be observed. Ekesi and Mohamed (2011) pointed out that stable rearing conditions and diet formulas have great influence on growth, survival, fecundity, fertility and mating ability of crickets in large scale rearing operations.

2.11 Economic analysis

An economic analysis of any aquaculture enterprise would give the profitability benefit of the enterprise. In the current study, to compare the different treatments effects in terms of profitability, enterprise budgets were conducted. An enterprise budget is an estimate of the costs and returns associated with the production of a product or products (Shang, 1990).

2.11.1 Fish production using fishmeal and insect meal

Fishmeal and fish oils are vital ingredients whose usage in aquaculture has risen to 2.94 million and 0.80 million tonnes in 2003, representing 53.2 and 86.8%, respectively (Tacon *et al.*, 2006). Farming of carnivorous fish did put unnecessary pressure on fishmeal by consuming five times more fish protein than what is produced (Naylor *et al.*, 2000). Some fish and other aquatic species are specifically targeted for their conversion into fish meal and oils.

According to Anon, 2004 in Fish Information Network (FIN), aquaculture is the biggest user of fishmeal accounting for up to 46% on global use. Major consumers of fishmeal are Asia, Europe and America though they

are minor in fish oils consumption. Half of fishmeal usage in Europe is for aquaculture, particularly the fin fish and crustaceans production.

European aquaculture mostly sources their fishmeal from European feed fisheries (FAO, 2006; Huntington, 2009). Peruvian anchovy and Chilean jack mackerel are both imported from South America for use in the European fish feeds (FAO, 2006). The balance of fishmeal is obtained from processing the wastes.

Aquaculture is growing at a very high rate as a food industry globally (FAO, 2017). The sector contributes more than half of global fish production, amounting to 66.6 million tonnes in 2012, which was valued at US\$ 137.7 billion and is expected to grow by 62% in 2030 (FAO, 2016b; FAO, 2014; Shaalan *et al.*, 2017). As the demand for aquafeeds continue to increase, more pressure is being placed on the relatively fixed global supply of fishmeal and fish oils (Seafeeds, 2003). The world population will also continue to increase and therefore the global production of aquatic food will need to increase to meet the needs of the growing populations (Magalhaes *et al.*, 2017). This therefore calls for more studies aimed at ensuring sustainability of the industry (Taufek *et al.*, 2017) and also to reduce resource consumption, the environmental impact of aquaculture and simultaneously increase productivity and profitability of the sector (Asche *et al.*, 2008; Bossier & Ekasari, 2017; FAO, 2017).

Research on sustainable food resource to allow for continuity of aquaculture sector at economically and environmentally sustainable levels is

therefore important (Barroso *et al.*, 2014). Sustainable food resource will also allow optimal growth and development of fish (Ayoola, 2010) and also replace fishmeal as a protein source to the fish (Van Huis *et al.*, 2013). The reason for all this is because of the fact that fishmeal is becoming environmentally unsustainable and it contributes to the high prices of the fish feed formulations (Hardy, 2010). Prices of feeds are the sole cause of slowing down the sustainable development of the industry as the rise of feed prices are not reflected in the final product sale price (Adwan, 2017) and therefore the economic feasibility of the individual business is highly affected (Shaanan *et al.*, 2017).

In this light therefore the alternative solutions to limit the environmental burden and contain the farming costs are being researched for and also those which can allow a better quality commercial feed with reduced prices. Substitute for fishmeal as a protein source is therefore desirable with the aim of ensuring robustness in the fish performance, good quality feed and minimize the environmental impact.

Due to the problem of fishmeal having a negative impact on the environment and the economic sustainability of the sector, the European Commission came up with guidelines 893/2017 allowing the use of insect meal in fish diets, their production and the amounts to be used in the feeds (Henry *et al.*, 2015; Magalhaes *et al.*, 2017). Only three species of insects were allowed for use as insect meals with the house cricket (*Acheta domesticus*) being one of them. Others included the silent cricket (*Gryllus assimilis*), the tropical cricket

(*Grylloides sigillatus*), the black soldier fly (*Hermetia illucens*), the common fly (*Musca domestica*), the yellow mealworm beetle (*Tenebrio molitor*), and *Alphitobium* (*Alphitobius diaperinus*).

In respect to the protein content and amino acid profiles, insects represented a valid substitute of fishmeal as was confirmed by several researchers (Barroso *et al.*, 2014; Henry *et al.*, 2015; Magalhaes *et al.*, 2017). These insects are good candidates to solve the problem experienced in the fishmeal production industry because they have low environmental impact and require less arable land for their production as depicted by researchers (Henry *et al.* 2015; Oonincx and De Boer, 2012). They also exhibit a rapid breeding cycle (Gasco *et al.*, 2016) and have high valued protein content (Henry *et al.*, 2015) which varies between 50% and 82% (Rumpold and Schluter, 2013). Requirements for protein for various fish species range between 28% and 55% (Henry *et al.*, 2015).

The intensification of the aquaculture sector therefore requires use of a high protein diet which is important in the sector so that growth of individual company is driven by the use of insect as fish feed as they have high protein profile (Shaanan *et al.*, 2017). Also considering the forecast of BOM (2016), about the competitiveness of prices of insect proteins which will be low compared with fishmeal after 2023. Mass rearing of these insects will allow for stable quantity production with high quality and constant supply (Sanchez-Muros *et al.*, 2016) coupled with price reduction (Mancuso *et al.*, 2016).

Presently the cost of insect meals is still not competitive compared with other protein sources (Koeleman, 2014).

An economic analysis of any aquaculture enterprise would give the profitability of the enterprise. In the current study, to compare the different treatments effects in terms of profitability, enterprise budgets were conducted.

An enterprise budget is an estimate of the costs and returns associated with the production of a product or products (Shang, 1990). There are two type of enterprise budgets namely complete and partial budgets.

Complete enterprise budgets are comprised of all the cost and revenue items to a single statement using the given budget basis and reporting period (Ernest, 2001). Cost and revenue items are totalled and net profit or loss is calculated. Each item is quantified by a unit cost and the number of units used or produced. Variable costs vary with the size of the enterprise and management decisions made (Hepher and Pruginin, 1981). They are therefore inputs that would not be used if production ceased. In the current study, variable costs included fingerlings, feed, agricultural lime, and labour.

2.12 Summary of literature and gaps identified

From the literature it is clear that aquaculture and fin fish farming is an important sector in the world and in the region.

The use of insect meal is gaining preference as an animal feed due to the fact that the insects have low environmental impact and they require limited space for their production as well as having rapid breeding cycles. They also have a high protein contents and a very good amino acid profile desirable for

the growth of fish (Gasco *et al.*, 2016; Henry *et al.*, 2015; Oonincx and de Boer, 2012).

