DEPARTMENT OF MARINE AND FISHERIES SCIENCES

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Evaluation of Farm-Made and Commercial Fish Diets for Hapa Culture of Nile Tilapia (*Oreochromis niloticus* L.) in Ghana

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DECLARATION

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ABSTRACT

One of the major constraints to aquaculture development and expansion in Ghana is affordable nutritionally balanced and cost effective fish diet. Although some fish farmers produce their own farm-made fish diets, these diets do not meet the nutritional requirements of the cultured fish as the farmers do not follow the appropriate feed formulation protocol. This study was carried out to generate information on the commercial fish diets and feed ingredients currently used by small-scale pond fish farmers in five major pond fish farming Regions (Ashanti, Brong-Ahafo, Central, Volta and Western) in Ghana. Six of the commonly used ingredients by the farmers were selected and used to formulate and prepare farm-made tilapia diets which were evaluated against two commonly utilised commercial tilapia diets for Nile tilapia (*Oreochromis niloticus*). In all, five diets namely *A* (farm-made diet supplemented with vitamin-mineral premixes, lysine and methionine), *B* (farm-made diet without supplements), *C* (commercial tilapia diet, *Coppens*), *D* (commercial tilapia diet, *Raanan*) and *E* (mixture of *B* and *Raanan* in a ratio of 1:1). The first part of the study was conducted in net *hapas* installed in a 0.2 hectare earthen pond over a 140-day growth period at the Aquaculture Research and Development Centre (ARDEC), Akosombo. *O. niloticus* with an initial mean weight of 22.8 ± 2.1 g were stocked at a density of 2 fish m^{-2} and fed at 4-3 % body weight three times a day. The second part of the study involved digestibility of the diets and this was carried out in plastic tanks with 20 L of water each for 20 days. After the culture period, the final mean weights of *O. niloticus* were 140.3 ± 23.4, 131.0 ± 24.4, 148.3 ± 25.4, 187.6 ± 42.1 and 140.7 ± 28.5 g for *A, B, C, D* and *E* respectively. There was no significant difference ($p > 0.05$) in specific growth rates among all the dietary

treatments. Apparent nutrient digestibility coefficients were high (> 60 %) in all the dietary treatments. Crude protein ranged from 77.49 to 87.02 %, crude lipid ranged from 81.46-93.90 % whilst carbohydrate (nitrogen free extract) ranged from 65.28 to 85.94 %. Higher crude protein depositions and lower fat contents were observed in the carcass of fish fed farm-made diet *A* and Raanan. There were no internal and external abnormalities in *O. niloticus* fed with the various diets. Both the farm-made and commercial diets did not impact negatively on water quality. In terms of cost-effectiveness, the farm-made diets were more profitable than the commercial ones. The results indicated that nutritionally balanced farm-made fish diet is cost-effective and will boost growth of aquaculture in rural areas where semi-intensive pond aquaculture is mainly practised in Ghana. The current fish production (2 500 kg ha^{-1} yr^{-1}) by Ghanaian small-scale pond fish farmers could increase up to a fourfold by using appropriately formulated and prepared farm-made fish diets with locally available ingredients. This is likely to increase their profit margin to over four hundred percent of what they are making currently using commercial fish diets. The costs associated with the use of commercial fish diets by small-scale pond fish farmers are high, and in terms of fish growth and economic returns, the use of appropriately formulated and prepared farm-made diets will be a better alternative. Fish farmers should be trained on the formulation and preparation of nutritionally balanced and cost effective farm-made fish diets so as to reduce their production cost and increase their profit margin.

DEDICATION

To my wife, Abigail for her perpetual companionship and support.

To my children, Eyram and Likem whose upbringing brings me a sense of responsibility at all times.

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CHAPTER 1.0 INTRODUCTION

1.1 Background Information

The growing demand for fish protein in Ghana has motivated active development of aquaculture both at the commercial and peasant levels. The contribution of aquaculture production to the Ghanaian economy has grown over the past decade, with an annual average growth rate of 12.4% (FAO, 2006–2012). Aquaculture is seen as an important foreign exchange earner, contributes to food security as well as providing much needed employment to many people in Ghana. The Ghana National Aquaculture Development Plan (GNADP) designed in 2012 and launched in 2014 was to increase the national fish stock from 27, 750 metric tonnes to 130, 000 metric tonnes in six years (GNADP, 2012). The GNADP is intended to generate about 220, 000 jobs within the same period. In general, fisheries are estimated to contribute 3 % of the total national gross domestic product (GDP) and 5 % of the agriculture GDP of Ghana (FAO, 2006–2012).

Aquaculture is defined by FAO (1990) as "the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding and protection from predators". Farming of aquatic organisms may be individual or corporate ownership of the stock being cultivated. Increasing production capacity of aquaculture resources through intensification seems to be the way forward to meet the ever increasing demand for fish. This entails increasing primary, intermediate and terminal productivity capacities of our natural aquatic ecosystem and creation of productive artificial aquatic

ecosystems through proper planning, development and management (Sadiku and Jauncey, 1995).

The first scientifically managed aquaculture facility in Ghana was put up by the University of Ghana at its Agricultural Research Station situated near Nungua, Accra in 1959. By 1969, there were about 220 reservoirs of variable sizes in Northern Ghana (FAO, 2006–2012). In the 1980s, aquaculture received a major boost, especially in the Ashanti, Central, Eastern, Western and Greater Accra regions, this time from government as a way of meeting Ghana's fish deficit (Mensah *et al*., 2006).

Most fish farmers in Ghana use earthen ponds and rely on natural productivity while others supplement with agricultural by-products. Other systems of culture include the cages, pens and raceway systems, which are not commonly practised nationwide (Awity, 2005). In terms of numbers, cages come after ponds. For instance, in 2012, a total of 2, 278 cages whilst 4, 749 ponds were recorded in the country (FD, 2013). However, fish production during the year was higher in cages than in ponds. Production from ponds was 1, 771.50 and that of cages was 24, 248.50 metric tonnes.

The Nile tilapia (*Oreochromis niloticus*) is the major tilapia species cultured in Ghana. Most of the fish produced are either consumed directly by fish farmers or sold locally. Currently, there is a ban on tilapia import in Ghana (FAO, 2006–2012) and so there is a call for an increase in its production locally. However, there are constraints to the expansion of aquaculture in Ghana of which the main one being high cost of fish feed.

Feed is known to be a major determinant of successful growth and intensification of aquaculture production. It accounts for a major part (30-70 %) of the total operation cost of an average fish farm (El-Sayed, 2004; Rumsey, 1993). It is generally accepted that the highest recurring cost in aquaculture comes from feeds. Alone, feed accounts for about 60-80 per cent of operational costs in intensive aquaculture (Rola and Hasan, 2007). With the increasing demand for food fish and the decline in capture fisheries production, aquaculture in Ghana is shifting from low density to high density culture that is traditional to semi-intensive or intensive culture. This will consequently lead to an unprecedented rise in the demand for feeds more than that of fertilizers (Kaushik, 1990). Aquaculture in Ghana started with the use of no feed, then the use of farm-made feeds to factory-made feeds. This demonstrates a real possibility of increasing production and reveals the potential importance of fish feeds in Ghana. Now aquaculture feeds have been considered a major subsector of the feed milling industry (Kaushik, 1990). From the economic point of view, feed cost appears to be one of the major constraints against the greater expansion of aquaculture.

Fish meal is the major dietary protein source for fish feeds, commonly making up between 20-60 % of fish diets (FAO, 2012a; Glencross *et al.*, 2007; Watanabe, 2002). It has been estimated that in 2008, the aquaculture sector used 60.8-71.0 % of world fish meal production (FAO, 2012a; Lim *et al.*, 2008; Tacon and Metian, 2008). Dietary protein is the major and most expensive component of formulated fish feeds (Wilson, 2002) and feed costs have tended to increase with the rising price of fish meal. For instance, the cost of fish feeds increased by 73 % from 2005 to 2008 (FAO, 2012a).

Therefore, in order to reduce feed costs and the use of fish meal in aquafeeds, more extensive use of alternative feed ingredients is needed (Burr *et al.*, 2012; Hardy, 2010; Lim *et al.*, 2008; Glencross *et al.*, 2007).

Although plant protein such as soybean meal has been used in fish feeds as a replacement for animal protein, trash fish (fish meal of marine origin) is still the main dietary protein source comprising 20-60% of the feed (Da *et al.*, 2011; Phumee *et al.*, 2009; Hung and Huy, 2007). However, using fish meal is not a sustainable long-term feeding strategy (FAO, 2010; Naylor *et al.*, 2009), because it will lead to the decline or extinction of some trash fish species (Edwards *et al.*, 2004). As the aquaculture industry is projected to continue expanding, fish meal must be used more strategically as the required aqua feed production volumes increase (Güroy *et al.*, 2012). This poses a major challenge for thousands of small-scale fish farmers, as the feed is a major component of the total production costs and many fish feed producers still rely heavily on trash fish and fish meal (Tacon and Metian, 2008). In 1993, Rumsey documented that cost effective practical aquaculture feeds can be produced without the use of fish meal with no apparent loss in fish growth in some species such as tilapia. Despite the fact that most plant ingredients are readily available at a lower cost than fish meal, their use within fish feeds is usually restricted by relatively low protein content, unbalanced essential amino acid profile, high levels of fibre and starch and the presence of one or more anti-nutritional factors (Agbo *et al.*, 2011; NRC, 1993).

Increased use of cheap, locally available feed resources and more sustainable protein sources is considered a high priority in fish feed industry that could provide a way to reduce the total production costs (Hardy, 2010; Edwards and Allan, 2004). Other studies have also shown the use of different types of feedstuffs in traditional aquaculture, ranging from kitchen wastes and foliage in homestead-type fish farming to fishery and agro-industrial by-products like oil cakes, wheat and rice bran, mill wastes, brewery waste, bean residues, silkworm pupae, poultry wastes, slaughterhouse wastes (blood and entrails), trash fish and fish offal (Pillay and Kutty, 2005). Cocoa pod husk and groundnut peel have also been used (Ofori, 2001).

The most important characteristics of feedstuffs are the bioavailability of nutrients; hence, reliable data on different ingredients for each species need to be well considered as a necessary prerequisite (Fagbenro *et al*., 2003; Jauncey, 1993). Digestibility of nutrients in fish diets needs to be studied because it is the digested feed which is absorbed and made available for cellular metabolism. The resultant of which are tissue synthesis and repair of worn-out tissues and various energy utilization channels (NRC, 1993; Yudkin, 1985). Borghesi *et al*. (2007) reported that knowing nutrient digestibility of feed ingredients elicit interchangeability of feed ingredients without reducing animal performance. De Silva and Anderson (1995) also observed that it is essential to have knowledge of the digestibility of the main ingredients as well as of the whole diet in feed formulation and manufacture. In combination, chemical analysis and apparent digestibility coefficient (ADC) results allow us to precisely estimate not only the contribution of a particular protein source to a complete fish feed but also how much feed

wastes and undigested nutrients (faeces) will potentially accumulate in fish pond (Jimoh *et al*., 2010; Koprucu and Ozdemer, 2005).

Local or sub-regional agricultural by-products could provide nutritionally sound and cost-effective feeds to support increased fish production in Ghana (Agbo, 2008). In order to increase and sustain aquaculture production in Ghana, there is the need to encourage use of the abundant locally available ingredients to develop low cost feeds and discourage import of very expensive formulated or pelletised feed from abroad (Agbo, 2008). Thus, production of fish diets using locally available feed ingredients for small-scale fish farming in Ghana is the way forward to increase the profitability of the industry and make the production more sustainable. In Ghana, there are a variety of agro-based industrial wastes, such as oil palm waste, pineapple waste, cassava waste, pawpaw waste, yam waste, and coconut waste. Efforts have been made to make use of these organic wastes in formulating feeds for animals, including fish. In addition to selecting the proper feeds or ingredients to develop cost effective feeds that will maximize growth, appropriate feed management and feeding practices are critical to obtaining efficient aquaculture production and minimizing pollution of the aquatic environment (NRC, 2011).

It is against this background that this study was designed to find answers to the following research questions:

- What types of feed ingredients and commercial fish diets are being used by small-scale pond fish farmers in five major pond fish farming regions (Ashanti, Brong Ahafo, Central, Volta and Western) of Ghana?
- What are the chemical constituents of the commonly used feed ingredients and commercial fish diets by the fish farmers?
- What are the biological utilization levels of the commonly used commercial fish diets and farm-made (formulated) diets from the commonly used feed ingredients when fed to *O. niloticus*?
- What is the state of health of *O. niloticus* when fed separately with the farm-made diets and the commonly used commercial ones?
- Does feeding *O. niloticus* with the farm-made and commercial diets negatively impact on the physiological well-being (condition factor) of the fish?
- Do the farm-made diets and commonly used commercial fish diets negatively impact pond/hapa water quality?
- Does the water quality in the pond/hapa negatively impact on the condition factor of the cultuered fish?
- Is the farm-made diets relatively cost-effective compared with the commonly used commercial ones?

1.2 Aim of the Study

This study was to generate information on the feed ingredients and commercial fish diets currently used by small-scale pond fish farmers in five major pond fish farming regions

in Ghana and to evaluate the commonly used commercial fish diets and farm-made diets produced with selected commonly used ingredients for *O. niloticus*.

1.3 Objectives of the Study

The specific objectives were to:

1. Conduct a survey of feed ingredients and commercial fish diets small-scale pond fish farmers are currently using for fish production in five main pond fish farming Regions of Ghana;
2. Determine the proximate compositions of commonly used feed ingredients and commercial fish diets by small-scale pond fish farmers in five main pond fish farming Regions of Ghana;
3. Evaluate two most commonly used commercial diets and two farm-made diets formulated and prepared using six selected commonly used feed ingredients on growth and feed utilization of *O. niloticus*;
4. Evaluate the digestibility of the commercial fish diets and the compounded ones in *O. niloticus*;
5. Assess the state of health and physiological well-being (condition factor) of *O. niloticus* when fed separately with the farm-made diets and that of commercial ones;
6. Assess the effect of the farm-made diets and that of the commercial ones on water quality;
7. Assess the effect of water quality in the hapas on the growth of the fish and
8. Evaluate the cost effectiveness of the farm-made and commercial diets.

1.4 Justification of the Study

Pond fish farming is on the increase in all the ten (10) Regions of the country (FD, 2013). Most of these farmers are small-scale producers who cannot afford the ever escalating cost of commercial fish diets. This could discourage most of them from being in the fish farm business which will negate national efforts on food security. Furthermore, there is a paucity of information on the nutrient contents of commercial fish feeds in Ghana as well as no reliable published information on chemical composition of these products (Personal Observation). Although there are guidelines for the establishment of a new fish feed industry (GNADP, 2012) these are yet to be enforced. Hence, there is a great possibility that fish farmers may be deceived by the commercial feed manufacturers due to the quality assurance gap. Therefore, there is an urgent need to assess the actual chemical composition and nutritive value of commercial fish feeds and ingredients used by fish farmers in the country.

Small-scale fish farmers may use ingredients based on location, affordability and seasonality. Plant feedstuffs are known to contain anti-nutritional factors (ANFs). ANFs limit the use of plant feedstuffs at high dietary inclusion levels in compounded fish feeds (Tacon, 1993). This study will provide appropriate information to small-scale fish farmers on the availability, proximate composition and the optimal inclusion levels of used ingredients in farm-made fish diet productions so that the farmers could develop suitable farm made fish feeds. Hence, small-scale fish farmers will be knowledgeable in the appropriate feed ingredients to utilize in their formulations as well as including each of them at their optimal levels.

Currently, most commercial fish diets in Ghana are imported from Brazil and United States of America (USA) and they are prohibitively expensive for small-scale fish farmers to buy. Although some of these farmers could afford the cost of these diets, but with much difficulty. Consequently, most of the farmers have resorted to feeding their cultured fish with food scraps and food wastes from their farming activities. This practice makes the cultured fish take a significantly longer time period (10-12 months) to reach market size (Ashanti, Brong-Ahafo and Central Regional Small-Scale Fish Farmers Associations; Personal Communication). Farmers who compound their own feeds produced unbalanced diets as their productions do not follow an appropriate feed formulation protocol so as to meet the nutritional requirements of the target fish (Personal Observation).

Imported commercial fish feeds continue to flood the local market due to the intensification of *O. niloticus* and expansion of the aquaculture industry in recent years. This is particularly in the Eastern and some parts of Volta Regions where cage fish farming is widespread due to the presence of the Volta River. Some of these commercial feeds may be of poor quality, and may not meet the nutritional requirements of the target fish. Currently, about sixteen (16) of these feeds have been recorded in the Eastern Region alone (Personal observation). Unlike quality commercial poultry feeds, that are readily available in Ghana, there is an acute paucity of nutritionally sound, cost effective feeds for finfish in general, and for *O. niloticus* in particular.

It is therefore necessary that data is gathered on the commercial fish feeds and feedstuffs currently utilized by small-scale pond fish farmers in Ghana so as to evaluate them for *O. niloticus* as it is the main fish cultured in the country. Ultimately, it is anticipated that value addition to the used feed ingredients in the five Regions will be a major contribution towards production of quality fish feed, cutting back fish feed cost and increasing the returns from fish farming in the country. The use of appropriate, cheap and locally available feed ingredients in farm-made fish feed production is necessary to increase fish farming yield, improve food security, reduce poverty among rural folks and create employment.

CHAPTER 2.0 LITERATURE REVIEW

2.1 Fish Consumption Patterns in the World

Global food fish supply has grown steadily in the last five decades, at an average annual rate of 3.2 percent, outpacing world population growth (1.6 %). Therefore, average per capita availability has risen. World per capita apparent fish consumption increased from an average of 9.9 kg (live weight equivalent) in the 1960s to 17.0 kg in the 2000s and 18.9 kg in 2010, with preliminary estimates for 2012 pointing towards further growth to 19.2 kg (FAO, 2014). However, there are distinct regional differences; the lowest consumption is in Africa (9.1 kg/capita), followed by 9.9 kg for Latin America and the Caribbean, 20.7 kg for Asia, 22.0 kg for Europe, 24.1 kg for North America, and 24.6 kg for Oceania (FAO, 2012a, 2012b). Although consumption has grown steadily in developing regions (5.2 kg in 1961 to 17.0 kg in 2009) and in low-income food-deficit countries (LIFDC; 4.9 kg in 1961 to 10.1 kg in 2009), levels are still considerably less than in more developed regions. These aggregate figures cover a very wide variation in consumption, influenced by location, tradition, household customs, fish access, trade connections, market power, and emerging consumption drivers such as urbanization, income distribution changes, and retail development (FAO/SFLP, 2008).