The main cost of production in aquaculture being cost of feeds and with a very volatile and unstable production of fishmeal which is currently the most preferred source of protein to the fish an alternative source is desirable for economically and environmentally sustainable aquaculture production. Although cricket meals have been recommended as a good fish feed, there has not been documented evidence of its utilization or inclusion levels in Nile tilapia fish production. Furthermore, due to the high cost of fishmeal, it was urgent to evaluate cricket meal as a replacement for fishmeal in fish feeds. This research evaluated the suitability of using cricket meals for fish feeds in terms of growth performance of the fish, whether their survival were affected adversely by the feed or not and the cost of producing the fish using the insect meal, in this case the house cricket meal, as an alternative source of protein as compared with the fishmeal.

CHAPTER THREE: MATERIALS AND METHODS

3.1 The Study Area

The study was conducted at Kenya Marine Fisheries Research Institute (KEMFRI) Sagana fish farm located 2 km from Sagana town in Kirinyaga County, and 105 km Northeast of Nairobi City (Figure 3.1). The farm lies at a latitude $0^{\circ} 39'S$, longitude $37^{\circ} 12'E$, and altitude of 1230 m above sea level. Sagana experiences a warm-humid climate in most parts of the year, with a mean temperature range between 17 to $26^{\circ}C$ (Veverica and Bowman, 1999). The farm lies on gently sloping plains within the meander of River Ragati, a tributary of the Tana River on the Southern slopes of Mt. Kenya. Water flows to the ponds through gravity by a diversion canal approximately 1.5 km on the west of the farm. The soils of the area are mainly black-cotton soils with a pH range of 5.4 to 7.5 (Veverica & Bowman, 1999).

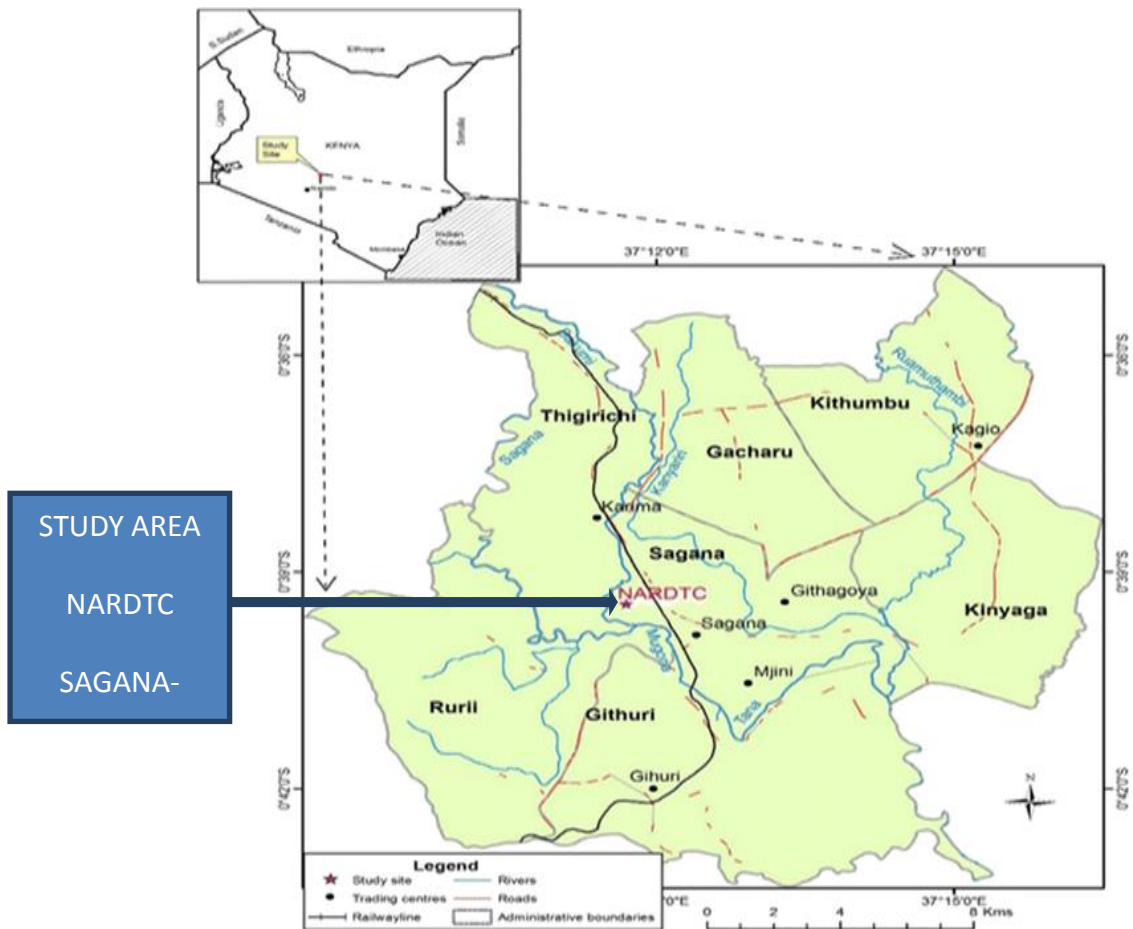


Figure 3. 1: Map of study area (Omondi *et al.*, 2017)

3.2 Experimental diets

House crickets (*Acheta domesticus*) were obtained from the International Centre for Insect Physiology and Ecology (ICIPE), dried in an oven at 60° C until constant weight in a forced air oven and then milled to fine powder before being used in the treatment diets formulation. The other ingredients for compounding the treatment diets were fishmeal (omena), wheat pollard and maize germ, which were purchased from local feed centres in Sagana and Thika towns. All the ingredients were grounded, right proportions hand mixed and water added prior to pelletizing using a feed pelletizer machine

(HDC- Henan model, China) to produce 4mm sized pellets which were then sun dried and stored for use.

Five iso-nitrogenous diets (35%CP) were formulated using wheat pollard, maize germ and either fishmeal as the main source of protein (treatment 1); 25% replacement of fishmeal with cricket meal (treatment 2); 50% replacement of fishmeal with cricket meal (treatment 3); 75% replacement of fishmeal with cricket meal (treatment 4) and 100% replacement of fishmeal with cricket meal (treatment 5) (Table 3.1). Winfeed (version 2.8) software was used to formulate diets (Suresh, 2016; Winfeed, 2012), employing the least cost feed formulation. It can handle unlimited number of ingredients and nutrients making it suitable in this experiment.

Table 3. 1: Proportions of ingredients used to formulate the trial diets

Ingredients (g/kg)	Treatments				
	T1	T2	T3	T4	T5
Fish Meal (omena)	40.67	30.79	21.05	11.32	0
Cricket Meal	0	12.65	25.3	37.97	50.02
Maize Germ	25	22.16	21.04	20	21.92
Wheat Pollard	34.33	34.41	32.61	30.73	25.06
Totals	100	100	100	100	100
Calculated chemical					
Composition (%)	34.94	34.95	34.93	34.94	34.94
Crude protein					

3.3 Experimental procedures and design

The study was set up in a large earthen pond of an area of 800 m², which had been limed using agricultural lime at 2.5 tonnes ha⁻¹ to kill any microorganism present in the pond and also to stabilize the pH prior to water filling to a depth of 1 m and fish stocking (Appendix II and III). Fifteen (15) hapa nets (cages) measuring 2x2x1M were prepared, mounted in the earthen pond and supported to the pond banks to avoid being swayed by the wind. The tops of the cages were covered with a cover net to prevent bird predation and fish escape.

Since there was homogeneity in all experimental units, the experiment was laid out in completely randomized design with five treatments replicated three times. Four hundred and fifty Nile Tilapia fingerlings of the same age (8 weeks) and size weighing 30 ± 5 g were obtained from Kenya Marine Fisheries Research Institute (KMFRI) Sagana station and randomly allocated to the replicates (hapas) with each having 30 fingerlings. These were stocked in the fifteen hapa nets randomly. All the groups were fed with commercial diet twice daily at 8% body weight at 0900hr and 1500hr for two weeks to acclimatize them to the experimental conditions before starting the feeding trials. Some fish were held separately in hapas to replace fish that died during the first two week acclimatization period. This was done because, the fish used in the study are not normally adapted to a hapa environment and removing them from ponds to hapa, causes a lots of stress to the fish.

At the end of acclimatization period, feeding with the experimental diets started twice a day at 0090hrs and 1500hrs at 8% body weight until they averaged 50g when the rate was changed to 3% body weight. Data collection and recording on weights and deaths was done biweekly for 22 weeks. To replace water loss due to seepage and evaporation, water was added to the ponds on a weekly basis.

3.4 Laboratory analysis of feed ingredients and test diet

Proximate analysis of the feed ingredients used to formulate the treatment diets was done in Kenyatta University animal science laboratory for

moisture, crude protein (CP), total lipids and total ash according to the standard method AOAC (2003). Crude protein was determined by Kjeldahl method after acid digestion (AOAC, 2003). To determine moisture and dry matter content the material was dried at 105° C in an oven to a constant weight. Muffle furnace at 600°C was used to determine ash by combustion (AOAC, 2003). Crude lipid (CL) content was measured using Soxhlet method, with petroleum ether extraction (AOAC, 2003). Crude fibre (CF) was determined through digestion by an alkaline and an acid then ashing the dry residue at 550°C in a muffle furnace for 4hrs. Proximate analysis was also done to the samples of the five trial diets using similar method as that used to analyse the ingredients.

3.5 Fish sampling and growth analysis

Data on weight was obtained, using a bench scale, (Avery Berkel HL-220 model) to the nearest 0.1 g any deaths and recorded in data sheet in Microsoft excel® for Microsoft office 2007. Thereafter the fish were returned to their respective Hapa nets. The feeding rate was calculated and adjusted after every sampling based on average weights. Before fish attained 50gms they were fed 8% of their body weight and thereafter at 3% body weight according to the feeding standards guidelines. The number of fish dead were recorded and removed from the hapas on daily basis.

The fish were removed from the hapas using a scoop net and weight measured using a weighing bench scale to the nearest 0.1 g. This was done biweekly for 22 weeks. Average weights of each hapa were then determined and mean total weight for each treatment computed and plotted to give the

growth trend of each treatment. To reduce fish stress during sampling, gentle scooping of the fish was done and placed in plastic basin containing fresh water to half-way mark which was replaced after each hapa handling and weighing done under a shade.

3.5.1 Performance parameters calculations

Body Weight Gain (BWG), Growth Rate (GR), Feed Conversion Ratio (FCR), Total Feed Intake (TFI) and Survival Rate (SR) were determined and calculated as per the formula described by Busacker et al. (1990).

Body weight gain (BWG) = final weight (g) (W_{t_2}) – initial weight (g) (W_{t_1}). Therefore, $BWG = W_{t_2} - W_{t_1}$

Growth Rates = body weight gain/culture period; $GR = (W_{t_2} - W_{t_1})/t$ Where: W_{t_1} is initial stocking weight, W_{t_2} is the final harvested weight, t is the culture period (days).

Fish growth calculation involved the mean weight (g) and their standard errors ($\pm SE$) which were calculated for fish samples from each treatment at each sampling occasion. Graphical plots of mean weights against time were used to study trends in the arithmetic growth of *Oreochromis niloticus*.

Feed conversion ratio (FCR) = Total food supplied (g, dry basis)/live weight gain (g).

3.6 Survival of the fish

Survival rate is the number of fish that survive during the experimental period expressed as a percentage of the stocked fish. It was calculated by subtracting the number of fish dead during the culture period from the fish stocked and then expressing it as percentage (Charo-Karisa *et al.*, 2006).

Thus, $SR (\%) = (\text{initial number of fish stocked} - \text{mortality}) / \text{initial number of fish stocked} \times 100$

3.7 Water quality analysis

Temperature, and dissolved oxygen were measured in situ at depth intervals of 0 cm, 20 cm, and 50 cm at 0700 hrs -0800 hrs and 1500 hrs -1600 hrs with an oxygen meter (YSI model 54) and recorded. This was conducted biweekly. At the same time, pH was also measured using a HI 9024 microcomputer meter model (Hanna Instruments Ltd., Chicago, IL., USA) and recorded.

3.8 Economic analysis

Feed cost to raise unit biomass of fish was determined by simple economic analysis based on the local retail prices of all the dietary ingredients at the time of the study. This was done to assess the cost effectiveness of diets used in the feed trial. Cost of feeds was solely used in the calculation with the assumption that all other operating costs remained constant. Market prices of ingredients in Kenya as per June 2014 were used to calculate the cost of the feeds as shown in Table 3.2.

Table 3. 2: Cost of ingredients used in formulating the trial diets

Ingredient	Price per kg (Kshs)
Fish meal (omena)	160
Maize germ	35
Wheat pollard	35
Cricket meal	200

The parameters used to determine the economic performance included:

a) Incidence Cost (IC), which was the cost of the feed used to produce a kg of fish. The lower the value the more profitable it is to use that particular feed (Abu *et al.*, 2010; Nwanna, 2003).

$$IC = \text{cost of feed} / \text{weight of fish produced}$$

b) Profit Index (PI), which was calculated according to Abarike et al. (2012).

$$PI = \text{value of fish produced} / \text{cost of feed.}$$

3.9 Statistical Analysis

All data was subjected to analysis of variance (ANOVA) using the SPSS 23.0 (SPSS Inc. Chikago IL.USA). A complete randomized design was used where the linear model was;

$$Y_{ij} = \mu_j + \alpha_i + \sum_{ij} \quad (\text{Hinkelmann \& Kempthorne, 2008}).$$

Where; Y_{ij} represents the dependent variables (weight, death rate)

μ is the overall mean of weight and death rate.