In Africa, fish provides about 22 % of the protein intake in sub-Saharan Africa (SSA) (FAO, 2012b). This can, however, exceed 50 % in the poorest countries, especially where other sources of animal protein are scarce or expensive (WorldFish Center, 2005). Per capita fish consumption has remained static or decreased in some countries in SSA (e.g. the Congo, South Africa, Gabon, Malawi and Liberia), whilst the most substantial

increases in annual per capita fish consumption have occurred in North Africa (from 2.8 kg in 1961 to 10.6 kg in 2009) (FAO, 2012b). Of the 126 million tonnes available for human consumption in 2009, fish consumption was lowest in Africa (9.1 million tonnes with 9.1 kg per capita). This has been attributed to levelling off in capture fish production and increasing population growth (World Bank, 2004). Based on 1997 levels of production, aquaculture would have to increase by 267 % by 2020 to maintain the current fish consumption level in Africa (Delgado *et al*., 2003).

In Ghana, fish is the preferred source of animal protein and it is consumed by the majority of the people. Ghana is among the highest fish consuming countries in the world, with an average per capita consumption of 25 kg. With a population of approximately 24 million fish demand for 2012 was estimated at 968, 000 metric tonnes, whilst fish production for the same year stood at 486, 000 metric tonnes (MoFA, 2013). About 175, 000 metric tonnes of fish were imported at an estimated cost of $ 157 million to make up for the shortfall. The demand for fish is higher than what total domestic fish catch can supply and the gap is widening year after year. Fish provides approximately 60 % of the animal protein consumed in Ghana (GFAR, 2011). About 75 % of the total domestic fish (captured and farmed) is consumed locally. The preferred fish species in Ghana are the sea bream, red snapper and croaker but these are expensive and unaffordable by the majority of the population. Thus, the affordable types-mackerel, horse mackerel, chub mackerel, sardines and tuna are mostly consumed (GFAR, 2011).

2.2 Contribution of Fish to Human Health and Food Security

Consumption of fish can play a key role in access to proteins, minerals, and essential fatty acids, and can have a significant impact for maternal and early child health (Kawarazuka and Béné, 2011; Thilsted *et al*., 1997). There is evidence of beneficial effects of fish consumption (FAO/WHO, 2011) in relation to coronary heart disease (Mozaffarian and Rimm, 2006) stroke, age-related muscular degeneration and mental health (Peet and Stokes, 2005). Also, increasing consumption of fish has been found to enhance learning in children, protects vision and eye health, and offers protection from cardiovascular disease and some cancers (FAO, 2012b). The role of small indigenous fish species, which are often given less prominence in fishery or aquaculture development, can be very critical for poorer households in reducing protein, vitamin and mineral (especially calcium and iodine) deficiencies (Roos *et al*., 2007).

Food fish currently represents the major source of animal protein (contributing more than 25 percent of the total animal protein supply) for about 1 250 million people within 39 countries worldwide, including 19 sub-Saharan countries (FAO, 2009). Fish contributes more than 50 percent of protein intake for about 400 million people from the poorest African and South Asian countries. The quality of fish protein compares very well with that of meat and relatively fish digestion is easier than that of meat (Steiner-Asiedu *et al*., 1993). The ease of digestion makes it an excellent protein source in complementary foods for young child feeding, especially in less developed countries. Fish provides not only high-value protein, but also a wide range of essential micronutrients, including various vitamins (A, B, D and E), and minerals (including calcium, iodine, zinc, iron and

selenium) and polyunsaturated omega-3 fatty acids (mainly docosahexaenoic acid and eicosapentaenoic acid) (FAO, 2012b; Roos *et al*, 2007). Generally, fish is usually low in saturated fats and cholesterol. The fats and fatty acids in fish, particularly the long chain n-3 fatty acids (n-3 polyunsaturated fatty acids (PUFAs)), are highly beneficial and difficult to obtain from other food sources (Kawarazuka and Béné, 2011). Of particular importance are eicosapentaenoic acid (20:5n-3, EPA) and docosahexaenoic acid (22:6n-3, DHA).

With a primary policy focus on access to food calories, fish or aquatic foods have been relatively under-recognized in their contribution to global food supply and food security (FAO, 2012b). However, in 2009, fish accounted for 16.6% of the world's intake of animal protein and 6.5% of all protein consumed, providing around 4.3 billion people with about 15% of their animal protein. With growing recognition of the need to define global targets of food sufficiency and security by nutritional quality (FAO, 2012b; Shetty, 2009), particularly in maternity and early life stages, the role of fish is becoming much more clearly appreciated.

Interactions between fishing and food security are also critical in many parts of the world, where small-scale and often seasonal fishing activity provides both income and household food supply, and there is common concern that over-zealous regulation and removal of fishing capacity may cause more negative social and nutritional impact than the resource efficiency gains being sought (Béné *et al*., 2010). However, though aquaculture might supplement or compensate for capture fisheries, Beveridge *et al*.

(2010) note its constraints of meeting lowest income social objectives, as small- and medium-scale commercial producers and wealthier market/retail consumers are more likely to benefit. However, through market displacement, by producing smaller indigenous species in polycultures, and/or by providing occasional employment for cash or food, additional benefits may be provided for poorer groups. There are also important consequences of trading fish for other food items, either locally or at the market economy level (Kurien, 2004). In favourable conditions this can create advantages for all parties, widening and expanding nutritional options for catchers/producers of fish while improving access to key foodstuffs. This is particularly valuable for peri-urban supplies and urban markets, though there may be issues of reduced local market access where higher urban prices drive out purchasing options. The development of infrastructure–road access, ice production, and market facilities may also accelerate the shift to urban markets. However, there are also specific challenges with meeting needs of poor urban dwellers (Ruel *et al*., 2008), particularly where urbanization is rapid and is not accompanied by strong employment opportunities. It is clear that expansion of fish supplies will be essential to meet future food needs.

2.3.1 Global Production of Aquaculture

Global food fish aquaculture production expanded at an average annual rate of 6.2 percent in the period 2000–2012, more slowly than in the periods 1980–1990 (10.8 percent) and 1990–2000 (9.5 percent) (FAO, 2014). Between 1980 and 2012, world aquaculture production volume increased at an average rate of 8.6 percent per year. World food fish aquaculture production more than doubled from 32.4 million tonnes in

2000 to 66.6 million tonnes in 2012, with an estimated total value of US$137.7 billion (FAO, 2014). Of the 66.6 million tonnes of farmed food fish produced in 2012, two-thirds (44.2 million tonnes) were finfish species grown from inland aquaculture (38.6 million tonnes) and mariculture (5.6 million tonnes). When farmed aquatic algae (mostly seaweeds) are included, world aquaculture production in 2012 was 90.4 million tonnes, worth US$144.4 billion. FAO estimates that world food fish aquaculture production rose by 5.8 percent to 70.5 million tonnes in 2013, with production of farmed aquatic plants (including mostly seaweeds) being estimated at 26.1 million tonnes (FAO, 2014). By continent, annual aquaculture production growth was fastest in Africa (11.7 %) and Latin America and the Caribbean (10 %) in the first twelve years of the new millennium (FAO, 2014). When China is excluded, the expansion in farmed food fish production in the rest of Asia recorded an annual growth rate of 8.2 % from 2000 to 2012, which is significantly higher than in the periods 1980–1990 (6.8 %) and 1990–2000 (4.8 %). The annual growth rate in China, the single largest aquaculture producer, fell to an average of 5.5 % in the period 2000–2012, less than half that of 1980–1990 (17.3 %) and 1990–2000 (12.7 %). Europe and Oceania had the lowest average annual growth rates in the period 2000–2012 at 2.9 and 3.5 %, respectively. In sharp contrast to other regions, production in North America started to shrink gradually from 2005 and, by 2012, was lower than in 2000, owing to the production fall in the United States of America (FAO, 2014).

Worldwide, 15 countries produced 92.7 percent of all farmed food fish in 2012, with Asia accounting for about 88 % of total production by volume. Cut to just over half a million tonnes by the 2011 tsunami, Japan's aquaculture production recovered slightly to more

than 0.6 million tonnes in 2012 (FAO, 2014). Production peaked at more than 0.6 million tonnes in both the United States of America and the Republic of Korea in 2004 and 2007, respectively. In 2012, their respective production levels were slightly more than 0.4 million tonnes and just less than 0.5 million tonnes. Farmed food fish production has been rising steadily among the other leading producers, except in Chile, where disease outbreaks in marine cage culture of Atlantic salmon hit production in 2009–2010 before recovery and further expansion in production in 2011–12 (FAO, 2014).

World aquaculture production can be categorized into inland aquaculture and mariculture. Inland aquaculture generally use freshwater, but some production operations use saline water in inland areas (such as in Egypt) and inland saline-alkali water (such as in China). Mariculture includes production operations in the sea and intertidal zones as well as those operated with land-based (onshore) production facilities and structures (2014).

More than 600 aquatic species are raised in captivity worldwide for production in a variety of farming systems and facilities of varying input intensities and technological sophistication, using freshwater, brackish water and marine water (FAO, 2014). However, the stage of development and the distribution of aquaculture production remain imbalanced in all regions. A few developing countries in Asia and the Pacific, SSA and South America have made considerable progress in aquaculture development in recent years and they are becoming significant or major producers in their respective regions (FAO, 2014). However, the disparity remains huge across the continents and georegions,

as well as among countries of comparable natural conditions in the same region, with aquaculture in many of the least developed countries yet to make a significant contribution to national food and nutrition security.

World aquaculture production is vulnerable to adverse impacts of natural, socioeconomic, environmental and technological conditions (FAO, 2012a, WWF, 2012). In 2010, aquaculture in China suffered production losses of 1.7 million tonnes (worth US$3.3 billion) caused by diseases (295 000 tonnes), natural disasters (1.2 million tonnes), pollution (123 000 tonnes) etc. Disease outbreaks virtually wiped out marine shrimp farming production in Mozambique in 2011 (WWF, 2012).

Total aquaculture production in Africa in 2012 was estimated to be 1 485 367 mt which is about 2.23 % of global production by volume. North Africa contributed about 1 030 675 mt whilst SSA contributed about 454 691 mt accounting for 69.39 and 30.61 % respectively of African production (FAO, 2014). Aquaculture production in SSA is dominated by Nigeria contributing about 15.57 % with the other top five producers (Uganda, Kenya, Zambia, Ghana and Madagascar) together contributing about 10.43 % of the total production in 2010. Between 2000 and 2010, overall aquaculture production in SSA increased by 84.52 % from 55 690 mt to 359 790 mt (FAO, 2012a). More than 70 % of total aquaculture production in SSA comes from commercial farms, produced by less than 20 % of farmers, whilst the remaining less than 30 % is produced by small-scale farmers that represent over 80 % of all farmers (Hecht, 2007). The systems used by the commercial sector range from semi-intensive to intensive pond, cage and tank culture of

catfish (*Clarias spp*.) and tilapia (*Oreochromis spp*.) and high-valued products such as shrimp (Madagascar and Mozambique) and abalone (South Africa) while noncommercial subsistence aquaculture primarily consists of small-scale pond culture of tilapia, catfish and common carp, *Cyprinus carpio* (Hecht, 2007). Machena and Moehl (2001) reported that the major aquaculture products in Africa are mainly fresh- and brackish-water finfish.

The share of freshwater aquaculture production in Africa increased from 21.8 percent in the 1990s to 39.5 percent in 2010 as a result of rapid development in freshwater fish farming in Nigeria, Uganda, Zambia, Ghana and Kenya (FAO, 2012a). African aquaculture production is mainly finfishes (99.3 percent by volume), with only a small fraction from marine shrimps (0.5 percent) and marine molluscs (0.2 percent). In spite of some limited successes, the potential for bivalve production in marine waters remains almost completely unexplored.

In Ghana, aquaculture became important in the 1980's when the Government of Ghana (GoG) recognized fish farming as an assured way of meeting the deficit in Ghana's protein requirements (GFAR, 2011). Due to massive GoG support, fish farming became established in many parts of the country. However, the growth of the sector was slow due in part to the subsistence nature of fish farming, inefficient and inappropriate production practices, and dependency on government support. In addition, the sector faced many challenges including lacking inputs such as fingerlings and fish feed produced commercially to support the growth of the industry (GFAR, 2011).

Commercial fish farming in Ghana is a recent development that has been adopted in the past few years. Presently, there are about seven main commercial aquaculture farms operating in Ghana and over 200 medium/small-scale fish farms. In the last five years aquaculture production has increased by 80 percent from 2005 to 2010 as a result of proliferation of commercial fish farming particularly the cage farming on the Lake Volta (GFAR, 2011).

Tilapia constitutes about 80 % of aquaculture production while catfish and others account for the remaining 20 %. While there is no major shrimp/prawn farming in Ghana yet, research shows that there is a great potential for commercial farming of local shrimp species (GFAR, 2011). The majority of the aquaculture operators grows or culture fish in earthen ponds either as a monoculture of tilapia or poly-culture of tilapia with catfish. Cage fish farms contribute over 80 percent of total fish yield in aquaculture production. The commercial operators do not produce their own fish feed but buy high quality pelletized balanced feed from animal feed companies (GFAR, 2011).

Most medium/small-scale fish farmers do not produce their own fingerlings, instead they buy from the large scale farmers; others collect old stocks from other fish ponds or from rivers and streams. Tilapia fingerlings used on most medium/small-scale fish farms are mostly of poor quality (GFAR, 2011). The small/medium-scale operators produce various species of tilapia and catfish. Most small/medium-scale fish farmers rely on the natural productivity of the ponds to achieve their production. Others use agricultural by products, or poor quality feedstuffs in unbalanced proportions to feed tilapia.

2.4 Aquaculture Growth and Fish Feeding

In 2012, global aquaculture production totalled 90.4 million tonnes, made up of 66.6 million tonnes of food fish (i.e. finfishes, crustaceans, molluscs, amphibians, freshwater turtles, sea cucumbers, sea urchins, sea squirts and edible jellyfish) and 23.8 million tonnes of aquatic algae (mostly seaweeds) (FAO, 2014). Farmed food fish contributed 42.2 % of the total 158 million tonnes of fish produced by capture fisheries (including for non-food uses) and aquaculture in 2012. This compares with just 13.4 % in 1990 and 25.7 % in 2000 (FAO, 2014). Asia as a whole has been producing more farmed fish than wild catch since 2008, and its aquaculture share in total production reached 54 % in 2012, with Europe at 18 % and other continents at less than 15 %. FAO estimates in 2012 indicated that about 46.1 million tonnes (69.2 percent of total global aquaculture production including aquatic plants) of fish and crustaceans were feed-dependent, either as farm-made aquafeeds or as industrially manufactured compound aquafeeds (FAO, 2014). Continuing its established trend, the share of fed species in total farmed food fish production increased further from 66.5 % in 2010 to 69.2 % in 2012, reflecting a relatively stronger growth in the farming of fed species (FAO, 2014).

While more than 200 species of fish and crustaceans are currently believed to be fed on externally supplied feeds, just 8 species or species groups account for 62.2 percent of the total feed used. These are: grass carp, common carp, Nile tilapia, Indian major carps (catla and rohu), whiteleg shrimp, crucian carp, Atlantic salmon, and pangasiid catfishes. More than 67.7 percent of farmed fed fish production is contributed by freshwater fishes,

including carps and other cyprinids, tilapias, catfishes and miscellaneous freshwater fishes (FAO, 2012a).

2.5 Production and Use of Fish Feed

Compound aquafeeds are used for the production of both lower-value (in marketing terms) food fish species, such as non-filter-feeding carps, tilapias, catfishes and milkfish, as well as higher-value species, such as marine finfishes, salmonids, marine shrimps, freshwater eels, snakeheads and crustaceans (FAO, 2012a). Globally, 708 million tonnes of industrial compound animal feeds were produced in 2008, of which 29.2 million tonnes were aquafeeds (4.1 percent of all animal feeds). As animal production has increased, so has global industrial compound animal feed production – almost fourfold from 7.6 million tonnes in 1995 to 29.2 million tonnes in 2008, at an average rate of 11 percent per year (FAO, 2012a). Production is expected to grow to 51.0 million tonnes by 2015 and to 71.0 million tonnes by 2020.

While there is no comprehensive information available on the global production of farm-made aquafeeds (De Silva and Hasan, 2007), the estimate is that it was between 18.7 million and 30.7 million tonnes in 2006. More than 97 percent of carp feeds used by Indian farmers are farm-made aquafeeds (7.5 million tonnes in 2006/07), and they are the mainstay of feed inputs for low-value freshwater fishes in many other Asian and sub-Saharan countries.

2.6 Feed Ingredient Production and Availability

Feed ingredients used for the production of aquafeeds are broadly categorized into three types depending upon their origin: animal nutrient sources (including both aquatic and terrestrial animals); plant nutrient sources; and microbial nutrient sources (Tacon *et al*., 2012).

2.6.1 Animal Nutrient Sources

The major aquatic animal protein meals and lipids used in aquafeeds include: fish/shellfish meals and oils; fish/shellfish by-product meals and oils; and zooplankton meals and oils (FAO, 2012a). The major terrestrial animal protein meals and lipids commonly used in aquafeeds are: (i) meat by-product meals and fats; (ii) poultry by-product meal, hydrolysed feather meal and poultry oil; and (iii) blood meals (Tacon *et al*., 2011). In recent years, increasing volumes of fishmeal and fish oil have originated from fisheries by-products (capture fisheries and aquaculture). An estimated 6 million tonnes of trimmings and rejects from food fish are currently used for fishmeal and fish-oil production (Tacon *et al*., 2011). Although some marine zooplanktons have potential for use as feed ingredients for aquaculture, commercial operations only exist for Antarctic krill (*Euphausia superba*), with total landings of 118 124 tonnes in 2007 (Tacon *et al*., 2011). Although krill meal and krill oil are available, information concerning their total global production and market availability is currently unavailable.

Processed animal protein ingredients (often referred to as land animal products) such as blood meal, feather meal and poultry by-product meal are comparable with many other

protein sources used in fish feeds on a cost-per unit protein basis (NRC, 2011). No effects on growth performance and feed utilization were observed when fish meal protein in finfish diets was replaced with 60-80% of poultry by-products (PBM) or with 30-40% hydrolysed feather meal (FeM) (Yu, 2008). A number of published reports are available regarding the suitability of different animal protein feeds as alternatives to fish meal in fish feeds (Rossi Jr and Davis, 2012; Hernández *et al.*, 2010; El-Haroun *et al.*, 2009; Rawles *et al.*, 2009; Hu *et al.*, 2008; Saoud *et al.*, 2008; Wang *et al.*, 2008; El-Sayed, 1998).

2.6.2 Plant Nutrient Sources

The major plant dietary nutrient sources used in aquafeeds include: cereals, including by-product meals and oils; oilseed meals and oils; and pulses and protein concentrate meals (Tacon *et al.*, 2011). Total global cereal production was 2 489 million tonnes in 2009, with maize totalling 817.1 million tonnes (32.8 percent of the total), followed by wheat, rice paddy, and barley. In 2009, oilseed production was 415 million tonnes, with soybean being the largest and fastest-growing oilseed crop and accounting for slightly more than 50 percent (210.9 million tonnes) of this total. Among the pulses, protein concentrate meals from peas and lupins are commercially available for use within compounded animal feeds, including aquaculture feeds.