α_i is the effect due to the i^{th} treatment (diet), and

Σ_{ij} is the random error effect.

The significant means were separated using LSD at $P < 0.05$.

3.10 Ethical and Logistical Considerations

The research project was reviewed and approval to carry out the study granted by Kenyatta University Graduate School (Appendix IV). Animal welfare concerns were addressed and the experimental fish fed well and handled humanely during the sampling.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Proximate analysis

The results of the proximate analysis of the feed ingredients and the trial diets are shown in table 4.1 and 4.2, respectively. The proximate composition of the fishmeal used in the experiment was 53.61%, 4.62% and 2.4% for crude protein (CP), crude fiber (CF) and crude lipid (CL) respectively. On the other hand cricket meal had 57.3%, 9.21% and 27.2% for CP, CF, and CL respectively (Table 4.1).

Table 4. 1: Proximate analysis (% DM) of feed ingredients used in the feeding trial

Component	Fishmeal (Omena)	Cricket meal (house cricket)	Maize germ	Wheat pollard
Dry matter	90.7	94.7	91.7	85.8
Crude protein	53.61	57.3	15.3	10.7
Crude fibre	4.62	9.21	5.9	8.7
Crude ash	19.3	25	21	5.2
Crude Lipid	2.4	27.2	7.7	3.8

Proximate analysis conducted on the house cricket (*Acheta domesticus*) meal used in the formulation of the diets in the current study showed a higher CP, CL and CF on dry matter basis compared to fishmeal. Consequently, the isonitrogenous diets formulated had higher crude lipid and crude fiber than the control (Table 4.2).

Table 4. 2: Chemical composition of the five experimental diets

Composition	T1	T2	T3	T4	T5
Dry matter	91.6	93	92.5	91	91.3
Crude protein	34.94	34.95	34.93	34.94	34.94
Crude lipid	6.8	9.3	10.2	11.7	14.2
Crude ash	22.5	21	21	15.7	14
Crude fibre	1.81	1.92	1.98	2.22	2.55

T1 (0% CM) control; T2 (25% CM); T3 (50% CM); T4 (75% CM); T5 (100% CM)

The levels of CP and CL of fishmeal (omena) in this study were slightly lower than the values reported by Jabir et al. (2012). The present findings agree with those reported by Taufek et al. (2013). The differences in CP and CL levels of the fishmeal used in this research with other fishmeal (omena) used elsewhere may be as a result of different methods of processing, handling and storage (FAO, 2010b). Feeds in this study were sun dried and this could have affected the nutrient levels. The crude protein of the house cricket (*Acheta domesticus*), analysed was slightly lower compared with the documented results by Nakagaki et al. (1987) at 62% CP. This difference could be as a result of origin of the insect, diet fed to the insect and also the stage of metamorphosis of the insect as was reported by Kourimska and Adamkova, 2016. This was however slightly higher than other species of cricket such as

field cricket (*Gryllus bimaculatus*) at 57% (Shaharudin *et al.*, 2018; Taufek *et al.*, 2017) but slightly lower than for *Gryllus testaceus* and Mormon cricket (*Anabrus simplex*) at 58.3% and 59.9% respectively (Finke *et al.*, 1985; Sanchez-Muros *et al.*, 2014).

Fishmeal (omena) used in this study was locally obtained and is the one mostly utilized by the farmers in Kenya. As analysed, it contained a relatively high CP level which was comparable with the commonly used fishmeal in the commercial fish feeds manufacturing industries in the country (Munguti *et al.*, 2012). The CF for the FM (4.62%) was within the recommended standard for the fish feeds (6%) while that of CM (9.29%) was above the recommended levels (Appendix 1). The levels of CF and CL in the ingredients used also contributed to the levels of various treatments (Table 4.2). All the formulated diets were isonitrogenous and offered the same amount of protein to the fish including the control which only had fishmeal as the sole source of protein.

4.2 Growth performance of the *Oreochromis niloticus*

The growth performance of the Nile tilapia (*Oreochromis niloticus*) fish fed on the various diets containing house cricket (*Acheta domesticus*) meal is shown in Table 4.3. Daily feed intake (DFI) was not significantly different ($p>0.05$) across the treatment. However, daily weight gain (DWG) of fish fed treatment 2 differed with all other treatments despite the similar feed intakes of the fish. Fish fed on treatment 2 had the highest DWG (1.12g/day) which was significantly different ($p< 0.05$) from the other treatments. The DWG of all treatments except treatment 2 showed no statistical difference ($p>0.05$).

Similarly, the highest final average weight was recorded in the fish fed treatment 2 (199.97g) while the least was in the fish fed treatment 5 (147.56g).

Table 4. 3: Performance of *Oreochromis niloticus* fed on different dietary treatments for 22 weeks

Parameters	T1	T2	T3	T4	T5
Initial Weight (g)	29.06±0.47 ^a	29.14±0.44 ^a	29.74±0.49 ^a	29.06±0.33 ^a	29.71±0.5 ^a
Final Weight (g)	169.86±3.01 ^a	199.97±2.68 ^b	164.64±2.41 ^a	151.6±2.54 ^a	147.56±2.19 ^a
DFI (g/fish)	2.46±0.01 ^a	2.34±0.03 ^a	2.39±0.04 ^a	2.27±0.04 ^a	2.13±0.05 ^a
DWG (g/Fish)	0.91±0.01 ^a	1.12±0.04 ^b	0.88±0.02 ^a	0.80±0.03 ^a	0.77±0.01 ^a
FCR	2.70±0.02 ^a	2.09±0.01 ^b	2.72±0.02 ^a	2.84±0.03 ^a	2.77±0.03 ^a
SR (%)	96.7 ^a	97.8 ^a	97.8 ^a	96.7 ^a	97.8 ^a

Mean values in the same row with different superscript are significantly different ($P < 0.05$): T1=treatment 1, T2=Treatment 2, T3=Treatment3, T4=Treatment 4, T5=Treatment 5: DWG=Daily Weight Gain, FCR=Feed Conversion Rate, SR=Survival rate, DFI=daily feed intake.