Using plant-based proteins in aquaculture feeds requires that the ingredients possess certain nutritional characteristics, such as low levels of fibre, starch and anti-nutritional compounds. They must also have a relatively high protein content, favourable amino acid

profile, high nutrient digestibility and reasonable palatability (NRC, 2011; Lim *et al.*, 2008). A number of previous studies discuss the suitability of plant protein feeds and/or local agricultural by-products as an alternative protein source in fish feeds (Burr *et al.*, 2012; Bonaldo *et al.*, 2011; Brinker and Reiter, 2011; Cabral *et al.*, 2011; Nyina-Wamwiza *et al.*, 2010; Pratoomyot *et al.*, 2010; Garduño-Lugo and Olvera-Novoa, 2008; Olsen *et al.*, 2007).

Duckweeds grown on water with 10-30 mg NH_3-N/litre have high protein content (around 40%) of high biological value (Hillman and Cully, 1978). Fresh duckweed is highly suited to intensive fish farming systems with relatively rapid water exchange for waste removal (Gaigher *et al.*, 1984) and duckweed is converted efficiently to live weight by certain fish including carp and tilapia (Hasan and Edwards, 1992; Robinette *et al* 1980; Hepher and Pruginin, 1979; Van Dyke and Sutton, 1977). A duckweed lagoon with a standing crop of duckweed is harvested and placed fresh into a second lagoon containing a mixed size tilapia culture. The pond is harvested twice weekly and the fish sorted into various groups for return to the lagoon or sale. Under these circumstances the average yield of fish per hectare of lagoon is estimated at around 10 tonnes annually using only duckweed as the supplement to the naturally available fish feed (Skillicorn *et al.*, 1993).

2.6.3 Microbial Ingredient Sources

Microbial-derived feed ingredient sources for aquafeed include algae, yeasts, fungi, bacteria and/or mixed bacterial/microbial single-cell protein sources (Tacon *et al.*, 2011).

The only such sources available in commercial quantities globally are yeast-derived products, including brewer's yeast and extracted fermented yeast products, but with limited information concerning their total global production and availability (FAO, 2012a). Given the relatively low cost of some of these single-cell proteins, they are probably most relevant as a major protein ingredient in fish feed or may at least partially replace fishmeal in feeds for some fish species (FAO, 2012a).

Various species of macroalgae and microalgae have been incorporated into fish feed formulations to assess their nutritional value, and many have been shown to be beneficial: *Chlorella* or *Scenedesmus* fed to Tilapia (Tartiel *et al*., 2008); *Chlorella* fed to Korean rockfish (Bai *et al*., 2001); *Undaria* or *Ascophyllum* fed to Sea Bream (Yone *et al*., 1986); *Ascophyllum*, *Porphyra*, *Spirulina*, or *Ulva* fed to Sea Bream (Mustafa and Nakagawa, 1995); *Gracilaria* or *Ulva* fed to European Sea Bass (Valente *et al*., 2006); *Ulva* fed to Striped Mullet (Wassef *et al*., 2001); *Ulva* or *Pterocladia* fed to Gilthead Sea Bream (Wassef *et al*., 2005); *Porphyra* or a *Nannochloropsis-Isochrysis* combination fed to Atlantic Cod (Walker *et al*., 2009, 2010). Unfortunately, it has rarely been possible to determine the particular nutritional factors responsible for these beneficial effects, either because no attempt was made to do so or poor design of the study. For example, in one of the few studies that has focused on the effects of substituting algal protein for gluten protein, the control and all the test diets contained casein plus added methionine and lysine, no analysis of the algal protein was provided, and the algal protein (a biofuel process by-product) contained very high levels of aluminium and iron (Hussein *et al*., 2012).

2.7 Anti-nutrients in Feed Ingredients

The use of plants or plant-derived feedstuffs such as legume seeds, different types of oilseed cake, leaf meal, leaf protein concentrates and root tuber meals as fish feed ingredients is limited by the presence of a wide variety of anti-nutritional substances (Francis *et al.*, 2001) (Table 2.1). However, only a few are of major importance for fish feed formulation. The effects of these substances on fish can include reduced palatability, altered nutrient balance of the diet, disturbance of digestive processes and growth, decreased feed efficiency, pancreatic hypertrophy, hypoglycaemia, liver dysfunction, goiterogenesis and immune suppression (NRC, 2011; Krogdahl *et al.*, 2010).

It has been observed that common processing techniques, such as cooking, soaking, drying and wet heating, as well as adding feed supplements, can reduce the concentration of anti-nutritional factors in plant feeds and improve the feed intake (Rehman and Shah, 2005; Francis *et al.*, 2001; Alonso *et al.*, 2000). By-products of animal origin may also contain anti-nutritional compounds, especially if the products are not properly preserved or processed (NRC, 2011). However, whilst some anti-nutritional factors are easy to eliminate by processing, others may be more difficult to eliminate.

Table 2.1 Anti-nutrient compounds and their biological effects on animals

Compound	Biological effects	References
Fibres	Interfere with digestion, absorption and utilization of macro- and micro-nutrients.	Van Der Kamp *et al*. (2004)
Phytic acid	Impairs mineral digestion and contains phosphorus in a form unavailable to monogastrics.	Thompson (1993)
Protease inhibitors	Growth reduction, inhibition of proteolytic enzymes.	Francis *et al*. (2001)
Enzyme inhibitors	Reduce the digestion of protein, carbohydrates and lipids.	Thompson (1993); Krogdah and Holm (1979)
Goitrogen	Growth reduction, thyroid hyperplasia, changes in T3 and T4 levels.	Francis *et al*. (2001)
Oestrogens	Growth reduction, induction of vitellogenin secretion.	Francis *et al*. (2001)
Lectins	Make the gut more permeable for increased influx of macromolecules and bacteria, stimulate insulin production and alter metabolism. Growth reduction.	Grant (1991)
Saponins	Interfere with lipid and protein digestion. Growth and feed efficiency reduction.	Cuadrado *et al*. (1995)
Glucosinolates	Reduce the uptake of iodine into the thyroid gland and may lead to goitre.	Liener (1980)
Cyanogens	Respiratory failure. Growth and feed efficiency reduction.	Liener (1980)
Phytoestrogens	Interfere with endogenous oestrogen.	Price and Fenwick (1985)
Phytosterols	Interfere with cholesterol absorption and metabolism.	Ostlund Jr *et al*. (2003)
Quinolizidine alkaloids	Lupine alkaloids, may cause nervous symptoms and intestinal disorders.	Wink *et al*. (1998)
Oligosaccharides	Alter the microbiota in the gut and increase osmotic pressure in the intestine.	Cummings *et al*. (1986)
Alkaloids	Growth and reduced feed palatability, liver abnormalities.	Francis *et al*. (2001)
Anti-vitamins	Reduced vitamin availability.	Melcion and Poel (1993)
Toxic fatty acids	Effect on reduction mortality.	Liener (1980)

Data source: Adapted from Hardy (2010); Krogdahl *et al*. (2010); Francis *et al*. (2001); Melcion and Poel (1993).

2.8 Culturing of Tilapia

"Tilapia" is a generic term which is used to designate a group of commercially important food fish belonging to the family Cichlidae. Tilapia have been raised as food for human consumption for a long time; illustrations from Egyptian tombs suggest that the Nile tilapia, *Oreochromis niloticus*, was cultured more than 3000 years ago (Maar *et al.*, 1966). Tilapia is referred to as "Saint Peter's fish" in reference to biblical passages about the fish fed to the multitudes (Popma and Masser, 1999). Although endemic to Africa their distribution has been extended by introduction to include much of the tropics and subtropics. More than 100 species have been identified (Balarin, 1979). Currently, tilapia culture is widely practised in many tropical and subtropical regions of the world. More than 22 tilapia species are being cultured worldwide. However, Nile tilapia (*Oreochromis niloticus),* Mozambique tilapia *(O. mossambicus),* blue tilapia *(O. aureus), O. hornorum, O. galilaeus, Tilapia zillii and T. rendalli* are the most commercially cultured tilapia species (Fitzsimmons, 2000). Tilapia species are used in commercial farming systems in almost 100 countries and are developed to be one of the most important fish for aquaculture in this century.

2.9 Reproduction in Nile Tilapia

Sexual maturity of Nile tilapia is reached at 10-30 cm total length (TL) and is related to the maximum size attained in a given population and condition, which in turn is determined by food availability and temperature (Trewavas, 1983; Pullin and Lowe-McConnell, 1982). Reproduction occurs only when temperature exceeds 20 °C. The breeding cycle is latitude dependent and spawning becomes more seasonal at higher

latitudes. In many instances the breeding cycle is synchronized with the rainy season (Trewavas, 1983). The species is a nest building, batch spawning mouth brooder that can spawn every 30 days. The nest, like in many tilapiine fishes, is a circular depression in sandy areas of up to 1m in diameter and 0.5 m deep. The average nest diameter is twice the length of the male making it. Males are highly territorial and defend their nests (Trewavas, 1983). Batches of eggs are spawned into the nest, fertilized externally and then picked up by the female. The female incubates the eggs for 5-7 days when they hatch and the early fry remain in the mouth until after yolk sac absorption. Depending on size, females can carry up to 200 eggs. The eggs are large and ovoid (pear shaped) and at hatching the fish are around 4 mm in length (Trewavas, 1983).

2.10 Natural Food and Feeding Habits of Nile Tilapia

Early juveniles and young fish are omnivorous, feeding mainly on zooplankton and zoobenthos but also ingest detritus and feed on aufwuchs and phytoplankton (Beveridge, 2000; Moriarty and Moriarty, 1973; Moriarty *et al*., 1973). At about 6 cm TL the species becomes almost entirely herbivorous feeding mainly on phytoplankton, using the mucus trap mechanism and its pharyngeal teeth. The pH of the stomach varies with the degree of fullness and when full can be as low as 1.4, such that lysis of blue-green and green algae and diatoms is facilitated (Moriarty, 1973). Enzymatic digestion occurs in the intestine where pH increases progressively from 5.5 at the exit of the stomach to 8 near the anus. Nile tilapia exhibits a dual feeding pattern. Ingestion occurs during the day and digestion occurs mainly at night (Trewavas, 1983). The digestive tract of Nile tilapia is at least six times the total length of the fish, providing abundant surface area for digestion and

absorption of nutrients from its mainly plant-based food sources (Opuszynski and Shireman, 1995).

2.11 Growth of Nile Tilapia

A study on the growth of 10 populations of *O. niloticus* under natural conditions showed that the von Bertalanffy growth function parameters range as follows: L_∞ (cm) = 22.9 to 57.2, K = 0.14 to 0.51 and t_o = -0.85 to 0.54 (Merona *et al.*, 1988). The maximum recorded size is 64 cm TL (Lake Kyoga) and in Lake Turkana fish of up to 7 kg have been recorded (Trewavas, 1983). The range of von Bertalanffy growth function parameters for cultured Nile tilapia as modelled by Moreau and Pauly (1999) were: L_∞ (cm) = 16.6 to 41.8, K = 0.637 to 4.566 and Ø' = 2.93 to 3.43. The wide range of values reported for Nile tilapia under natural conditions reflects the phenotypic response to the prevailing environmental conditions of the species and under culture condition is determined by sex ratio, stocking density, culture systems, feeds, temperature and water quality (Abdel-Tawwab and El-Marakby, 2004).

Several organizations have invested substantial resources in the genetic improvement of Nile tilapia. The Genetically Improved Farmed Tilapia (GIFT) strains developed by the WorldFish Center as well as other strains (GET EXCEL, GenoMar ASA and GenoMar Supreme Tilapia) have significantly better growth performance than "unaltered" strains (Asian Development Bank, 2005).

2.12 Use of Formulated Feeds for Nile Tilapia

High quality formulated feeds are used to achieve high yields and large sized fish (600-900 g) within a short period of time (Dey, 2001). Under semi-intensive farming systems, most tilapia farmers in Asia fertilize their ponds and use formulated feeds. However, in intensive pond and tank culture systems or in cages, tilapia farmers mainly depend on commercial pelleted feeds. In terms of pond yields, Dey (2001) reported that overall, the average yield of pond farming in Taiwan, Province of China is very high (12 to 17 tonnes/ha) while ponds in Bangladesh, China, the Philippines, Thailand and Vietnam produce around 1.7, 6.6, 3.0, 6.3 and 3.0 tonnes/ha, respectively.

Tilapia feeds accounted for about 8.1 percent of global aquafeed production in 2003 (Tacon *et al*., 2006). Commercial tilapia feeds are mainly dry sinking pellets and extruded floating pellets. Production estimates for farm-made tilapia feeds are not available as these are usually site specific and dependent on locally available feed ingredients (Tacon *et al*., 2006). In countries such as the Philippines, on-farm feeds are not very popular as tilapia farmers find it more convenient to purchase formulated feeds from feed companies.

The main issue in formulating feed is to meet the protein and essential amino acids (EAAs) requirements of the species to facilitate tissue/muscle growth. Fishmeal is generally the preferred protein source because of the high quality of the protein and its EAA profile (Jauncey and Ross, 1982). However, fishmeal is generally expensive and is not always available. Nile tilapia can be fed with a high percentage of plant proteins (Mbahinzireki *et al*., 2001; Ofojekwu and Ejike, 1984). It is economically judicious to

replace fishmeal with alternative protein sources including animal by-products, oilseed meal and cakes, legumes and cereal by-products and aquatic plants (Agbo *et al*., 2011; Rumsey, 1993). Most of these ingredients are deficient in some EAA and hence require supplementation or be compensated with other feedstuffs. Although most of the oilseed cakes/by-products are generally deficient in lysine and methionine, blending of different oilseed cakes often provides balanced amino acid profile (Lim and Webster, 2006). However, they contain many anti-nutritional factors (such as gossypol, glucosinolates, saponins, trypsin inhibitors etc.) which limit their use in compound feeds or require removal/inactivation through specific processing (such as heating, cooking etc.) (NRC, 1993). There are also several non-conventional protein sources that may be suitable for *O. niloticus* such as silkworm pupae, snails, earthworms, *Spirulina*, corn and wheat gluten, almond cake, sesame cake, brewery waste etc.

2.13 Feeding Schedules (Rates and Frequencies) for Cultured Tilapia

Feeding rate (allowance) in practical feeding of fish involves two options. One is to feed the fish to satiation (i.e. *Ad libitum*) and the other is to feed a restricted ration (Suresh, 2003). Best growth is normally achieved by feeding to satiation. However, satiation levels are not necessarily the most economic feeding levels, as food conversion at satiation levels is often poor. This may also lead to overfeeding, which is wasteful and deleterious to water quality. As a result, restricted rations are recommended for feeding fish (Suresh, 2003). It is also common practice to feed to satiety before determining the rate of feeding. It is generally known that smaller fish consume more feed per unit body weight compared to larger fish. Tilapia is known to consume less feed during the colder

months of the year in countries where there are substantial seasonal temperature fluctuations. Some recommended feeding schedules widely used for semi-intensive and intensive culture for tilapia in freshwater ponds in China are shown in Table 2.2 (Miao and Liang, 2007).

Table 2.2 Feeding schedules for various sizes of tilapia in semi-intensive and intensive culture in freshwater ponds

Fish size (g)	Feeding rate (% wet body weight)		Feeding frequency
	Semi-intensive (<20 000/ha)	Intensive (>20 000/ha)	(No./day)
<1	30-10	-	To satiation
1 to 5	10 to 6	-	6
5 to 20	6 to 4	-	4
20-100	4 to 3	-	4
100-250	3	-	3
250-500	3 to 2	2.0-1.5	3
>500	2-1.5	1.5-1.3	3-2

Source: Adapted from Miao and Liang (2007)

2.14 Nutritional Requirements of Nile Tilapia

Nutritional requirements of fish differ for different species and more importantly vary with life stage. Fry and fingerlings require diets with higher protein, lipids, vitamins and minerals and lower carbohydrates as they are developing muscle, internal organs and bones with rapid growth (Fitzsimmons, 1997). From various studies the protein requirements of juvenile tilapia have been reported to range between 30-56% (Agbo, 2008; Suresh, 2003; Jauncey, 1998).

Protein requirements of Nile tilapia for optimum growth are dependent on dietary protein quality/source, fish size or age and the energy contents of the diets and have been reported to vary from as high as 45-50 percent for first feeding larvae, 35-40 percent for fry and fingerlings (0.02-10 g), 30-35 percent for juveniles (10.0-25.0 g) to 28-30 percent

for on-growing (>25.0 g) (El-Sayed , 2006; Lim and Webster, 2006; Fitzsimmons, 2005; Shiau, 2002) (Table 2.3). The broodfish require about 40-45 percent protein for optimum reproduction, spawning efficiency and for larval growth and survival. Nile tilapia requires the same ten essential amino acids (EAAs) as other finfishes. The recommended EAAs for Nile tilapia are shown in Table 2.4 below:

Table 2.3 Dietary protein needs for Nile tilapia, *O niloticus* by life stage

Life stage	Weight (g)	Dietary protein content (%)
First feeding larvae		45-50
Fry	0.02-1.0	40
Fingerlings	1.0-10.0	35-40
Juveniles	10.0-25.0	30-35
Adults	25.0-200.0	30-32
	>200	28-30
Broodstock		40-45

Data source: El-Sayed (2006), Lim and Webster (2006), Fitzsimmons (2005), Shiau (2002)

Table 2.4 Essential amino acid needs of Nile tilapia, *O. niloticus* as % of dietary protein and of total diet

Amino acid	% of protein	% of diet
Arginine	4.20	1.18
Histidine	1.72	0.48
Isoleucine	3.11	0.87
Leucine	3.39	0.95
Lysine	5.12	1.53
Methionine	2.68[a]	0.75
Phenylalanine	3.75[b]	1.05
Threonine	3.75	1.05
Tryptophan	1.00	0.28
Valine	2.80	0.78

(a) In the presence of cystine at 0.54% of dietary protein. Total sulphur amino acid (methionine plus cystine) requirement is 3.21% of the protein
(b) In the presence of tyrosine at 1.79% of dietary protein. Total aromatic amino acid (phenylalanine plustyrosine) requirement is 5.54% of the protein
Data source: El-Sayed (2006), Lim and Webster (2006), Fitzsimmons (2005), Shiau (2002)

The minimum requirement of dietary lipids in tilapia diets is 5 percent but improved growth and protein utilization efficiency has been reported for diets with 10-15 percent lipids (Ng and Chong, 2004). Both n-3 and n-6 polyunsaturated fatty acids (PUFAs)

have been shown to be essential for maximal growth of hybrid tilapia (*O. niloticus* x *O. aureus*). For Nile tilapia the quantitative requirement for n-6 PUFA is around 0.5-1.0 percent. Unlike marine fish species, tilapia appear not to have a requirement for n-3 highly unsaturated fatty acids (HUFAs) such as EPA (20:5n-3) and DHA (22:6n-3) and its n-3 fatty acid requirement can be met with linolenic acid (18:3n-3). The recommended crude lipid, essential fatty acids and energy for Nile tilapia are shown in Table 2.5 below:

Table 2.5 Crude lipid, essential fatty acids and energy needs for growth of *O. niloticus* (% dry feed)

Nutrient	Amount
Crude lipid, % min.	10-15
Essential fatty acids, % min.	
18:2n-6	0.5-1.0[a]
20:4n-6	1.0[a]
18:3n-3	
20:5n-3	
22:6n-3	
Carbohydrate, % max[b]	40
Crude fibre, % max	8-10
Protein to energy ratio (mg/kcal)	110[c]
	120[d]

(a) 1% 20:4n-6 or 0.5-1% 18:2n-6.
(b) Dieatry utilization of carbohydrate appear to decrease with decrease in fish size
(c) mg protein for kcal of gross energy (GE); (d) mg protein for kcal of digestible energy (DE)
Data source: El-Sayed (2006), Lim and Webster (2006), Fitzsimmons (2005), Shiau (2002)

Carbohydrates are included in tilapia feeds to provide a cheap source of energy and for improving pellet binding properties. Tilapia can efficiently utilize as much as 35-40 percent digestible carbohydrate (El-Sayed, 2006). Nile tilapia is capable of utilizing high levels of various carbohydrates of between 30 to 70 percent of the diet. It has also been demonstrated that larger hybrid tilapia (*O. niloticus* x *O. aureus*) utilized carbohydrates better than smaller sized fish. Older fish seem to cope with higher dietary fibre content, a

maximum of 8-10 % (El-Sayed, 2006; Lim and Webster, 2006; Jauncey, 1998) and younger ones at about 6-8 % (Fitzsimons, 2005; Shiau, 2002).