Feed conversion rate was significantly lower ($p < 0.05$) in T2 which had 25% CM, compared to other treatments with higher inclusion level of CM and the control diet (T1) (Table 4.3). Growth performance and feed utilization of fish fed 25% CM were greatly improved compared to higher inclusion of CM and the control diet. The FCR for T1 (0% CM) was slightly higher than in T2 (25% CM) indicating lower performance when the fish were fed FM as the sole source of protein. The FCR also increased with the increased level of CM above 25% depicting poor growth performance with higher inclusion of CM.

Feed Conversion Rate is an indicator of feed quality where a lower FCR shows a better feed (Fry *et al.*, 2018; Naylor *et al.*, 2009; Torrissen *et al.*, 2011). Diets used in this experiment had FCR ranging from 2.0 to 2.8. T2 with 25% CM inclusion rate had the lowest FCR indicating a better quality diet. T1 and T3 with 0% and 50% inclusion of CM, respectively had statistically similar FCR indicating comparable qualities ($P > 0.05$), while T4 and T5 which had 75% and 100% inclusion of CM respectively had the poorest qualities. Though the mean initial weights were not significantly different ($P > 0.05$) among the treatments, the mean final weights differed significantly ($P < 0.05$) among treatments. T2 had a significant ($P < 0.05$) high mean final weight and the highest DWG compared with other treatments. The harvest mean weight for T4 was significantly higher ($P < 0.05$) from T1 but significantly lower ($P < 0.05$) than T3. At 25% inclusion level of CM, the FCR was better compared with higher inclusion rates which indicates that this is the optimal inclusion level of CM in tilapia fish feed. This level can be raised if dechitinization and lipid extraction of the insect meal is done prior to fish feed formulation (Alegbeleye

et al., 2012; Lim *et al.*, 2011; Taufek *et al.*, 2016). They also reported that high fiber content in the chitin component of cricket meal affect digestibility. Further research by Veldkamp and Guido (2015), showed that CM contains chitin, a linear polymer of β -(1-4) N-Acetyl-D-glucosamine unit with a chemical structure similar to that of cellulose. Chitin is known to dissolve in dilute acids found in the stomach to form a highly viscous solution which may cause distension of the stomach in an animal, thereby increasing satiety (Kroeckel *et al.*, 2012), affecting feeding and subsequently growth rate.

Additionally, the crude lipid level for CM was high (27.2%), agreeing with results by Kourimska and Adamkova (2016,) who stated that edible insects contain an average of 10-60% of fat on dry matter basis. This in turns led to high levels of CL in the treatment diets (6.8%-14.2%) compared with the maximum requirement (10%) of the fish (Appendix 1). This could also have led to lowered growth performance of the fish fed high levels of CM beyond 25% which agrees with findings by Lim *et al.* (2011) and NRC (1993) where it was indicated that, though lipids are preferred energy source to carbohydrate for fish, increased dietary levels of crude lipids could potentially affect protein digestibility.

The improved performance indicated in T2 may be due to the complementary nutritional profile contributed by both fishmeal and cricket meal (*Acheta domesticus*) at the indicated substitution rate. This agrees with what was previously reported by Pelletier *et al.* (2018), that multiple protein sources enhance tilapia fish performance. Further, Taufek *et al.* (2016) reported

that cricket meal showed a better FCR and protein efficiency ratio (PER) when fed at lower inclusion rates.

During the feeding trial, all the experimental diets were well accepted by the fish with no refusals and shortened feeding time (less than 5 minutes). The growth trend of the fish exhibited a normal growth curve for all the five treatments (Figure 4.1).

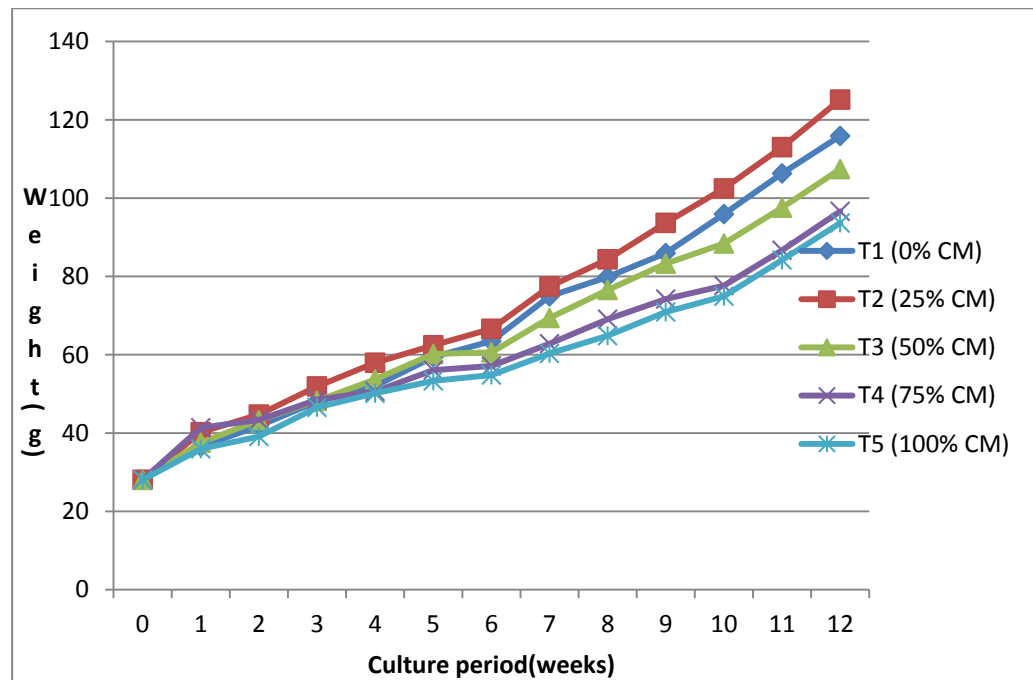


Figure 4. 1: Growth trends of *Oreochromis niloticus* for 22 weeks culture period sampled at 2 weeks interval

The results of the study showed that there was variation in growth performances of the Nile tilapia fed on the experimental diets with different inclusion rates of CM. The mean weights per treatment over the experiment period indicated a steady weight gains across all the five treatments with a representation of normal growth curve indicating an exponential growth of the

fish ranging from 0.77g/day to 1.12g/day. The normal growth curve observed in the study could be attributed to minimal stress to the fish and good palatable diet with desirable nutritional profile. This finding is in agreement with the reports of other researchers (Makkar *et al.*, 2014; Taufek *et al.*, 2013). This finding confirms that optimal conditions for growth for Nile tilapia were maintained throughout the study period which resulted in good growth performance and low mortality.

4.3 Effects of various treatments on survival of the fish

Fish survival was not adversely affected by the treatments at 0%, 25%, 50%, 75%, and 100% inclusion of CM in the diets as shown in figure 4.2. Fish survival rates among fish in the 5 treatments ranged between 96.7% and 97.8%, with no statistical difference ($P>0.05$). The minimal deaths recorded during each sampling were attributed to handling stress and not as a result of the treatments applied.