Table 2.6 Mineral requirements of *O. niloticus* (% of dry feed except otherwise mentioned)

Minerals	Amount
Macro elements (%)	
Calcium, max.	0.7[a]
Phosphorus, min.	0.8-1.0
Magnesium, min.	0.06-0.08
Sodium, min.	
Potassium	0.21-0.33[b]
Microelements, min mg/kg dry diet	
Iron	60
Sulphur	
Chlorine	
Copper	2-3
Manganese	12
Zinc	30-79
Cobalt	
Selenium	0.4
Iodine	1.0
Molybdenium	
Chromium	139.6[b]
Fluorine	

[a]Based on data from *O. aureus*; [b]Based on data from hybrid tilapia (*O. niloticus* X *O. aureus*).
Data source: Shiau (2002), Fitzsimmons (2005), El-Sayed (2006), Lim and Webster (2006)

There is little information on the mineral requirements of tilapia. Like other aquatic animals, tilapias are able to absorb minerals from the culture water which makes the quantitative determination of these elements difficult to carry out (Stickney, 1997). Despite its ability to absorb minerals from the culture water and the presence of minerals in feed ingredients, tilapia feeds should contain supplemental mineral premixes. This is to ensure that sufficient levels are available to protect against mineral deficiencies caused by reduced bioavailability such as when plant phosphorus sources are used in tilapia feeds

(Shiau and Su, 2003). The mineral requirements of Nile tilapia as percentage of dry feed is shown in Table 2.6 above.

Table 2.7 Vitamin needs of *O. niloticus* (% of dry feed except otherwise mentioned)

Vitamin	Amount
Vitamins, min IU/kg dry diet	
	5 000
Vitamin A (Retinol)	
Vitamin D (Cholecalciferol)	3.75[b]
Vitamin, min mg/kg dry diet	
Vitamin E (α-tocopherol)	50-100[c]
Vitamin K	4.4
Vitamin B_1 (Thiamine)	4
Vitamin B_2 (Riboflavin	5-6[d]
Vitamin B_3 (Niacin/nicotinic acid)	26-121[b]
Vitamin B_5 (Pantothenic acid)	10[a]
Vitamin B_6 (Pyridoxine)	1.7-9.5[e]
Vitamin B_9 (Folic acid)	0.5
Vitamin B_{12} (Cyanocobalamin acid)	Not required
Choline	1 000[b]
Inositol	400[b]
Vitamin B_7 (Biotin)	0.06[c]
Vtamin C (Ascorbic acid)	420

[a]Based on data from *O. aureus*; [b]Based on data from hybrid tilapia (*O. niloticus* X *O. aureus*).
[c]Based on diets with 5% lipid. Vitamin E requirement increases to 500 mg/kg dry diet at 10-15% dieatry lipid level; [d]Based on data from hybrid tilapia (*O. mossambicus* X *O. niloticus*) and *O. aureus*
[e]Based on data from hybrid tilapia (*O. niloticus* X *O. aureus*) at dietary protein level of 28%, requirement 15-16.5 mg/kg diet at 36% protein diet
Data source: Shiau (2002), Fitzsimmons (2005), El-Sayed (2006), Lim and Webster (2006)

Vitamin supplementation is not necessary for tilapia in semi-intensive farming systems, while vitamins are generally necessary for optimum growth and health of tilapia in intensive culture systems where limited natural foods are available (El-Sayed, 2006; Lim and Webster, 2006). The vitamin requirements of Nile tilapia as percentage of dry feed is shown in Table 2.7 above.

2.15 Nutritional Deficiencies in Nile Tilapia

Deficiency signs of farmed tilapia may occur when fish are fed nutrient deficient diets or raised in a low nutrient-input culture system (Dabrowska *et al*., 1989). Essential amino acid (EAA) deficiency in tilapia generally leads to loss of appetite, retarded growth, and poor feed utilization efficiency (Table 2.8).

Table 2.8 Dietary nutritional deficiency of essential amino acid and essential fatty acid

EAAs/EFA	Deficiency signs/syndrome
EAAs	
Lysine	Dorsal/caudal fin erosion, retarded growth, increased mortality
Methionine	Retarded growth, cataract
Tryptophan	Retarded growth, scoliosis, lordosis, caudal fin erosion
Essential fatty acid	
Linoleic acid (18:2n-6)	Retarded growth, swollen pale liver, fatty liver

In bold: Reported EFA deficiency signs for *O. niloticus*, not in bold: general EAA deficiency symptoms in fish
Data source: Tacon (1987), Tacon (1992)

In some fish species (e.g. rainbow trout, sockeye salmon, Atlantic salmon, chum salmon, coho salmon), lysine, methionine or tryptophan deficiency results in various signs such as scoliosis, lordosis, fin erosions and cataracts although none of these deficiency signs have been reported for tilapias (Tacon, 1987). Similar to EAA deficiency, the lack of essential fatty acids (EFA) will also lead to loss of appetite and poor growth in tilapia. Other reported signs of EFA deficiencies in Nile tilapia include swollen pale and fatty livers (Tacon, 1992).

Mineral deficiencies are difficult to assess in tilapia as most trace elements are obtained both from the dietary ingredients and from the culture water (Dabrowska *et al*., 1989). Table 2.9 below shows the dietary nutritional deficiencies of some minerals in fish.

Table 2.9 Dietary mineral deficiency signs and symptoms associated with tilapia species

Minerals	Deficiency signs/syndrome
Phosphorus	Lordosis, poor growth
Calcium	Reduced growth, poor feed conversion and bone mineralization
Potassium	Reduced growth and feed efficiency, anorexia, convulsions
Magnesium	Reduced growth/whole-body hypercalcinosis
Iron	Microcytic, homochronic anaemia
Zinc	Reduced growth and appetite, cataracts, high mortality, erosion of fins and skin, short body dwarfism, fin erosion
Manganese	Reduced growth and skeletal abnormalities, anorexia, loss of equilibrium
Copper	Reduced growth, cataracts
Selenium	Increased mortality, muscular dystrophy, reduced growth, cataracts, anaemia
Iodine	Thyroid hyperplasia (goitre)

In bold: Reported deficiency signs for *O. niloticus*, Not in bold: general mineral deficiency symptoms in fish

Data source: Chow and Schell (1980), Tacon (1987), Tacon (1992), NRC (1993), Jauncey (2000)

Table 2.10 Specific vitamin deficiencies associated with tilapia species

Vitamins	Species	Deficiency signs/syndrome
Vitamin B_2 (Riboflavin)	*O. aureus*	Poor growth, high mortality, lethargy, fin erosion, anorexia, loss of body colour, dwarfism, cataracts
Vitamin B_5 (Pantothenic acid)	*O. aureus*	Poor growth, hyperplasia of epithelial cells of gill lamellae, fin erosion, haemorrhage, anaemia, sluggishness
Vitamin B_3 (Niacin/nicotinic acid)	Hybrid tilapia (*O. niloticus* x *O. aureus*)	Haemorrhage, deformed snout, gill oedema, and skin, fin, and mouth lesions
Vitamin B_1 (Thiamine)	Hybrid tilapia (*O. mossambicus* x *O. niloticus*) and Nile tilapia	Poor growth and poor feed efficiency, anorexia, light colouration, nervous disorders, low haematocrit and red blood cell count, and increased serum pyruvate
Vitamin B_6 (Pyridoxine)	Hybrid tilapia (*O. niloticus* x *O. aureus*)	Poor growth and poor feed efficiency, high mortality, abnormal neurological signs, anorexia, convulsions, caudal fin erosion, mouth lesion
Vitamin B_7 (Biotin)	Hybrid tilapia (*O. niloticus* x *O. aureus*)	Poor growth
Folic acid	Nile tilapia	Poor growth, reduced feed intake and efficiency
Vitamin B_2 (Riboflavin)	Nile tilapia	Requirement not reported
Choline	Hybrid tilapia (*O. niloticus* x *O. aureus*)	Poor growth and survival, and reduced blood triglyceride, cholesterol, and phospholipid concentration
Inositol	Nile tilapia	Requirement not reported
Vitamin C (Ascorbic acid)	Nile tilapia	Poor growth and poor feed efficiency, scoliosis, lordosis, poor wound healing, haemorrhage, fin erosion, anaemia exopthalmia and gill and operculum deformity
Vitamin A (Retinol)	Nile tilapia	Poor growth and poor feed efficiency, restlessness, abnormal swimming, blindness, exophthalmia, skin, fin, and eye haemorrhages, pot-belly syndrome, reduced mucus, secretion, high mortality
Vitamin D (Cholecalciferol)	Hybrid tilapia (*O. niloticus* x *O. aureus*)	Poor growth and poor feed efficiency, low haemoglobin, , reduced liver size
Vitamin K	Nile tilapia	Requirement not reported
Vitamin E (α-tocopherol)	Nile tilapia	Poor growth and poor feed efficiency, anorexia, skin and fin haemorrhage, muscle degeneration, depigmentation

Data source: Jauncey (2000), El-Salyed (2006), Lim and Webster (2006)

Under culture conditions, vitamin deficiency signs are not a common occurrence in tilapia (El-Sayed 2006; Lim and Webster 2006; Jauncey, 2000). In fact, several studies have reported on the "non-essentiality" of adding vitamin premixes to tilapia diets (Jauncey, 2000). Vitamins obtained from natural food in fertilized ponds, endogenous vitamins present in feed ingredients used in tilapia feeds and the microbial biosynthesis of some vitamins in the gut are all likely to contribute significantly to the vitamin requirements of tilapia. Table 2.10 shows the dietary nutritional deficiencies of some vitamins in fish.

2.16 Pond Culture

Pond culture is a very popular aquaculture production method with many aquatic species cultured in ponds. To have successful pond production, ponds must be properly sited and built, with careful assessment of water availability, quantity, and quality. There are two main types of pond systems: watershed and levée systems (Whitis, 2002). The climate and topography of a region will determine which type of pond system is appropriate. Areas that have enough rainfall to fill and keep ponds filled will be more suited to watershed pond systems. In an area where the main water source is groundwater, then a levée pond may be more suitable (Whitis, 2002).

Most commercially produced warm-water species, some cool-water species, and baitfish are typically reared in ponds (Tucker *et al*., 2002). In commercial pond culture, there is either some degree of fertilization or supplemental feeding to increase production to commercially viable levels, greater than would occur naturally. Ponds differ from flow-

through systems in that they are basically static and do not rely on water replacement to maintain water quality. Ponds rely mainly on internal natural processes to purify the water (Tucker *et al*., 2002). The biological community acts upon the dissolved wastes and helps to stabilize and recycle waste. Settled solids accumulate and undergo microbial decomposition in the pond sediment, much in the same way that a municipal water treatment facility functions.

A pond's production capacity is directly related to the daily amount of feed that can be added to the pond while still maintaining adequate water quality. As pond production intensifies, supplemental aeration must be used to maintain acceptable water quality (Tucker *et al*., 2001). Cole and Boyd (1986) pointed out that truly significant improvements in water quality appear possible only by reducing daily feeding rates to value less than about 50 kg/ha/day. Pond water quality needs to be well-managed and balanced by aquaculturists for their crops to survive and grow well (Tucker *et al*., 2002; Tucker, 1998).

Pond culture is still the most commonly used method of raising tilapia (Stickney, 2000). One of the big advantages with a pond culture is that is closely resembles the life of wild tilapia and makes it possible for the fish to feed on naturally occurring food. Unfortunately, tilapia loves to spawn in ponds and the number of fry and fingerlings can rapidly reach large quantities if male and female fish are kept together. This will result in a situation where fry and fingerlings compete for food with the adults, resulting in a

lower growth speed for the fish in the pond. One way of solving the problem is to cultivate male fish only in the pond (Stickney, 2000).

2.17 Use of Hapa in Fish Rearing

Hapas are constructed of netting material which is sewn together to form a square or rectangular enclosure. Hapas differ in size and mesh according to use. Breeding hapas hold tilapia broodstock and are constructed of netting which has a mesh size of 1.6 to 2.0 mm (Little and Hulata, 2000). Inverted mosquito nets are often used for this purpose, but the fine mesh will become clogged with plant growth if not cleaned frequently. Clogging prevents fresh water from circulating into the hapa and can result in a low oxygen condition which kills fish. Larger mesh sizes allow greater water exchange in the hapa, and are used for nursing fingerlings stocked at high densities. A cover is often attached over the hapa to prevent larger fish from jumping out and keeps predatory birds from injuring fish or picking relatively smaller ones (Little and Hulata, 2000).

Hapas can be used in every phase of tilapia culture from fingerling production to growing market size food fish (Mandal and Shrestha, 2001). Hapas protect fish from predators and allow high survival. Produced fry and fingerlings are transferred to ponds, other hapas or tanks for further grow-out (Costa-Pierce and Hadikusumah, 1995; Guerrero and Garcia, 1983).

Experience with fish culture in hapa indicates that the device has the versatility for use in solving most of the problems encountered in farming fish. For example, the problem commonly faced in pond culture in Bangladesh is multiple ownerships of ponds. This can

be easily solved by farming fish in hapa (Hasan *et al*., 2010). This ensures that one is confined to one's own area of the pond demarcated by mutual arrangement with co-shares.

Hapa fouling is one of the major problems for the hapa-based system (Bhujel, 2000). It reduces the exchange of water (Claereboudt *et al*., 1994; Littlewood, 1990; Paul and Davies, 1986) affecting natural food availability (Claereboudt *et al*., 1994; Paul and Davies, 1986) and dissolved oxygen levels (Dubost *et al*., 1996; Claereboudt *et al*., 1994). Algae, fish faeces and particulate materials suspended in water column are the major causes of the fouling (Dubost *et al*., 1996).

2.18 Hapa-Cum-Pond Culture System

Pond production systems in many countries are becoming increasingly reliant on external resources (feed and/or fertilizer) to supplement or autochthonous food production for fish (Hasan *et al*., 2010). Such a system often discourages small-scale poor farmers because of low returns on investment. On the other hand, such poor farmers have limited financial resources to turn their whole ponds to culture high-valued species using expensive artificial feeds. However, the hapa-cum-pond fish culture system may provide an opportunity for small-scale farmers to use their limited resources, to include small amount of high-valued species in their ponds, to generate more income and improve their livelihood (Hasan *et al*., 2010). This is achieved through improved nutrient utilization efficiency, marketing high-valued species and saving fertilizer cost because fish in open pond can efficiently utilize hapa wastes and almost no fertilization required. Also this

hapa-cum-pond system is eco-friendly due to less waste nutrients released to the environment (Hasan *et al*., 2010).

Hapa-cum-pond culture system has been developed and practised using combinations of catfish-tilapia and tilapia (Lin and Diana, 1995; Lin, 1990) and tilapia-tilapia (Yi and Lin, 2001 and 2000; Yi, 1997; Yi *et al*., 1996). The nutrient utilization efficiency could reach more than 50 % in hapa-cum-pond system, resulting in the release of much less nutrients to the surrounding environment (Yi, 1997).

2.19 Water Quality in Aquaculture

The proper balance of physical, chemical and biological properties of water in ponds, lakes and reservoirs is an essential ingredient for successful production of fish and other aquatic resources (Mostafa, 2005). Fish are totally dependent upon water to breathe, feed and grow, excrete wastes, maintain a salt balance, and reproduce; for these reasons understanding the physical and chemical qualities of water is critical to successful aquaculture (Swann, 1997). For fish production, water is always a limiting factor. Both the quality and quantity of water available has to be in major concern for the site selection (Swann, 1997).

Optimal water quality varies by species and must be monitored to ensure growth and survival (Svobodová *et al*., 1993). Water quality parameters that are commonly monitored in the aquaculture industry include temperature, dissolved oxygen, pH, alkalinity, hardness, ammonia, and nitrites (Svobodová *et al*., 1993). Any changes of

these parameters may affect the growth, development and maturity of fish. Some parameters such as alkalinity and hardness are fairly stable, but others like dissolved oxygen and pH fluctuate daily (Svobodová *et al*., 1993). Table 2.11 indicates the water quality preferences for some commonly cultured fish species.

Table 2.11 Water quality tolerance by some commonly cultured fish species

Species	Temp (^{O}C)	Dissolved Oxygen (mg L^{-1})	pH	Alkalinity(mg L^{-1})	Ammonia (%)	Nitrite (mg L^{-1})
Baitfish	16-24	4-10	6-8	50-250	0-0.03	0-0.6
Catfish/Carp	18-27	3-10	6-8	50-250	0-0.03	0-0.6
Hybrid Striped Bass	21-29	4-10	6-8	50-250	0-0.03	0-0.6
Perch/Walleye	10-18	5-10	6-8	50-250	0-0.03	0-0.6
Salmon/Trout	7-20	5-12	6-8	50-250	0-0.03	0-0.6
Tilapia	24-34	3-10	6-8	50-250	0-0.03	0-0.6
Tropical	20-29	4-10	6-8	50-250	0-0.03	0-0.5

Data source: Adapted from Tarazona and Munoz (1995), Svobodová *et al*. (1993), Boyd (1990)

2.19.1 Water Quality Parameters for Tilapia

Tilapias are also easily cultured fish in that they grow fast, are resistant to diseases and handling, easy to reproduce in captivity and able to tolerate a wide range of environmental conditions (Suresh, 2003; Shiau, 2002). Some of the cultured species have been shown to survive dissolved oxygen concentration of 0.1 mg L^{-1} and tolerated unionized ammonia concentration of 2.4 mg L^{-1} (Lovell, 1998). Although tilapias are typically fresh water, they are euryhaline and able to grow well in saline water if properly acclimated. However, their activity and feeding become reduced below 20 ^{o}C and feeding stops around 16 ^{o}C (Lovell, 1988). Suitable ranges of water quality parameters for tilapia to survive are shown in Table 2.12.

Table 2.12 Water quality parameters for tilapia

Parameters	Tolerance range*	Desirable level+
Temperature, ^{o}C	12-35	26-32
Salinity, ppt	3-25	0-20
pH	5-10	6.5-8.5
Dissolved oxygen, mgL^{-1}	2.0-8.0	>3.0-5.0
Ammonia, mgL^{-1}	0.0125	<1.0
Nitrite, mgL^{-1}	0.1-0.2	-
Nitrate, mgL^{-1}	0.0-3.0	-
Alkalinity, mgL^{-1}	>20	>20
Hardness, mgL^{-1}	>20	<50

Data Source: Agbo, 2008; *Adapted from (Swann, 2007, Hussain, 2004; Popma and Masser, 1999; Stickney R.R. 1979); + (Suresh, 2003)

CHAPTER 3.0 METHODOLOGY

3.1 Selection of Study Area for Survey of Fish Feed Ingredients and Commercial Fish Diets

Data on small-scale (production from 10 to 20 metric tonnes per annum) pond fish farmers per Region of Ghana for 2011 were obtained from the Fisheries Commission Head Office, Accra. Surveys of fish feed ingredients and commercial fish diets were conducted in the five major small-scale pond fish farming Regions in terms of number of farmers (Table 3.1).

Table 3.1 Number of pond fish farmers in Ghana on regional basis in 2011

Region	No. of Pond Farmers
Ashanti	320
Brong-Ahafo	829
Central	180
Eastern	-
Greater Accra	57
Northern	4
Upper East	20
Upper West	-
Volta	97
Western	240
Total	1 747

Source: Adapted from Fisheries Directorate 2011 Annual Report

The Regions were Ashanti, Brong Ahafo, Central, Western and Volta (Figure 3.1). The survey was carried out during a period of eight months (December, 2012-July, 2013).

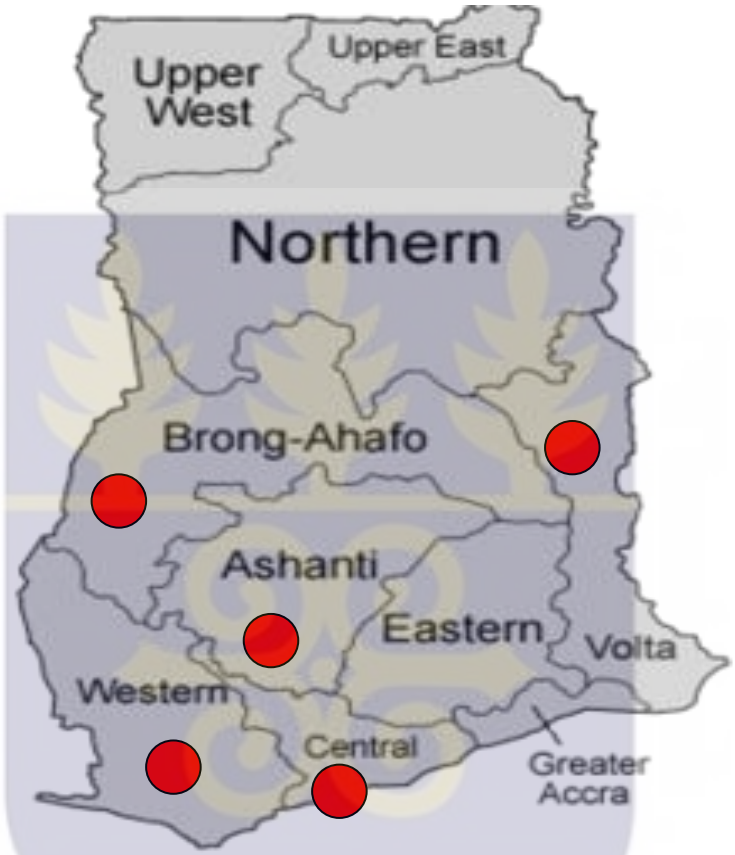

Figure 3.1 Map showing the five Regions in Ghana (where the survey of fish feed ingredients and commercial fish diets were conducted are indicated by the red spots)

3.2 Pre-Survey of Fish Feed Ingredients and Commercial Fish Diets Activities

Interviews with fish farmers were preceded by preparation and testing of the interview schedule, and training of field assistants. The pre-survey activities included reconnaissance for the pilot survey, revision of survey instruments and preparation of the sampling frame. An Interview guide was prepared following personal visits to some fish farms and interactions with fish farmers. An informed consent form (Appendix I) was

prepared which explained the objectives and rationale of the survey. The form also spelt out the description of procedure and prospective interviewees were assured of the confidentiality of any information they would provide.

3.3 Data Collection

List of fish farmers in active production were obtained from the Regional Fisheries Offices in the five selected Regions. Standardised and structured interview guide (Appendix II) was administered to gather data from fish farmers who were in active production. A total of 147 fish farmers were interviewed from all the five regions surveyed for in-depth data collection. 27 farmers were interviewed in Ashanti, 44 in Brong Ahafo, 20 in Central, 38 in Western and 18 in the Volta.

Interview with fish farmers were mainly conducted in their houses and/or farm sites. Interview with each farmer lasted at least an hour and was focused on location of farm/farmer, bio-data, livelihood/household, fish farming culture practice, productivity, production constraints and fish diets as well as fish feed ingredients. In certain districts of some of the Regions, farmers were met in groups (Plate 3.1), and after the purpose for the survey and the objectives were explained to them, they were interviewed individually with the help of field assistants. Following the interview guide, farmers were posed questions and their responses were recorded. In cases where the interviewee did not understand English language, the assistance of interpreter was solicited. Further, visits were made to selected farms to observe farming practices.

Plate 3.1 Interaction with fish farmers in the Prestea Huni-Valley District of Western Region, Ghana

To validate the information gathered from the interview, it was cross-checked with key informants. A key informant is someone with special knowledge on a particular topic. Key informants are expected to be able to answer questions about the knowledge and behaviour of others, and about the operations of the broader system (Ahmed and Garnett, 2010). These were Regional Fisheries Directors, Fisheries Extension Officers, Aquaculture Research Scientists, fishmongers, commercial fish diet retailers, feed ingredient retailers and relevant food processors. Where data was found to be contradictory, additional assessments were carried out. A total of 31 key informants were interviewed in their offices, homes and/or at their workplaces. A check-list was created to indicate the use of commercial fish diets and ingredients in the various Regions of the survey.

3.4 Selection of Feed Ingredients and Commercial Fish Diets

The ingredients used in the formulations and preparations of the various diets were selected based on the findings of the regional survey. Six commonly used ingredients in the five regions surveyed were selected based on their nutritional value, availability all year round and costs. These were cassava (*Manihot esculenta*) flour, white maize (*Zea mays*), fish meal (*Rastrinneobola argentea*), soybean (*Glycine spp)* meal, wheat (*Triticum aestivum*) bran, and palm oil (*Elaeis quineensis*). The ingredients were found to be locally available in all regions of Ghana. Broiler vitamin-mineral premix, L-lysine, L-methionine and common salt (iodized table salt) were included as additives/supplements. The two most commonly used commercial fish diets were also selected. These were Raanan (30 % crude protein) and Coppens (34 % crude protein).

3.5 Procurement of Selected Feed Ingredients and Commercial Fish Diets

The selected ingredients and diets were purchased at locations that were in close proximity to Akosombo in the Eastern Region of Ghana where the diet preparation and growth study were carried out. All the ingredients and additives/supplements except the cassava flour, palm oil and common salt were purchased from feed ingredients dealers at Ashaiman Timber Market located in the Greater Accra Region of Ghana. The cassava flour, palm oil and common salt were obtained from the Akosombo market. The ingredients were packaged in linen bags except the cassava flour and the additives which were in plastic bags. The palm oil was in a plastic gallon. Coppens and Raanan fish diets were purchased from their respective producers' retail shops at Atimpoku, a town located on the outskirts of Akosombo. The production date of Coppens was October 8, 2013

whilst that of Raanan was September 4, 2013. The batch numbers of the diets were 258913 and WF40113190400 for Coppens and Raanan respectively.

3.6 Storage of Ingredients and Commercial Fish Diets

After the procurement, the ingredients, diets and additives/supplements were labelled accordingly and stored in a well-ventilated room with daily ambient temperatures ranging from 28-34 ^{o} C during the dry season. Samples of all the ingredients and the two commercial diets were sent to the Animal Nutrition Laboratory of the School of Agriculture of the University of Cape Coast for proximate analyses so as to determine their proximate compositions.

3.7 Determination of the Proximate Compositions of Ingredients and Diets

Proximate analyses of the selected commercial fish diets and feed ingredients for the study were done following the procedures that broadly adhere to the Association of Official Analytical Chemists (AOAC, 1995). The protocol was applied in the determination of the percentage (%) dry matter (DM), % crude protein (CP), % ash, % crude lipid (CL) also known as ether extracts (EE) and % crude fibre (CF).

3.7.1 Moisture and Dry Matter Determination

The moisture content of each sample was determined by weighing 3.0 g of sample into a dry pre-weighed crucible in triplicates. The weighed samples were then dried in an oven at 105 ^{o}C for 24 hours. The gravimetric measurement of water in the samples was expressed as a percentage of the initial weight of the samples. The weight of the samples

after drying was expressed as a percentage of that of the initial samples to obtain the percentage of dry matter as follows:

$$\% \text{ Moisture} = \frac{\text{Weight of sample taken} - \text{Weight of sample after drying}}{\text{Weight of sample taken}} \times 100\ \% \quad \text{(AOAC, 1995)}$$

$$\% \text{ Dry Matter} = \frac{\text{Weight of sample after drying}}{\text{Weight of sample taken}} \times 100\ \% \quad \text{(AOAC, 1995)}$$

3.7.2 Ash Determination

Ash is a measure of the total inorganic matter by incineration (AOAC, 1995). Approximately 2.5 g of each sample was weighed in triplicates in pre-weighed crucibles and incinerated for about 12 hours overnight at 600 ^{o}C using a Gallenkamp muffle furnace size 2. The crucibles and their contents were removed and cooled in a desiccator and then weighed afterward. The increase in the final weights of the crucibles represented the ash and was expressed as percentage of the original sample using the formula:

$$\% \text{ Ash} = \frac{\text{Weight of ash}}{\text{Weight of original sample}} \times 100\ \% \quad \text{(AOAC, 1995)}$$

3.7.3 Crude Protein Determination

The Micro-kjeldahl method (AOAC, 1995) was used for the determination of % CP of samples in triplicates. An amount of 0.2 g of each sample was weighed into numbered kjeldahl flasks and 4.5 ml of concentrated sulphuric acid was added. The flasks were then placed in the digestion block (BD-20) under a fume hood and the temperature of the digester was gradually increased to about 370 ^{o}C. Samples were allowed to heat overnight

till the solution became colourless, indicating that the digestion was completed. The digestion flasks were allowed to cool and the digests poured into 100 ml volumetric flasks and made up to volume with distilled water. About 20 ml of the digests were pipette into the steam section of distillation apparatus, and then 10 ml of alkaline mixture was added. Then the apparatus was set to produce steam containing nitrogen, which was condensed in the condenser and trapped in 5 % boric acid. About 50 ml of the distillates were collected into flat-bottomed flasks and titrated against 0.0071 M hydrochloric acid. The percentage nitrogen in the samples was calculated using the formula:

$$\%N \text{ in sample} = 100 \left\{ \frac{\text{Hydrochloric acid used in titration x normality of standard acid}}{\text{Weight of sample used}} \right\} \text{x } 0.014$$

(AOAC, 1995)

The percentage of crude protein in the samples was determined by multiplying the percentage nitrogen with a factor of 6.25 (AOAC, 1995).

3.7.4 Crude Lipid Determination

The percentage crude lipids in samples were determined using Soxhlet solvent extraction technique. Approximately 2.0 g of air-dried samples in triplicates were weighed into a soxhlet extraction thimble and plugged with cotton wool. The plugged thimble with its content was transferred into a 50 ml capacity soxhlet extractor. A clean dry 250 ml round bottom flask was weighed. About 200 ml of petroleum-ether was added to the flask and connected to the extractor. A reflux condenser was inserted and extracted for 4-6 hours using a heating mantle. The flask was removed after the 6 hours and it was placed in a

hot air oven at 50 ^{o}C to dry off the ether. The flask was cooled in a desiccator and re-weighed. The difference in weight was expressed as a percentage of the original samples as follows:

$$\% \text{ Crude Lipid} = \frac{\text{Weight of lipid}}{\text{Weight of sample}} \times 100\ \% \quad \text{(AOAC, 1995)}$$

3.7.5 Crude Fibre Determination

1g of defatted, dry samples in a pre-weighed Scintaglass crucible was used for crude fibre determination using acid-base hydrolysis in triplicates. The crucible was fitted to a Fibercap and run according to the manufacturer's operating instructions. Hydrolysed and oven-dried sample was later ashed in the muffle furnace at 550 ^{o}C and crude fibre in the defatted samples was expressed as a percentage of the original undefatted samples as follows:

$$\% \text{ Crude Fibre} = \frac{\text{Weight loss through Ashing}}{\text{Original weight of sample}} \times 100\ \% \quad \text{(AOAC, 1995)}$$

3.7.6 Nitrogen Free Extracts (NFEs) Determination

Percentage Nitrogen-free extract (% NFE) was computed using the formula:

% NFE = % DM - (% CP + % Ash + % CL + % CF) (AOAC, 1995)

3.7.7 Phosphorus Determination

The procedure requires the preparation of colour forming reagent and P standard solutions. The colour forming reagent is made up of reagents A and B. Reagent A is

made up of 12 g ammonium molybdate in 20 ml distilled water, 0.2908 g of potassium antimony tartarate in 100ml distilled water and 1L of 2.5M H_2SO_4. The three solutions were mixed together in a 2 L volumetric flask and made up to volume with distilled water. Reagent B was prepared by dissolving 1.56g of ascorbic acid to every 200mL of reagent A. A stock solution of 100 μg P/mL solution was prepared from which 5 μg P/mL solutions were made as a set of working standards of P with concentrations 0.0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 μg P/mL in 25 mL volumetric flasks. 2 mL aliquot of the digested samples was pipette into 25 mL volumetric flasks. About 2 mL aliquot of the blank digest was pipetted into each of the working standards to give the samples and the standards the same background solution.

About 10 mL of distilled water was added to the standards as well as the samples after which 4 ml of reagent B was added and their volumes made up to 25 ml with distilled water and mixed thoroughly. The flasks were allowed to stand for 15minutes for colour development after which the absorbances of the standards and samples were determined using a spectrophotometer (Model CE 1021, 1000 SERIES; Make: Cecil) at a wavelength of 640 nm. A calibration curve was plotted using their concentrations and absorbance. The concentrations of the sample solutions were extrapolated from the standard curve and the amount of phosphorus was determined as follows:

If C = μg P/ml obtained from the graph,

$$\text{then } \mu\text{g P/g (sample)} = \frac{\text{C x Dilution Factor}}{\text{Weight of sample}} \quad \text{(IITA, 1985)}$$

3.7.8 Gross Energy (GE) Determination

The gross energy for the feed ingredients, the commercial fish diets and formulated ones were computed by using the physiological fuel values of 23.64, 39.54 and 17.15 $MJkg^{-1}$ for protein, fat and carbohydrate respectively (Ali and Al-Asgah, 2001).

3.7.9 Chromic Oxide Analysis

Chromic oxide was determined based on the method of Furukawa and Tsukahara (1966). 100 mg of sample was weighed into a Kjeldahl flask. 5 ml of concentrated nitric acid were added to the flask and the mixture was boiled (using an electric mantle) gently for about 20 minutes (without boiling dry). After cooling the sample, 3 ml of 70 % perchloric acid was added to the flask. The mixture was then gently heated again until the solution turned from a green to an orange colour after which it was left to boil for a further 10 minutes to ensure oxidation was complete. The solution was transferred to a 100 ml volumetric flask and diluted to volume. The absorbance of the solution was determined by spectrophotometer (UV mini-1240) at 350nm against distilled water and chromic oxide was computed using the formula:

$$\text{Chromic oxide (\%)} = \left(\frac{\frac{(\text{Absorbance} - 0.0032)}{0.2089}}{\text{Sample weight}} \right) \times 100\ \%$$ (Furukawa and Tsukahara, 1966)

3.8 Study Area for Diet Formulation, Preparation and Evaluation

The formulation, preparation and evaluation of the diets were carried out at Aquaculture Research and Development Centre (ARDEC) of Water Research Institute (WRI) of Council for Scientific and Industrial Research (CSIR) at Akosombo which lies between

latitude 6^0 13′ North and the longitude 0^0 4′ East at Akosombo in the Eastern Region of Ghana (Figure 3.2).

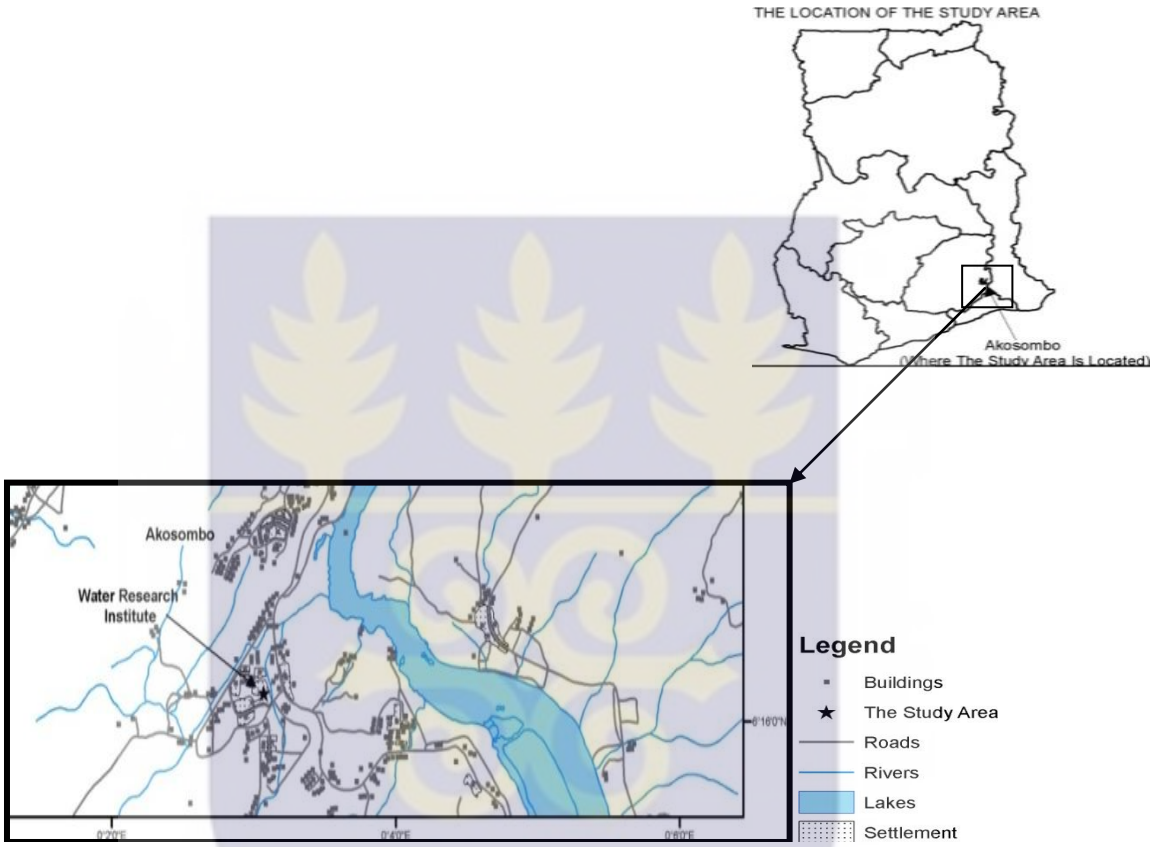

Figure 3.2 WRI, ARDEC, Akosombo where the feed trials were conducted

3.9 Diet Formulation and Preparation

In all, five diets namely: *A*, *B*, *C*, *D* and *E* were evaluated for fish growth study. Two main diets, A and *B* were formulated using the selected ingredients. Broiler vitamin-mineral premix (Kardelen 2 400 VM) and essential amino acids (L-Lysine and L-Methionine) were added to diet *A* at 5 g kg^{-1} each. Common salt was added at 2 g kg^{-1}. Diet *B* lacked premix and essential amino acids; instead the content of dietary lipid was

adjusted for their inclusions (Table 3.2). Diets *C* and *D* were the two commercial diets commonly used by small-scale pond fish farmers in the five Regions of Ghana where the survey was carried out. The diets were Coppens and Raanan respectively. The fifth diet, *E* was prepared by mixing diets *B* and *D* (Raanan) in a ratio of 1:1.