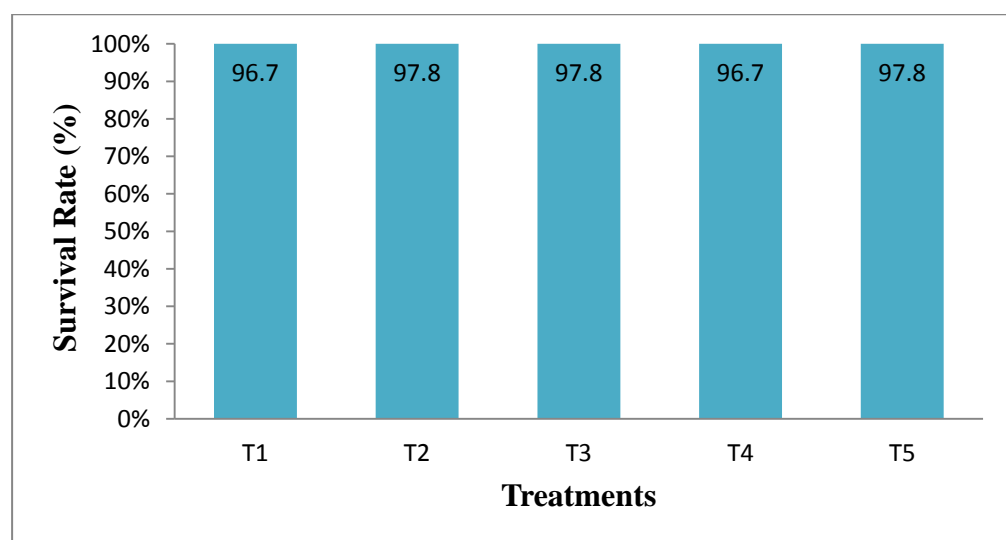


Figure 4. 2: Survival rate of fish fed on the five treatments

Survival rate is an important parameter in estimating the number of animals in each holding. It helps to plan for the expected output and calculating the feed rations and the standing biomass in the culture system (Goddard, 1995). In the present study, there was high survival rate of the fish (97%) and was comparable among all treatments throughout the experiment. The high survival rate in the study could be attributed to good pond preparation where initial liming using agricultural lime was done to stabilize the pH of the water within the pond and also to kill any microorganism in the pond as a way of controlling disease incidences (Ngugi *et al.*, 2007).

Further, stocking fingerlings at the age of 8 weeks with a weight of 30 g could have contributed to high survival rates recorded. This agrees with observations by Bichi and Ahmad (2010) who reported that aged fish are difficult to acclimatize to caged conditions leading to high mortality rates. Additionally, mono sexed fish were stocked to ensure that no breeding took place which in-turns could have led to breeding stress causing stunted growth, low yields or even deaths. This concurs with Guerrero (1982) who reported that, in the tropics and sub-tropics Nile tilapia exhibit precocious maturation leading to prolific breeding hence overcrowding in the systems, stunted growth, low yields and even increased mortalities. The low mortalities witnessed in the present study were also attributed to good quality, highly palatable and well accepted feed offered to the fish. However, this disagrees with findings by Rodriguez-Serna *et al.* (1996), who concluded that when an alternative protein source is used to replace fishmeal in fish diets palatability and acceptance of the feed is affected thus affecting the performance. The good

acceptability and palatability of the trial diets on the present study may have been attributed to lack of anti-nutritive factors, good storage and handling devoid of any contaminations.

Proper handling of the fish during sampling and harvesting ensured minimal handling stress which could have led to low mortality rate. Sampling was also done under a shade to reduce possible heat stress and freshwater was supplied in fish holding basins during sampling and measurements. This cushioned the fish from extraneous stress thereby reduced mortalities before they were returned to the hapas. This is in conformity with observations by Bichi and Ahmad (2010) in their previous study that drew a similar conclusion.

Water quality management during the experimental period in the pond was well monitored and remained within the acceptable levels (Table 4.4) necessary for the optimal growth of Nile tilapia fish (Bhatnagar and Singh, 2010; Mjoun, *et al.*, 2010; Ngugi *et al.*, 2007; Santosh and Singh, 2007). This also contributed to high survival rates in the present study. Environmental factors such as water temperature, dissolved oxygen, water salinity and pH were important in the study. All these parameters were monitored and they were within the optimal levels for fish survival. To maintain conducive physio-chemical parameters in the pond water destabilized through evaporation and seepage and for continuous aeration, the water was replenished on weekly basis. Initial liming of the pond had also been done to ensure pH stability and ammonia levels were maintained at acceptable levels in the pond (Bhatnagar & Devi, 2013).

The few mortalities that occurred during the fish culture period may be attributed to stress due to handling during sampling for individual weight and counting. This was evident as some single dead fish could be observed the following day after sampling. Results from previous research have reported very low survival of caged fish (Kinyua, 2004).

Table 4. 4: Range and averages of physical-chemical parameters of the water during the tilapia fish growing period in the hapa nets and their environs.

Parameters	Range		Average		Acceptable levels	Reference
	Inside	Outside	Inside	Outside		
Temperature (°C)	24.05-29.6	22.12 – 29	27.61	28.20	25-31	Ngugi <i>et al.</i> , 2007
Dissolved oxygen (mg ^l ⁻¹)	0.97-2.99	0.96-2.86	2.22	2.20	3-5	Mjoun <i>et al.</i> ,2010; Ngugi <i>et al.</i> , 2007
pH	8.89-10.1	8.72-9.50	8.9	9.02	6.7-9.5	Santosh and Singh, 2007

4.4 Economic analysis

Treatment 2 had the highest value of biomass (Ksh.1,800), followed by Treatment 1 (control) ksh.1,530 (Table 4.5). The other trial diets: Treatment 3, Treatment 4 and Treatment 5 had slightly lower biomass value of Ksh.1,482, Ksh.1,365 and Ksh.1,327 respectively.

The Incidence cost (IC) was low in treatment 2 (169.90) while the other diets had Incidence cost of 191.29, 230.32, 257.66 and 258.73 in treatments 1, 3, 4 and 5 respectively (Table 4.5; Figure 4.3) implying that proportionately high CM levels in the fish diets translates to increased cost.