Table 3. 2 Inclusion levels (%) of ingredients used in diets *A* and *B* and their cost per kilogramme

Ingredients	A	B	Cost of ingredient (GHS kg^{-1})
Fish meal	25.0	25.0	2.30
Soybean meal	26.8	26.8	2.40
Maize (white)	27.0	27.0	0.72
Wheat bran	5.0	5.0	0.64
Cassava flour	10.0	10.0	1.32
Palm oil	4.5	6.0	3.74
Broiler vit/min. premix	0.5	-	6.00
Common salt (iodized)	0.2	0.2	1.60
L-Lysine	0.5	-	7.00
L-Methionine	0.5	-	13.00

In order to assess the apparent digestibility coefficients (ADCs) of dry matter (DM), crude protein (CP), crude lipid (CL) and carbohydrate of the experimental diets *in vivo*, 0.5 % of chromic oxide (Cr_2O_3) as a marker, was incorporated into 99.5 % of each of the complete diets *A*, *B*, *C*, *D* and *E*.

On the whole, the experimental diets were formulated to contain 300 g kg^{-1} protein, 100 g kg^{-1} lipid and 18 kJ g^{-1} energy. These levels were based on requirements for juvenile and adult Nile tilapia (El-Sayed, 2006; Lim and Webster, 2006; Fitzsimmons, 2005; Shiau, 2002). The diets were formulated on as-fed basis. The fish meal (Tuna fish meal, produced by Pioneer Food Canary, Tema) and soybean meal (locally produced) were used as the main dietary protein sources. The Cassava flour, Maize and wheat bran were

used as the main dietary carbohydrate sources. The cassava flour also served as a binder. The palm oil was used as the main source of lipid in the diets.

The fishmeal, maize, soybean meal and wheat bran were finely milled separately using a corn milling machine and subsequently sieved through a 800 µm sieve to rid them of relatively larger sized particles. The cassava flour was not milled as it was already in a powdered form before it was procured. However, it was also sieved. The dry powdered ingredients were weighed using top loading electronic balance (KERN EMB Version 3.1 11/2009) into large labelled plastic bowls according to the proportion based on the formulation for each diet. The ingredients were mixed with the hands protected with disposable gloves until uniformly blended and homogenous powdered mixtures were obtained.

Table 3.3 Composition of the vitamin-mineral premix used in diet *A*

Composition	For 2 500 g
Vitamin A	12 000 000 IU
Vitamin D_3	2 000 000 IU
Vitamin E	40 000 mg
Vitamin K_3	4 000 mg
Vitamin B_1	3 000 mg
Vitamin B_2	6 000 mg
Vitamin B_6	5 000 mg
Vitamin B_{12}	20 mg
Niacin	40 000 mg
Cal-Pan	15 000 mg
Folic Acid	1 000 mg
Biotin	50 mg

The measured quantity of broiler vitamin-mineral premix, L-lysine, L-methionine, common salt and palm oil were added to diet *A* and the mixture was mixed thoroughly.

The composition of the vitamin-mineral premix used in diet *A* is shown in Table 3.3 above.

For diet *B*, only common salt and palm oil were added. Between 40 – 50 % of water was added slowly to the mixtures with continuous stirring until dough was formed. A 32# Hand-Operated Meat Mincer was used to pellet the diets using a die size of 3 mm into strands (Plate 3.2).

Plate 3.2 Using hand-operated meat mincer to pellet prepared fish diet

The two commercial diets (*C* and *D*) which were originally extruded were milled into powdered forms and then pelleted so as to ensure consistency in the forms and sizes of all the diets. Diet *E* was prepared by mixing equal portions of powdered forms of Diet *B* and Diet *D* (Raanan) before pelleting. Table 3.4 and 3.5 show the constituents of diets *C* and *D* respectively as declared by the respective producers on the labels of their bags.

Table 3. 4 Constituent of Coppens (Diet *C*) as indicated on the label of the feed bag

Analytical Component	Percentage (%)
Crude Protein	34
Crude Fat	10
Crude Fibre	3.2
Crude Ash	8.4
Phosphorus	0.8
Calcium	1.0
Sodium	0.2
Additives	
Vitamin A	10 000 µg/kg
Vitamin D_3	1 000 µg/kg
Vitamin E	200 mg/kg
Vitamin C (Stable)	150 mg/kg
Antioxidants	
E 324 Ethoxyquin	100 mg/kg
E 321 Sutylated hydroxytclune	50 mg/kg
Trace Elements	
Iron (ferrous sulphate, monohydrate)	75 mg/kg
Iodine (Calcium iodate, anhydrous)	5 mg/kg
Cobalt (basic cobaltons carbonate, monohydrate)	1 mg/kg
Copper (cupric sulphate, pentahydrate)	5 mg/kg
Manganese (manganic oxide)	20 mg/kg
Zinc (zinc sulphate, monohydrate)	80 mg/kg
Selenium (sodium selenite)	0.3 mg/kg
Ingredients	
Wheat, soya dehulled, toasted fish meal, ranola oil, fish oil, hydrolised feather meal, palm oil, blood products, fish meal and/ or fish solubles	

Table 3.5 Constituent of Raanan (Diet *D*) as indicated on the label of the feed bag

Analytical Component	Percentage (%)
Crude Protein	30.0
Fat	5.0
Fibre	4.0
Ash	8.0
Phosphorus	1.1
Moisture	9.0
Additives	
Vitamin A	7 500 µg/kg
Vitamin C	90 µg/kg
Ingredients	
Products and by-products of poultry, oil seeds and cereals, vitamins and minerals	

The pellets were sun-dried for 8 to 10 hours to reduce the moisture content so as to prevent the growth of mould and consequently the pellets were broken into smaller sizes (between 1-2 mm) that the experimental fish could pick. The diets to be used immediately were put into labelled transparent plastic containers of each having a capacity of about 10 litres. The excess diets were then packaged in labelled polythene bags and stored in a well-ventilated room. Samples of the prepared diets and the commercial diets were analysed for proximate compositions and phosphorus as described in Section **3.7**. The values obtained were used to compute the energy contents of the various diets. Ten (10) kilogrammes of each diet type was prepared at a given time as and when the old stock was getting depleted.

3.10 Experimental System

Fish growth study was carried out in a 5.0 x 2.0 x 1.2 m (i.e. length, width and height) mosquito netting hapas. A monofilament nylon gill net of stretched mesh size 30.0 mm was sewn over the hapas as a cover and an opening was left at one end of the 2 m side so as to allow input and collection of fish during stocking, measurements and harvest. The

cover net was to keep predatory birds from injuring or picking the experimental fish and also to prevent the fish from jumping out as they grow bigger (Little and Hulata, 2000). The hapas were mounted in a 0.2 hectare (2 000 square metres) earthen pond at ARDEC, Akosombo. The pond was supplied with water from the Volta Lake to a mean height of about 1.4 ± 0.2 m. The hapas were suspended to bamboo poles by means of nylon twine and the former were inserted in the bed of the pond (Plate 3.3).

Plate 3.3 Experimental hapas being mounted in a 0.2 hectare earthen pond at ARDEC, Akosombo

Each hapa was separated from others by about 6 m distance to avoid easy drifting of contents of one system into another. About two-thirds (0.8 m) of the hapa heights were

constantly submerged in the pond water by ensuring periodic topping up of the water when the level fell mainly due to evaporation and seepage.

The experimental system for digestibility study consisted of plastic containers (about 0.10 m^2 bottom area), each with 45.0 L total volume capacity, filled with 20.0 L of water. There were three replicates for each treatment. Aeration in the containers was maintained by the insertion of air stones.

3.11 Experimental Fish

The eighth generation of hormonal sex-reversed, all-male *O. niloticus* known as the "Akosombo Strain" developed by CSIR-WRI at ARDEC, Akosombo through selective breeding was used in the growth study. The hormonal sex reversal process is not 100 % effective. Success rates have been between 80-92 %. The process can give an excess of 90 % male, averaging 95 % male, 100 % populations are seldom achieved (Mair *et. al*., 1997). The fish were randomly taken from a batch that was sex reversed and were being nursed to be supplied to fish farmers when they attain 2.0 g. The stock was nursed in isolated hapas and were fed daily at *ad libitum* until they attained sizes that they could be hand-sexed. This was to avoid using mixed sex fish in the growth study as the females are known to divert large amounts of food energy to egg production (Avault and Shell, 1968). During the nursing stage, the fish were fed twice a day with Raanan fish diet used at ARDEC.

3.12 Conditioning and Stocking of Experimental Fish

The hand-sexed all-male "Akosombo Strain" *O. niloticus* was kept in hapas or net enclosures (each with dimensions 5 m x 2 m x 1.2 m). They were not fed for about 48 hours. After which they were fed with a milled powdered mixture of white maize and cowpea in a ratio of 1:1 twice a day for a week. This was to completely wean them off the Raanan fish diet. At the end of the period, a sample of 3 fish was taken to determine the proximate composition.

The initial Standard Length (SL), Total Length (TL) and wet weight of the individual fish to be stocked were measured (to the nearest 0.1 cm and 0.1 g respectively) using a fish measuring board and a top loading electronic balance. In all, 300 all-male *O. niloticus* were used in the growth study. The fish were without any particular sizes (i.e. randomly) divided into five groups of 20 fish (5 treatments in triplicate) and stocked in fifteen hapas, each of operational volume of about 8.0 m^3 on December 14, 2013. For the plastic containers used in the digestibility study, the stocking was 4 fish per system.

3.13 Feeding Schedule

The experimental design used in the growth study was mainly completely randomized design (CRD) where the various dietary treatments were randomly assigned to the experimental units (hapas). Feeding of the stocked fish commenced the following day with the experimental diets *A*, *B*, *C*, *D* and *E* (i.e. the prepared diet containing lysine, methionine, and vitamin-mineral premix; Prepared diet without lysine, methionine and premix; Coppens; Raanan and a 1:1 mixture of *B* and *D* respectively). All the fish under

each treatment were manually fed at 4.0 % of their body weight (biomass) three times daily (between 0800-0830, 1200-1230 and 1600-1630 GMT) throughout the week including weekends.

During the first week of stocking, all dead fish in each hapa under each treatment were replaced with live ones of similar weights. The 4.0 % rate of feeding was maintained until the fish in any hapa had attained a mean body weight greater than 100.0 g. Then the feeding rate was reduced to 3.0 %, but feeding frequency of 3 times per day was maintained throughout the growth study.

Fish used for digestibility study were fed the chromic oxide diets, twice a day (0900 and 1500 hours) at a rate of 6 % of their body weight per day. A 5 day acclimatization period was allowed, during which the faeces collected were discarded and those collected in the subsequent days were analysed for proximate compositions and chromic oxide. After an hour of diet administration, the containers were cleaned and any uneaten diet and faecal residues were removed from the system by siphoning with a crystal siphon of an internal diameter 15 mm. About three-fourth of the water in the systems was replaced with fresh water so as to maintain a good water quality. Siphoning of faeces and cleaning of the systems were done in about 45-60 minutes before feeding the fish. Faeces collected each day from each tank of a dietary treatment were pooled and immediately centrifuged using *Sigma 2k15* Centrifuge at 3 800 g for 15 minutes and the supernatant discarded. Wet settled solids of faeces were rinsed with deionized water and stored in vials at -20 ^{o}C to retard bacterial decomposition. Faeces were collected for about two weeks. The samples

were later defrosted and oven dried at 60 ^{o}C, ground and analysed for proximate composition and Cr_2O_3.

3.14 Measurements of Fish during Growth Study

The SL, TL and weights of all the fish in each hapa under each treatment were measured fortnightly as described in Section **3.12**. A bamboo pole was used by two people at the opposite sides of the longer side of each hapa, starting from the bottom of the sewn end of the cover; the pole was drawn to confine the fish at the open end of the cover. All the fish were then netted and put into a large bowl containing pond water. The hapas were cleaned with pond water to ensure water circulation. The total number of fish was recorded. Each fish was gently blotted on a soft towel so as to remove excess water from the body. Then the lengths were measured followed by the weight. Each fish was then returned into a bowl containing fresh pond water. After measuring the lengths and weights of all the fish in each hapa, they were put back into their respective hapas. The biomass (total weight) of fish in each hapa under each treatment was computed and subsequently the quantity of each diet type for each fish group was adjusted accordingly. The measurements were done between 0630 and 0930 GMT. The fish were not fed on the day they were handled, feeding commenced at 0800 GMT of the following day. The growth study was carried out for 20 weeks (140 days). The day after the 140 days, all the fish from each treatment was harvested, counted and measured individually to determine the final growth and survival. A sample of 3 harvested fish (1 from each replicate) of each treatment was taken to determine the proximate composition.

3.15 Monitoring of Water Quality Parameters

In the determination of the effects of feeding fish with the various diets on water quality, the following water quality parameters were monitored during the growth study: Temperature, electrical conductivity (EC), pH, total suspended solids (TSS), dissolved oxygen (DO), salinity, alkalinity and hardness were monitored in and around the hapas and the open pond waters. Nutrients such as phosphate-P, nitrate-N, nitrite-N and Ammonia were also determined to indicate the extent of eutrophication of the various hapas status by feeding the experimental fish with each of the diets. Water quality analyses were conducted fortnightly during the same time period of the day (0630-0800 hours) using specified methods as laid down in Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF, 1998).

Water quality parameters such as temperature, electrical conductivity, salinity, pH and DO were measured *in situ* (using a pre-calibrated Hanna HI 9828 multi-parameter meter), whilst alkalinity, ammonia, hardness, phosphate, nitrite, nitrate and TSS were determined in the laboratory (using spectrophotometer, Hach DR 2800).

3.15.1 Determination of Water Quality Parameters in the Field

All the physico-chemical parameters were measured at a depth of about 0.4 m. The probe of the meter was immersed into the hapa and the pond *in situ* and the temperature, EC, pH, salinity and DO were read directly from the meter when equilibrium was achieved (Plate 3.4). Temperature was measured in degree Celsius (^{o} C), EC in microsiemens per

centimetre (μScm^{-1}), salinity in parts per thousand (ppt) and DO in milligram per litre (mgl^{-1}).

Plate 3.4 Measuring of physico-chemical parameters in an experimental hapa in the pond

3.15.2 Determination of Water Quality Parameters in the Laboratory

For the parameters that were determined in the laboratory, three replicate samples of water were taken from each hapa treatment and the pond into 250 ml plastic bottles which were acid clean and rinsed three times with distilled water and dried in an oven. The samples were immediately stored in an ice-chest, stocked with ice blocks and maintained at a temperature of about 4 ^{o}C. In the laboratory, the samples were thawed to

room temperature and various treatments were given to the samples for each parameter determination as follows:

Alkalinity

For the determination of the alkalinity, a sample volume of 100 mL and titration cartridge 1.600 N H_2SO_4 were used. A clean delivery tube was inserted into the 1.600 N sulfuric acid titration cartridge. The cartridge was attached to the titrator. The delivery knob was turned to eject air and a few drops of titrant. The counter was reset to zero and the tip was wiped. A graduated cylinder was used to measure the sample and it was transferred into a clean 250-mL Erlenmeyer flask. The contents of one phenolphthalein indicator powder pillow were added and it was swirled to mix. The solution was colourless, suggesting the phenolphthalein alkalinity was zero. The contents of one Bromcresol Green-Methyl Red Indicator powder pillow were added and it was swirled to mix. The titration was continued with sulfuric acid to a light pink colour. The digits displayed on the counter were recorded as alkalinity in mgL^{-1} (APHA, AWWA, WEF, 1998).

Ammonia

The spectrophotometer programmed number for ammonia analysis was keyed in and set to 655 nm wavelength. A sample cell was filled to the 10-mL mark with the sample. A second sample cell was also filled to the 10-mL mark with deionized water. The contents of one ammonia salicylate powder pillow were added to each cell. The cells were capped and shook to dissolve the contents. The instrument was started and a three-minute reaction period was allowed. When the timer expired, the contents of one ammonia

cyanurate reagent powder pillow were added to each cell. The cells were capped and shook to dissolve the contents (APHA, AWWA, WEF, 1998).

The instrument timer was started and a 15-minute reaction period began. A green colour developed. When the ammonia salicylate was added, a compound known as 5-aminosalicylate was formed. It was oxidized in the presence of a sodium nitroprusside catalyst to form a blue-coloured compound. The blue colour was masked by the yellow colour from the excess reagent present to give a final green-coloured solution. When the timer expired, the blank was wiped and it was inserted into the cell holder. The instrument was zeroed and the display showed 0.00 mgL^{-1} NH_3-N. The sample was wiped and it was inserted into the cell holder. The results were then read in mgL^{-1} NH_3-N (APHA, AWWA, WEF, 1998).

Hardness

The spectrophotometer programmed number for phosphate analysis was keyed in and set to 522 nm wavelength. For the determination of total hardness, magnesium test was first selected. A 100 mL of the sample is poured into a 100 mL graduated mixing cylinder. A 1.0 mL measuring dropper is used to add 1.0 mL of calcium and magnesium indicator solution. The cylinder is stopped and inverted several times. 1.0 mL of alkaline solution for calcium and magnesium test is added using a 1.0 mL measuring dropper. The cylinder is stopped and inverted several times. 10 mL of the solution is poured into each of three sample cells. One drop of 1 M EDTA solution is added to the first cell (blank) and the

mixture was swirled to mix thoroughly. After, one drop of EGTA solution was added to the second cell and the mixture was swirled to mix thoroughly

The indicator dye is calmagite, which forms a purplish-blue colour in a strongly alkaline solution and changes to red when it reacts with free calcium or magnesium. Calcium and magnesium determinations are made by chelating calcium with EGTA to destroy any red colour due to calcium and then chelating the calcium and magnesium with EDTA to destroy the red colour due to both calcium and magnesium. By measuring the red colour in the different states, calcium and magnesium concentrations are determined. The blank (first cell) was inserted into the cell holder. The spectrophotometer was zeroed and the display showed 0.00 mg L^{-1} Mg $CaCO_3$. The magnesium sample (second cell) was inserted into the cell holder. The results were read in mgL^{-1} Magnesium as Calcium Carbonate. This value was the amount of magnesium in the sample expressed as $CaCO_3$. The results of magnesium were recorded and its programme was exited. Then calcium test was selected. The instrument was zeroed and display showed 0.00 m gL^{-1} Ca $CaCO_3$. The second cell is removed and the third cell (calcium sample) was inserted into the cell holder. The results were read in mg L^{-1} calcium as calcium carbonate. This value was the amount of calcium in the sample expressed as $CaCO_3$. The values of Magnesium and Calcium were added to obtain the total hardness (APHA, AWWA, WEF, 1998).

Nitrates

25 ml of the sample was measured into 30 ml test tubes. 25 ml of distilled water was also measured into a separate test tube and labelled as blank. The spectrophotometer was set

up and programmed to analysed nitrate at 450 nm wavelength. Nitraver 5 nitrate reagent was added to the 25 ml sample including the blank. As soon as the reagent was added, the tubes were shaken vigorously for one minute. After which they were left undisturbed for five minutes reaction period.

The reagent which contained cadmium, induced nitrate to nitrite in the samples. The latter reacted with sulfanitic acid to form diazonium salt intermediate in an acid medium. The salt combined with gentisic acid to form amber-coloured product. At the end of the reaction period, the spectrophotometer was zeroed with distilled water and then the reading for the blank and the sample were determined. The values obtained for the blank were subtracted from those of the sample to obtain the actual amount of nitrate in the sample in milligrams per litre (mg l^{-1}) (APHA, AWWA, WEF, 1998).

Nitrites

25 ml of the sample was measured into 30 ml test tube. 25 ml of distilled water was also measured into a separate test tube and labelled as blank. The spectrophotometer was set up and programmed to analyse nitrite at 507 nm wavelength. Nitriver 3 nitrite reagent was added to the 25 ml sample including the blank. As soon as the reagent was added, the tubes were shaken vigorously for one minute. After which they were left undisturbed for five minutes reaction period.

Nitrite in the sample reacts with sulfanilic acid in the reagent to form an intermediate diazonium salt. This couples with chromotropic acid to produce a pink coloured complex

directly proportional to the amount of nitrite present. At the end of the reaction period, the spectrophotometer was zeroed with distilled water and then the reading for the blank and the sample were determined. The values obtained for the blank were subtracted from those of the sample to obtain the actual amount of nitrite in the sample in milligrams per liter (mg l^{-1}) (APHA, AWWA, WEF, 1998).

Phosphate

25 ml of the sample was measured using measuring cylinder into 30 ml reaction tube as well as 25 ml of distilled water. The spectrophotometer programmed number for phosphate analysis was keyed in and set to 880 nm wavelength. Phosver 3 phosphate reagent was added to the sample and the mixture was swirled to mix thoroughly. After that, two minutes reaction period was allowed. The phosver 3 phosphate reagent contains molybdate and ascorbic acid. Orthophosphate which was present in the sample reacted with the molybdate to form phosphomolybdate complex in an acid medium. Ascorbic acid then reduced the complex salt to give an intense molybdenum blue colour.

After the reaction time elapsed, the spectrophotometer was zeroed with distilled water, and values for the blank and the sample were read. The result for the blank was subtracted from that of the sample to obtain the actual amount of phosphate in the sample in mg l^{-1} (APHA, AWWA, WEF, 1998).

Total Suspended Solids (TSS)

The spectrophotometer was set at 810 nm in analysing the TSS. The sample was blended by vigorous shaking and the instrument at zero with distilled water, whilst the sample was poured into the cell and the value of the TSS was read in ppt (APHA, AWWA, WEF, 1998).

3.16 Determination of Biological Parameters

The various measurements made during the growth study using the 5 different diets and the results from analysis of the diets, faeces and the fish carcasses were used to determine the following biological parameters:

3.16.1 Growth Performance

Growth performance was evaluated by computing the mean weight gain by fish and specific growth rate (SGR).

3.16.1.1 Mean Weight Gain (MWG)

The MWG is the difference between the final mean body weight and the initial mean body weight of fish over a period of time and it was computed as follows:

$$\text{MWG} = \frac{\text{Final mean body weight} - \text{Initial mean body weight}}{\text{Initial body weight}} \times 100\ \%$$ (Ricker, 1979))

3.16.1.2 Specific Growth Rate (SGR)

SGR is the instantaneous change in weight of fish expressed as the percentage increase in body weight per day over any given time interval. It is calculated by taking natural logarithms of the fish body weight, and expresses growth as percentage per day (Ricker, 1979).

$$SGR = \frac{\text{In (final body weight)} - \text{In (initial body weight)}}{\text{Culture period (in days)}} \times 100\ \%$$

3.16.2 Survival Rate (SR)

$$SR = \frac{\text{Initial number of fish stocked} - \text{Total mortality}}{\text{Initial number of fish stocked}} \times 100\ \%$$ (Attipoe *et al.*, 2009)

3.16.3 Feed Conversion Ratio (FCR)

FCR is defined as the amount of dry feed fed per unit live weight gain. It often serves as a measure of efficiency of a diet. The more suitable a diet is for growth, less of it is required to generate a unit weight gain (i.e. a lower FCR) (De Silva and Anderson, 1995). It was computed as:

$$FCR = \frac{\text{Total feed fed}_{(g)}}{\text{Live weight gained by fish}_{(g)}}$$

FCRs of 1.5-2.0 are considered 'good' growth for most fish species (Houlihan *et al.*, 2001).

3.16.4 Feed Efficiency (FE)

FE is simply the reciprocal of FCR (1/FCR). It was computed as:

$$FE = \frac{\text{Live weight gained by fish}_{(g)}}{\text{Total feed fed}_{(g)}} \times 100\ \% = 1/FCR \times 100\ \%$$

FE greater than 50 % is considered 'good' growth (Houlihan *et al*., 2001).

3.16.5 Length-Weight Relationship

The Length-Weight relationship was analyzed by using the equation $W = aL^b$ (Pauly, 1983; Everhart *et al*., 1975).

Where: W= weight of fish in grammes (g)

L= Length of fish in centimetres (cm)

a = the intercept (it describes the rate of change of weight with length)

b = the slope (the weight at unit length)

The equation was log-transformed into a straight line of the form: $y = mx + c$, by double logarithmic transformation thus giving the equation as $\log W = b \log L + \text{Log } a$. By plotting Log W (y) against Log L (*x*) a straight line was obtained. From this line, the values *b* representing gradient of the straight line and *a* representing the intercept on the y-axis were estimated. When *b* is equal to three (3), isometric pattern of growth occurs but when *b* deviate significantly from 3, allometric pattern of growth occurs, which may be positive if >3 or negative if <3.

3.16.6 Condition Factor (K)

The condition factor or coefficient of condition (K) which is mathematical estimation of physiological well-being of a fish in its habitat is determined by using the equation:

$$K = \left(\frac{W}{SL^b} \right) \times 10^5$$ (Gomiero and Braga, 2005; Tesch, 1968).

Where:

W = the weight of the fish in grammes (g)

SL = the standard length of the fish in centimetres (cm)

b = the value (the weight at unit length) obtained from the length-weight equation.

The exponent 'b' value, that is equal to 3, was not used to calculate the 'K' value. Bolger and Connolly (1989) observed that it is not a real representation of the length-weight relationship for greater majority of fish species, therefore the 'b' value used was obtained from the estimated length-weight relationship equation ($W = aL^b$) as suggested by Lima-Junior *et al*. (2002).

In fish, the K reflects through its variations, information on the physiological state of the fish in relation to its welfare. From a nutritional point of view, there is the accumulation of fat and gonadal development (Le Cren, 1951). K also gives information when following up the degree of feeding activity of a species to verify whether it is making good use of its feeding source (Bagenal and Tesch, 1978).

3.16.7 Energy Retention (ER)

$$ER = \frac{\text{Final fish body energy} - \text{Initial fish body energy}}{\text{Gross energy intake}} \times 100\ \%$$ (Agbo, 2008)

3.16.8 Hepatosomatic Index (HSI)

At the end of the growth study, 5 fish were randomly selected from each hapa of each treatment, dissected and livers removed, weighed and used to estimate the hepatosomatic index (HSI) using the formula (Agbo, 2008; Strange, 1996):

$$HIS = \frac{\text{Liver weight}}{\text{Whole fish weight}} \times 100\ \%$$

3.16.9 Protein Efficiency Ratio (PER)

PER is defined as the ratio of the live weight gained by fish to the amount of crude protein fed (De Silva and Anderson, 1995).

$$PER = \frac{\text{Live weight gained by fish}_{(g)}}{\text{Crude protein of feed fed to fish}_{(g)}}$$

3.16.10 Protein Productive Value (PPV)

The PPV also known as 'efficiency of protein utilization' (Gerking, 1971), evaluates the protein in the diet by the ratio of the protein retained in the fish tissues to the dietary protein fed. PPV is determined by carcass analyses of protein in fish samples before and after feeding them with the evaluated diet, and it is generally expressed as a percentage of the protein of the diet fed.

$$PPV = \frac{\text{Protein retained in tissue}}{\text{Dietary protein consumed}} \times 100\ \%$$

PPV takes into account the transformation of the dietary protein into body protein rather than the overall increase in body weight. Hence, it is a more refined criterion for the evaluation of dietary protein compared to PER (Hepher, 1988).

$$\text{Nutrient Deposition} = \left[\frac{(FBW \times FBN) - (IBW \times IBN)}{(\text{feed intake} \times \text{feed nutrient})}\right] \times 100\ \%$$

Where: FBW = final body weight (g),

IBW = initial body weight (g),

FBN = final body nutrient and

IBN = initial body nutrient.

As a result of practical constraints in experiments with fish, in the calculation of FCR, PER and PPV (ANPU – Apparent Net Protein Utilization) the amount of diet fed instead of that which was consumed or intake by fish was used as it was impossible to quantify the un-ingested nor uneaten diet by the fish in the experimental systems. This could really bring about overestimation of feed and underestimation of the ratios (Agbo, 2008).

3.16.11 Apparent Digestibility Coefficient (ADC)

The ADC of CP, lipid and carbohydrate of the diets was determined using the following determination (Maynard and Loosli, 1956):

$$ADC_{nutrient} = 100 - \left[\left(\frac{\%\ \text{dietary } Cr_2O_3}{\%\ \text{faecal } Cr_2O_3}\right)\left(\frac{\%\ \text{faecal nutrient}}{\%\ \text{dietary nutrient}}\right)\right] 100$$

The ADC of dry matter was estimated as follows (Maynard and Loosli, 1956):

$$ADC_{dry\ matter} = 100 - \left[100\left(\frac{\%\ \text{dietary } Cr_2O_3}{\%\ \text{faecal } Cr_2O_3}\right)\right]$$

3.17 State of Fish Health

At the end of the growth study, 15 fish were selected at random from each treatment and their health profiles were taken using the score sheet described in Table 3.6 below, based on a modification of Barton *et al*., (2002); Adams *et al*., (1993); Goede and Barton (1990):

Table 3.6 Criteria used at the end of the growth study for fish health observations

Structure or tissue	Rating criteria	Numeric rating
Eyes	Normal	0
	Abnormal	1
Fat	None	0
	<50 % of gut covered	1
	>50 % of gut covered	2
	100 % of gut covered	3
Fins	No erosion	0
	Light erosion	1
	Moderate erosion	2
	Severe erosion	3
Gills	Normal	0
	Clubbed, frayed or discoloured	1
Gut	Normal	0
	Slight inflammation	1
	Moderate inflammation	2
	Severe inflammation	3
Kidney	Normal	0
	Abnormal	1
Liver	Normal	0
	Abnormal	1
Pseudobranchs	Normal	0
	Abnormal	1
Opercles	Normal	0
	Short	1
Spleen	Normal	0
	Cysts or enlarged	1

Source: Adapted from Barnes *et al*., 2012.

3.18 Economic Analyses of Diets

For the assessment of the cost effectiveness of the farm-made and commercial diets used in the growth study, simple economic analyses were employed. The costs of the diets were calculated using market prices of the ingredients and commercial diets per kilogramme as existed in the study area. Only the cost of the diets was used in the calculations with the assumption that all other operating costs (e.g. transport, hapa, fingerlings and labour) remained constant. However, ten percent (10 %) of the original

costs per kilogramme of farm-made diets *A* and *B* based on the price of the ingredients used was added to each diet to cover the cost of labour in the cost analyses of these diets.

3.18.1 Incidence Cost (IC)

The incidence cost was computed as:

$$IC = \frac{\text{Cost of feeding (GHS)}}{\text{Weight of fish produced (kg)}}$$

IC is the cost of feed used to produce a kilogramme of fish (relative cost per unit weight gain), and the lower the value the more profitable it is using a feed (Agbo *et al.*, 2011; Abu *et al.*, 2010; Nwanna, 2003; Vincke, 1969).

3.18.2 Profit Index (PI)

The profit index was computed as:

$$PI = \frac{\text{Value of fish produced (GHS)}}{\text{Cost of feed used (GHS)}}$$

The value of fish was based on the farm-gate price in the Asuogyaman District of the Eastern Region of Ghana, 2014. The higher the PI, the more cost effective (economical) a diet is (Agbo *et al.*, 2011; Miller, 1976).

3.19 Data Analyses

Data from interviews were coded and entered into a database system using Microsoft Excel software (2007 version). IBM SPSS (version 19.0, SPSS Inc., Chicago, IL) was

used to produce descriptive statistics. All data on fish growth performance, feed utilisation, carcass traits digestibility and water quality were tested for normality using the Kolmogorov-Smirnov test and homogeneity using the Levene's test. The tests were carried out to find out if the data were normally distributed and the variances were homogeneous. All percentages and ratios were arcsine transformed to normalize the data before analyses (Zar, 1984). Statistical analyses were carried out using one-way analysis of variance (ANOVA) to test differences among the various parameters of the dietary treatments. Tukey's multiple range test (MRT) was used to identify specific differences between pairs of treatments. Differences were regarded as significant when $p < 0.05$. Regression analysis was applied to determine the relationship between length and weight of *O. niloticus* in each dietary treatment.

CHAPTER 4.0 RESULTS

4.1 Fish Feed Ingredients Used by Fish Farmers in Ashanti, Brong-Ahafo, Central, Volta and Western Region

A check-list of feed ingredients and supplements/additives used by small-scale pond fish farmers in Ashanti, Brong Ahafo, Central, Volta and Western Regions and their unit cost are presented in Table 4.1a and Table 4.1b. In all, 34 fish feed ingredients and 5 feed supplements/additives were being used by small-scale pond fish farmers in farm-made fish diet production in all the five regions surveyed. Most of the ingredients were being utilized in at least three of the regions, except a few that were unique to one or two regions. Fish meal (*Rastrinneobola argentea*) (miscellaneous), Maize (*Zea mays*), Rice (*Oryza sativa*) bran and Wheat (*Triticum aestivum*) bran were being used in all the five regions, whilst Bean (*Phaseolus vulgaris*) leaves, Birds (dead poultry), Brewery waste, Cassava (*Manihot esculenta*) leaves, Coconut (*Cocos nucifera*) paste, Cotton (*Gossypium spp*) seed cake, Millet (*Urochloa ramose*), Palm fruit fibre, Pito mash, Potato (*Solanum tuberosum*) leaves, Poultry offal and Rice (*Oryza sativa*) were being used in only one region. In general, most of the ingredients were cultivated by the farmers themselves as most of them grow crops aside from fish farming. However, a section of them obtained most of the ingredients they used from food processors and feed ingredient retailers. There were both inter- and intra-regional differences in the price per kilogramme of all the ingredients. Ingredients whose unit cost is indicated by GHS 0.00 could be sourced off farm or the household at no cost.

Table 4.1a Checklist of utilized fish feed ingredients in Ashanti, Brong Ahafo, Central, Volta and Western Region of Ghana

Ingredient	Region									
	Ashanti		Brong Ahafo		Central		Volta		Western	
	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)
Bean (*Phaseolus vulgaris*) husks			✓	0.00			✓	0.00		
Beans (*Phaseolus vulgaris*)					✓	3.50-4.67	✓	3.00-3.20		
Bean (*Phaseolus vulgaris*) leaves							✓	0.00		
Birds (dead poultry)	✓	0.00								
Brewery waste					✓	0.00				
Cassava (*Manihot esculenta*)			✓	0.90-1.20			✓	1.10-1.25		
Cassava (*Manihot esculenta*) flour	✓	0.50-0.70	✓	0.60-0.80	✓	0.75-85			✓	0.80-0.85
Cassava (*Manihot esculenta*) leaves			✓	0.00						
Coconut (*Cocos nucifera*) paste					✓	2.05-2.20				
Cocoyam (*Caladium spp*) leaves			✓	0.00			✓	0.00	✓	0.00
*Common salt (*Sodium chloride*)			✓	1.00-1.60			✓	1.20-1.80		
Copra cake	✓	0.80-0.85			✓	0.44-0.48				
Cotton (*Gossypium spp*) seed cake	✓	0.9-1.0								
Cow (*Bos Taurus*) blood meal	✓	0.40-0.50	✓	0.40			✓	0.60-0.80		
Fish meal (*Rastrinneobola argentea*)	✓	1.60-2.60	✓	1.20-3.63	✓	1.30-2.40	✓	1.60-2.40	✓	4.00-5.00
Groundnut (*Arachis hypogaea*)			✓	4.00-4.43					✓	3.80-4.42
Groundnut (*Arachis hypogaea*) bran	✓	0.10-0.24	✓	0.17-0.40	✓	0.09-0.18			✓	0.10-0.20
Groundnut (*Arachis hypogaea*) cake	✓	1.20-1.44			✓	1.00-1.20				
Kitchen wastes					✓	0.00	✓	0.00		
*Lysine	✓	7.00								
Maize (*Zea mays*)	✓	0.70-1.00	✓	0.54-0.90	✓	0.70-0.90	✓	0.80-0.90	✓	0.80-1.00
Maize (*Zea mays*) bran	✓	0.10-0.40	✓	0.27-0.30	✓	0.29-0.50			✓	0.20-0.34
Maize (*Zea mays*) gluten/meal			✓	0.53-0.80			✓	0.60-0.90		
*Methionine	✓	13.00								
Millet (*Urochloa ramose*)							✓	1.22-1.40		

*Supplement/additive

Table 4.1b Checklist of utilized fish feed ingredients in Ashanti, Brong Ahafo, Central, Volta and Western Region of Ghana

Ingredient	Region									
	Ashanti		Brong Ahafo		Central		Volta		Western	
	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)	Occurrence	Cost per Kg (GHS)
*Oyster shells	✓	0.14-0.16	✓	0.30-0.40						
Palm fruit fibre							✓	0.60-0.80		
Palm kernel cake			✓	0.01-0.02	✓	0.02-0.08	✓	0.03-0.05	✓	0.01-0.02
Palm oil (*Elaeis quineensis*)	✓	3.80-4.40							✓	3.0-3.40
'Pito' mash			✓	0.20-0.30						
Potato (*Solanum tuberosum*) leaves							✓	0.00		
Poultry offal	✓	0.83-1.25								
*Premix (minerals and vitamins)	✓	6.00	✓	6.00	✓	6.50			✓	6.00
Rice (*Oryza sativa*)									✓	4.80-5.50
Rice (*Oryza sativa*) bran	✓	0.30-0.44	✓	0.27-0.46	✓	0.26-0.39	✓	0.22-0.36	✓	0.28-0.32
Soya bean (*Glycine max*)					✓	2.20	✓	2.90	✓	1.80-1.90
Soya bean (*Glycine max*) meal/cake	✓	1.20-1.50	✓	1.60	✓	1.20-1.40			✓	1.00-1.25
Wheat (*Triticum aestivum*) bran	✓	0.60-0.65	✓	0.44-0.54	✓	0.44-0.56	✓	0.52-0.60	✓	0.56-0.60

*Supplement/additive

4.2 Commercial Fish Diets Used by Fish Farmers in Ashanti, Brong-Ahafo, Central, Volta and Western Region

The checklist of the commercial fish diets used by some of the farmers in the five regions and the price per kilogramme are presented in Table 4.2. Four main commercial diet types were being used in all the five regions surveyed. Raanan was being used in all the regions whilst Coppens was being used in Ashanti, Brong Ahafo and Western regions. *Artemia* was being used in the Ashanti and Western regions and Biomar in the Western region only. *Artemia* was not used throughout the rearing period of fish, but it was mainly used to feed post larval African catfish, *Clarias gariepinus*. There were both inter- and intra- regional differences in the price per kilogramme of the commercial fish diets. The unit cost of a given brand of the diets was determined by its crude protein content. Diets with higher crude protein contents cost higher. The cost of any particular commercial diet was also influenced by location. The farther the location from the main retailers/dealers, the more expensive it was.