Table 4. 5: Economic analysis for production of Nile tilapia fed diet containing various levels of *Acheta domesticus* meal

Component	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
Cost per Kg of feed(Ksh)	85.84	94.30	103.06	111.76	116.48
Feed input (Kg)	11.37	10.81	11.04	10.49	9.84
Cost of feed (Ksh)	975.57	1,019.38	1,137.78	1,172.36	1,146.16
Harvested biomass (Kg)	5.1	6	4.94	4.55	4.43
Estimated value of biomas (Ksh)	1,530	1,800	1,482	1,365	1,327
Incidence cost	191.29	169.90	230.32	257.66	258.73
Profit Index	1.57	1.77	1.30	1.16	1.16

Estimates was based on market value of Ksh. 300 per kg of fish; 1US dollar=104

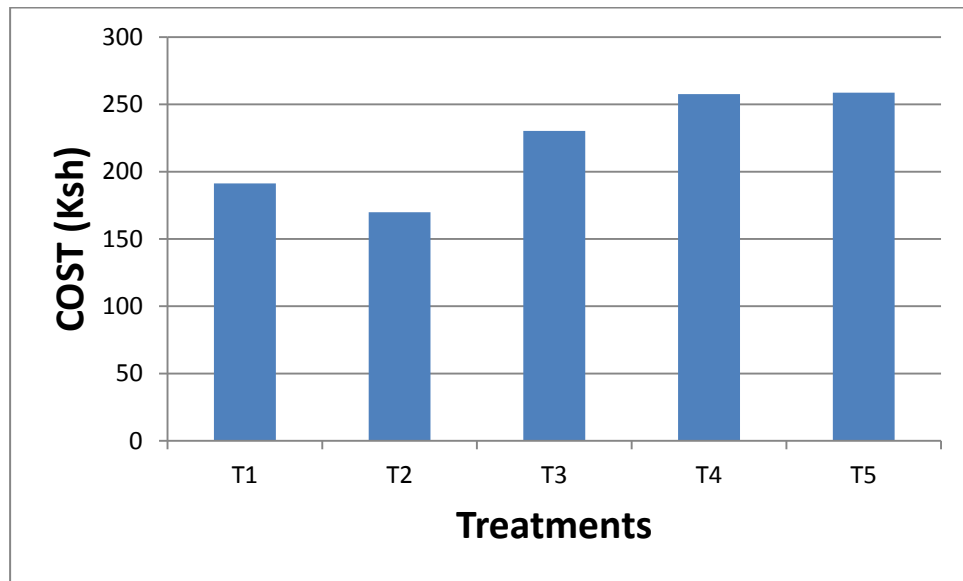


Figure 4. 3: Incident cost of five treatments of cricket meal fed to Nile Tilapia fish

Further, the profit index calculated as shown in Table 4.5 implies that it is relatively economical to formulate a diet with 25% CM replacement of fishmeal. The trend shows a declining profit index of the diet with increasing CM levels above 25% (Figure 4.4).

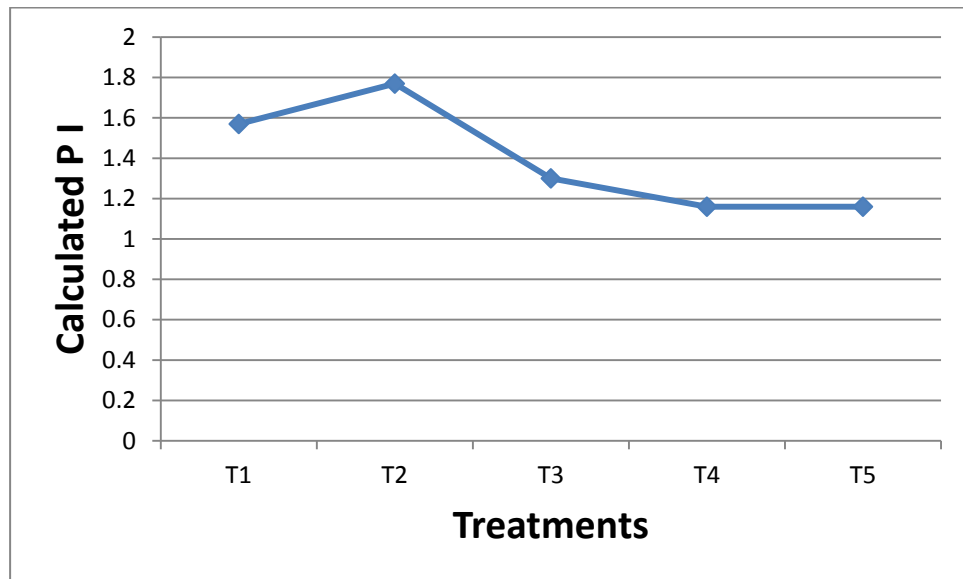


Figure 4. 4: Profit index of the five treatments of Cricket meal fed to Nile Tilapia fish

The present study shows that production of *O. niloticus* was more profitable at 25% cricket meal inclusion rate, which had the lowest incidence cost and the highest Profit Index. Previously it had been reported that a low incidence cost value depicts more profit when that particular feed was used (Abu *et al.*, 2010; Nwanna, 2003). The inclusion rate of cricket meal above 25% translated to higher incidence cost. This could have been attributed to high cost of harvested house cricket (*Acheta domesticus*) which was 4 times more costly than fishmeal due to limited production of cricket meal in Kenya.

Nonetheless, the study has demonstrated that there are good prospects of cricket meal replacing fishmeal. The cost implication of cricket meal of a higher incidence cost agrees with finding by Halloran *et al.* (2016), who reported that the cost of harvested house cricket could be as high as USD 6.77 which is higher than fishmeal. There are limited studies on economic use of

house cricket (*Acheta domesticus*) as a feed in Nile tilapia. However, a recent study by Shaharudin *et al.* (2018) indicated that field cricket (*Gryllus bimaculatus*) can economically replace fishmeal at high inclusion level in Catfish diet without adverse effect.

Globally, it is estimated that insect meal demand is on an upward trajectory with the market demand approximated at slightly over USD 500 Million by 2023 (Han *et al.*, 2017). This indicates that cricket meal will be a viable option in formulation of fish feed since crickets constitute 13% of all edible insect consumed by tilapia, which would establish an important economic diversity on the fish feed production (van Huis *et al.*, 2013).

In the tropics cricket meal can be technically produced profitably in large quantities and in a relatively short period of time. Crickets being good bio-convertors of bio-waste, they can utilize readily available organic matter both on small and large scale production (Dossey *et al.*, 2016; Orinda *et al.*, 2017; van Huis, 2013). However, presently the production of crickets in Kenya has not yet been embraced positively. Farmers producing them are few; hence the prices are still fairly expensive compared to fishmeal. Although prices are a limiting factor, further research for mass production, at low cost and in a more sustainable practical method will be needed to reduce the prices; in addition to sensitization of the society on the nutritional benefits of cricket meal. This will in turns translate to reduced cost of production in aquaculture once cricket meal is used as fish feed.

To date there is no documented study on house cricket meal (*Acheta domesticus*) as formulated feed for Nile Tilapia fish in Kenya. The present

study was conducted to assess the survival, growth performance and economic analysis of Nile tilapia fish farming when fed house cricket (*Acheta domestica*) meal as replacement of fish meal. Nevertheless, there are many studies done to evaluate cricket meal in poultry diet with good effects as earlier reported by Ramos-Elorduy (2008) who pointed out that Mormon cricket (*Anabrus simplex*) was capable of completely replacing fishmeal and soybean in broiler diets. Other studies by Nakagaki et al. (1987) and Defoliart et al. (1982) reported similar results with significantly better growth performance and good survival of broiler in cricket-based meal compared with corn diet. Similarly, Wang *et al.* (2005) indicated that replacing fishmeal diet with 15% field cricket meal (*Gryllus testaceus*) gave favorable results in broiler weight gain.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of significant findings

- All the trial diets were readily accepted by the fish since the daily feed intake did not vary across all the treatments although growth performance varied with various treatments. Fish which were fed on diet containing 25% cricket meal performed better than those fed on 0% CM, 50%CM 75%CM and 100%CM.
- The survival rates of the fish were not affected by the different inclusion rates of cricket meal in the diets since the survival rates across the trial diets were not statistically different. Therefore, cricket meal can be used in the substitution of fish meal in Nile tilapia fish without negatively impacting on the survival of the fish.
- In addition to better growth performance of the fish fed on diet formulated at 25% cricket meal, the diet had the highest profit index compared to all the other diets. The incidence cost increased as the level of cricket meal inclusion in the diets increased above 25%.
- Finally, the findings of this study suggests that, house cricket (*Acheta domesticus*) can replace 25 % fishmeal in Nile tilapia diet and produce good results in terms of growth performance and survival of the fish as well as lowering the cost of production.

5.2 Conclusions

The study of the insects as alternative sources of protein for fish diets has been growing over the years with an aim of getting a reliable resource to substitute the volatile and expensive fishmeal. However unlike other insects such as black soldier fry, silk worm, maggot meals, other species of crickets such as field cricket and black cricket, the information about house cricket as protein source for Nile tilapia was scarce thereby necessitating the study and the results obtained drew the following conclusions.

1. On the first study objective, it was concluded that growth performance and the feed conversion rate (FCR) of the Nile tilapia fish were optimal at 25% house cricket (*Acheta domesticus*) meal inclusion level as a replacement for fishmeal in the diet.
2. On the second study objective, it was concluded that feeding Nile tilapia with meals containing house cricket (*Acheta domesticus*) had no adverse effect on the survival of the fish making it a good candidate to be used as an alternative feed for Nile tilapia. The various inclusion levels of cricket meal had no effect on the survival rate (SR) of the Nile tilapia
3. On the third objective, the study concluded that using house cricket (*Acheta domesticus*) meal at 25% as a replacement of fishmeal in Nile tilapia diets produced an appreciable better profit index for the enterprise at a PI of 1.77 and thereby

economically feasible to rear fish with diets in which 25% of fishmeal is substituted by house cricket (*Acheta domesticus*) meal.

5.3 Recommendations

The following recommendations were made from the study:

1. Fish feed manufacturers and fish farmers may use cricket meal up to 25% as a replacement for fishmeal in formulation of Nile tilapia fish feeds which guarantees optimal growth performance and feed conversion rate.
2. Sensitization to mass rearing and production of cricket meal will provide a cheap alternative source of protein to substitute fishmeal and provide good profit margins to feed manufacturers and fish farmers.

5.4 Suggestion for further study

From the study the following areas may warrant further research,

1. Evaluation of the factors that may limit the utilization of cricket meals in Nile Tilapia fish diets at higher rates needs to be done.
2. Research on acceptability and palatability of Nile tilapia reared on cricket based meal should be undertaken.
3. Government agencies and research institutions to initiate and create awareness on the importance and feasibility of CM in fish nutrition and emphasize more on rearing of crickets as feed.

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APPENDICES

Appendix I: Table of Compounded Tilapia feeds Specification Kenya

Standard 2289- 1 Complete feed

S/No	Characteristic feature	Tilapia fingerling (Starter diet)	Tilapia growers (grower diet)	Finisher	Brooder diet
i)	Nile tilapia fish Weight in grammes	1-49	50-200	200-market size	≥50 females ≥80 males
ii)	Feeding rate % body weight	6-8	3	2-4	4-6
iii)	Crude protein % (min.)	35	30	24	32
iv)	Energy ME Kcal/kg	2500	2750	2900	2800
v)	Amino acid levels a) Lysine g/kg (min.) b) Methionine g/kg (min.)	1.2	1.2	1.2	1.2
		0.5	0.5	0.5	0.5
vi)	Crude fiber % (max)	4	6	6	6
vii)	Crude fat % (max)	8	10	10	10
viii)	Pellet size (mm)	2 (max.)	2-5	4-6	2-5
ix)	Pellets should float on water for (minutes)	2	2	2	2
x)	Moisture content of pellets (% max.)	10	10	10	10
xi)	Calcium %	0.4-0.6	0.4-0.6	0.4-0.6	0.45-0.65
xii)	Phosphorus %	0.5-0.7	0.5-0.7	0.5-0.7	0.6-0.7

Courtesy of ESP aquaculture working group 2012/2013


Appendix II: Figures of pond liming



Appendix III: Mounted Hapa nets in a Pond filled with water



Appendix IV: Research Approval from Kenyatta University Graduate School



**KENYATTA UNIVERSITY
GRADUATE SCHOOL**

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Internal Memo

FROM: Dean, Graduate School **DATE:** 23rd January, 2018

TO: Jane W. Mwangi **REF:** A149/OL/CTY/26823/2014
 C/o Department of Animal Science

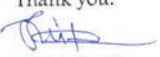
SUBJECT: APPROVAL OF RESEARCH PROPOSAL

This is to inform you that Graduate School Board, at its meeting on 10th January, 2018 approved your Research Proposal for the M.Sc. Degree entitled, "Assessment of Survival Rates and Growth Performance of Nile Tilapia Fed on Cricket Based Meal".

You may now proceed with your Data collection, subject to clearance with Director General, National Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking Forms per semester. The form has been developed to replace the Progress Report Forms. The Supervision Tracking Forms are available at the University's Website under Graduate School webpage downloads.

Thank you.


JULIA GITU
FOR: DEAN, GRADUATE SCHOOL

CC. Chairman, Department of Animal Sciences

Supervisor:

1. Dr. Isaac M. Osuga
 C/o Department of Animal Sciences
Kenyatta University
2. Dr. Purity Nguhiu
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3. Dr. Jonathan M. Mungutii
 Kenya Marine and Fisheries Research Institute, Sagana
 Research Center
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jg/mww