Table 4.2 Checklist of commonly utilized commercial fish feeds in Ashanti, Brong Ahafo, Central, Volta and Western Regions of Ghana

Fish Feed	Country of Origin	Region									
		Ashanti		Brong Ahafo		Central		Volta		Western	
		Occurrence	Cost per Kg (GH¢)	Occurrence	Cost per Kg (GH¢)	Occurrence	Cost per Kg (GH¢)	Occurrence	Cost per Kg (GH¢)	Occurrence	Cost per Kg (GH¢)
Artemia	China	✓	150.00							✓	140.00
Biomar	France									✓	3.60-4.00
Coppens	Germany	✓	5.40-6.53	✓	5.67-5.00					✓	5.30-6.60
Raanan	Ghana	✓	3.40-5.75	✓	3.50-6.30	✓	3.30-6.50	✓	3.40-6.30	✓	3.40-6.30

4.3 Use of Fish Diets by Fish Farmers in Ashanti, Brong-Ahafo, Central, Volta and Western Region

The use of fish diets varied widely among the 5 Regions surveyed (Figure 4.1). The Region with the highest usage of commercial fish diets among fish farmers was Western whilst the least was Ashanti. Of the 38 farmers interviewed in the Western Region, 21 of them representing about 55.3 % used only commercial fish diets whilst 3 representing about 11.1 % of the 27 farmers in the Ashanti used only commercial fish diets. On the whole, out of the 147 respondents in all the five regions, about 40.4 % used commercial fish diets in the Western region alone. There was no exclusive use of commercial fish diets among the respondents in the Volta Region. A larger proportion of farmers in the Ashanti Region (about 48.2 %) used both commercial and farm-made fish diets than farmers in the other Regions surveyed. A larger proportion of farmers in the Ashanti used farm-made fish diets than those in the other Regions. Most farmers in the Ashanti Region used both the commercial and farm-made diets than farmers in the other four Regions. Only in the Volta and Western Regions that some fish farmers did not feed their fish (i.e they maintained extensive culture systems). The percentage of this group of farmers was significantly higher in the Volta (33.3 %) than in the Western Region (7.9 %).

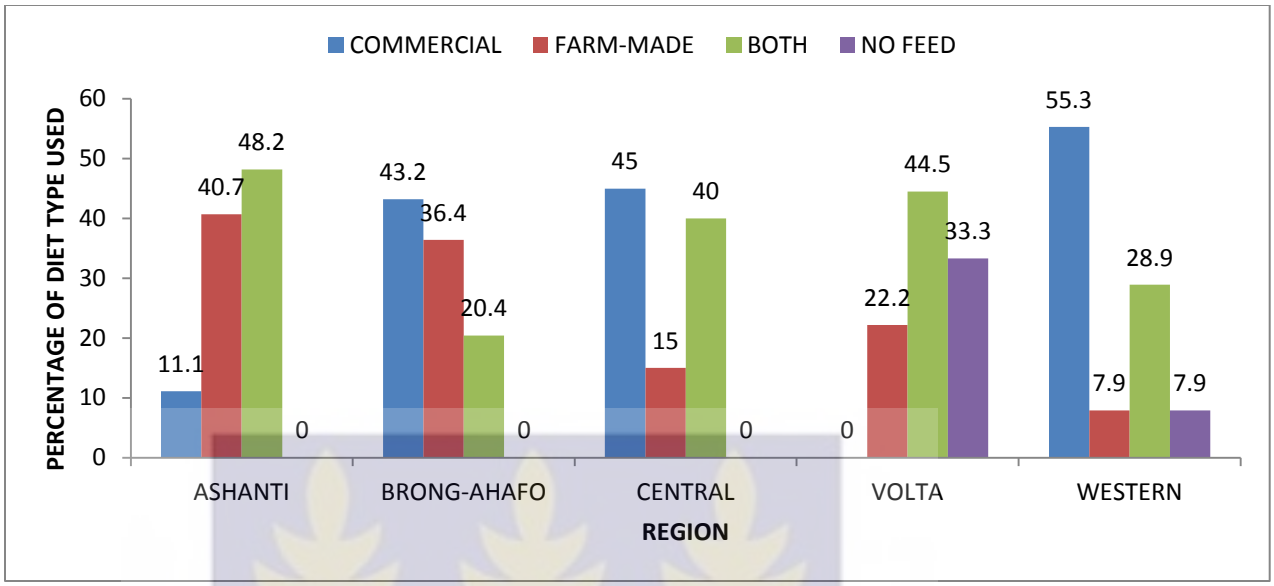

Figure 4.1 Percentage of fish diet types used by fish farmers in Ashanti, Brong-Ahafo, Central, Volta and Western Region

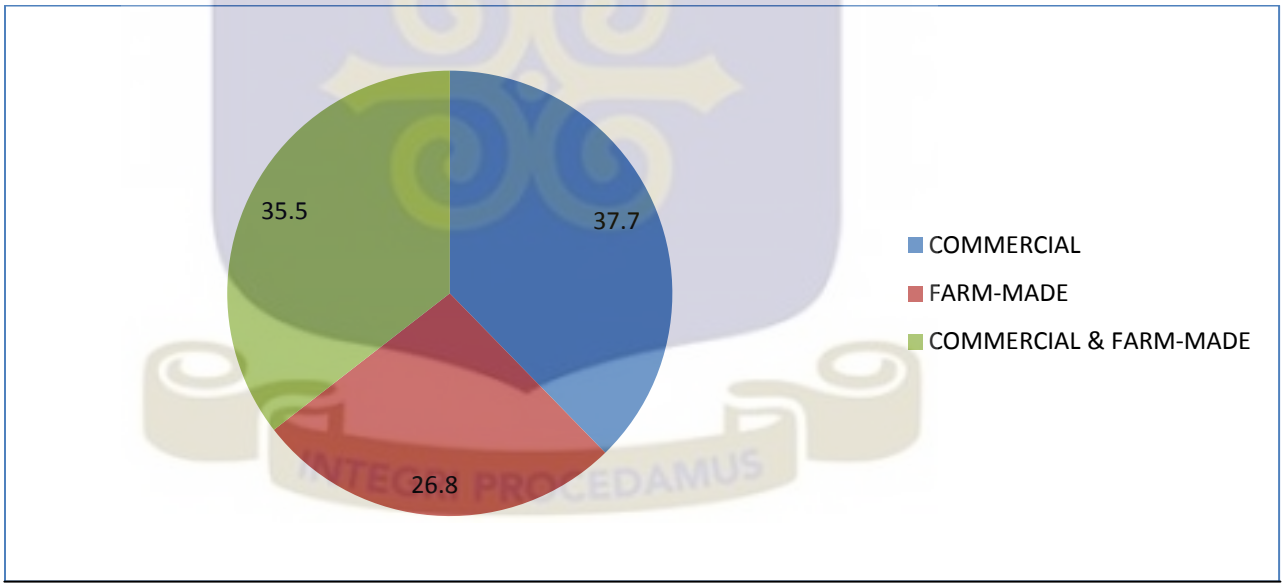

Figure 4.2 Percentage of fish farmers that used the various types of fish diets in Ashanti, Brong-Ahafo, Central, Volta and Western Region

The results of the survey indicated that out of the 138 fish farmers who used fish diets in all the five Regions, 37.7 % used commercial diets, 26.8 % used farm-made diets whilst 35.5 % used both commercial and farm-made diets (Figure 4.2).

4.4 Use of Commercial Fish Diets by Fish Farmers in Ashanti, Brong-Ahafo, Central, Volta and Western Region

The survey revealed that of the 102 fish farmers in all the five Regions, who used various types of commercial fish diets, majority of these (about 86.2 %) used Raanan, about 9.8 % used Coppens, about 2.0 % used Biomar and about 2.0 % also used *Artemia* (Figure 4.3).

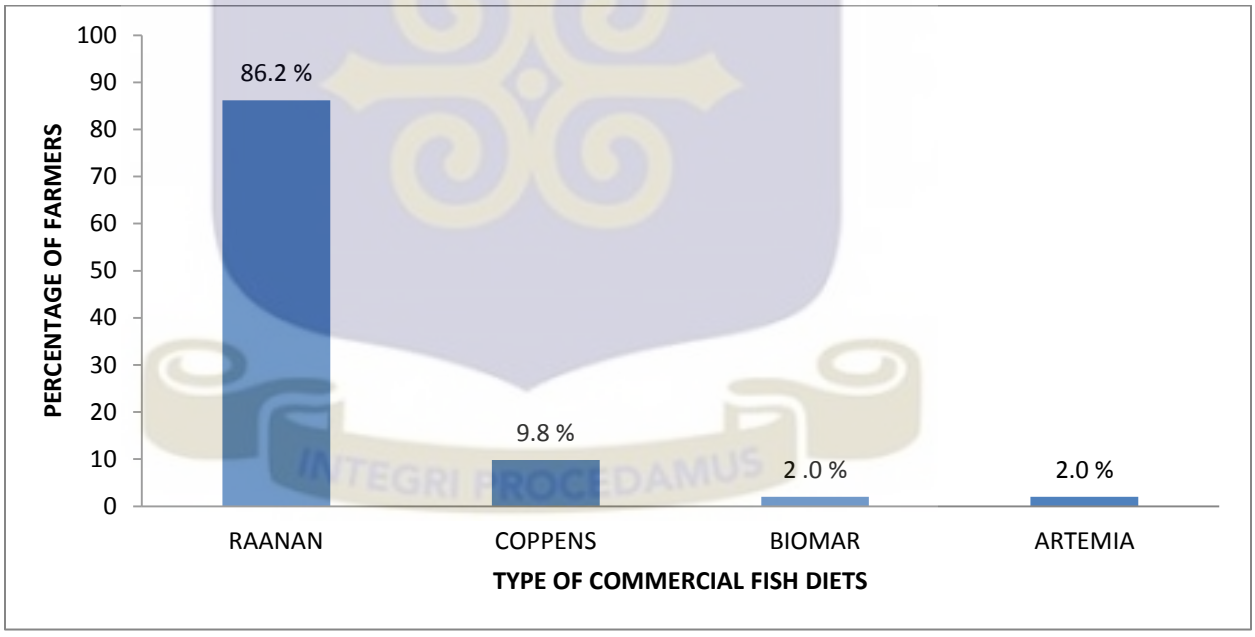

Figure 4.3 Percentage of fish farmers using the various types of commercial fish diets in Ashanti, Brong-Ahafo, Central, Volta and Western Region

4.5 Proximate Compositions of Selected Ingredients

The proximate compositions of the ingredients (as-fed basis) selected for the formulation and preparation of the farm-made fish diets are shown in Table 4.3 below:

Table 4.3 Proximate compositions (% as-fed), gross energy (kJ g^{-1}), phosphorous (%) and prices (GHS kg^{-1}) of the selected feed ingredients used in the formulation and preparation of farm-made diets *A* (supplemented diet) and *B* (unsupplemented diet)

	Cassava flour	Fish meal (Tuna)	Maize (white)	Palm oil	Soybean meal	Wheat bran
DM	88.25 ± 0.06	95.21 ± 0.04	88.93 ± 0.02	100.00 ± 0.01	91.54 ± 0.07	87.56 ± 0.08
CP	1.48 ± 0.03	60.20 ± 0.04	9.31 ± 0.02	0.00 ± 0.09	43.25 ± 0.03	18.42 ± 0.07
CL	0.46 ± 0.02	9.74 ± 0.06	3.38 ± 0.06	100.00 ± 0.01	8.55 ± 0.06	4.64 ± 0.06
CF	2.01 ± 0.07	5.73 ± 0.06	2.80 ± 0.03	0.00 ± 0.04	6.36 ± 0.07	9.87 ± 0.06
Ash	2.62 ± 0.01	17.73 ± 0.07	1.39 ± 0.09	0.00 ± 0.05	9.54 ± 0.03	5.71 ± 0.02
NFE	81.68 ± 0.04	1.81 ± 0.06	71.58 ± 0.03	0.00 ± 0.04	23.84 ± 0.04	48.92 ± 0.06
GE	14.54 ± 0.03	18.39 ± 0.09	15.81 ± 0.02	39.54 ± 0.05	17.69 ± 0.04	14.57 ± 0.09
P	0.96 ± 0.07	19.43 ± 0.06	2.19 ± 0.03	7.69 ± 0.04	4.23 ± 0.03	5.99 ± 0.04
Price	1.32	2.30	0.72	3.74	2.40	0.64

DM = dry matter, CP = crude protein, CL = crude lipid, CF = crude fibre, NFE = nitrogen free extract, GE = gross energy, P = phosphorus

The results of the proximate compositions of the ingredients showed that fish meal had the highest crude protein (60.20 %) whilst Cassava flour had the least (1.48 %). The gross energy for the ingredients ranged from 14.54 to 39.54 kJ g^{-1}, with Palm oil containing the highest (39.54 kJ g^{-1}). Fish meal had the highest amount of Phosphorus (19.43 %) whilst Cassava flour had the least (0.96 %). Crude lipid content of Palm oil was the highest (100.0 %). The ingredient with the highest Crude fibre content was Wheat bran (9.87 %) and Fish meal had the highest Ash (17.73 %) content. Palm oil was the most expensive (3.74 GHS kg^{-1}) whilst Wheat bran was the least expensive (0.64 GHS kg^{-1}).

4.6 Proximate Compositions of Study Diets

The proximate compositions of diets *A* (farm-made diet supplemented with lysine, methionine, and vitamin-mineral premix), *B* (farm-made diet with no supplements), *C* (Coppens), *D* (Raanan) and *E* (a 1:1 mixture of diets *B* and *D*) are shown in Table 4.4 below:

Table 4.4 Proximate composition (% as-fed), gross energy (kJ g^{-1}), phosphorous (g kg^{-1}), Chromic oxide concentrations and prices (GHS kg^{-1}) of Diets *A*, *B*, *C* (Coppens), *D* (Raanan) and *E*

	A	*B*	Coppens	Raanan	*E*
DM	89.60 ± 0.03	90.59 ± 0.02	96.58 ± 0.04	90.40 ± 0.02	89.66 ± 0.06
CP	31.29 ± 0.05	31.53 ± 0.04	34.58 ± 0.01	31.21 ± 0.07	33.80 ± 0.03
CL	10.36 ± 0.01	12.39 ± 0.03	6.94 ± 0.05	4.78 ± 0.06	10.00 ± 0.07
CF	5.21 ± 0.04	4.46 ± 0.02	4.48 ± 0.06	3.91 ± 0.06	4.01 ± 0.08
Ash	8.80 ± 0.09	8.39 ± 0.04	5.16 ± 0.01	9.45 ± 0.02	8.02 ± 0.05
NFE	33.94 ± 0.02	33.82 ± 0.07	45.42 ± 0.06	41.05 ± 0.08	33.83 ± 0.09
GE	17.31 ± 0.05	18.15 ± 0.04	18.70 ± 0.05	16.31 ± 0.03	17.75 ± 0.05
P	11.07 ± 0.06	12.80 ± 0.02	6.56 ± 0.04	8.54 ± 0.08	7.54 ± 0.04
Cr_2O_3	0.42 ± 0.02	0.41 ± 0.03	0.41 ± 0.01	0.42 ± 0.02	0.40 ± 0.05
Price	1.88	1.75	5.00	3.25	2.32

DM = dry matter, CP = crude protein, CL = crude lipid, CF = crude fibre, NFE = nitrogen free extract, GE = gross energy, P = phosphorus, GHS = Ghana cedis

Proximate analyses of the diets showed that Coppens had the least moisture content. Raanan had the least (31.21 %) crude protein content whilst Coppens had the highest (34.58 %). The analysed crude protein levels of Coppens and Raanan were higher than levels (34.00 % and 30.00 % respectively) declared by the manufacturers as indicated on the labels of their respective feed bags. Results of the analyses also showed that values (31.29 % and 31.53 % respectively) obtained for the crude protein contents were higher

for the formulated diets (*A* and *B*) than the calculated value (30.00 % for each diet). Diet *E* had higher (33.80 %) crude protein content than any of its constituent diets (*B* and Raanan). For crude lipid, values (6.94 % and 4.78 %) obtained for Raanan and Coppens respectively, were lower than those for the formulated diets (10.36 % and 12.39 % for *A* and *B* respectively). The value for Coppens was about two times lower than what the producer declared. The gross energy of the diets ranged from 16.31 to18.70 kJ g^{-1} with Raanan having the least and Coppens the highest. Values obtained for the analyses of Ash ranged from 5.16 to 9.45 %. Coppens had the least whist Raanan had the highest. Crude fibre contents of the diets ranged from 3.91 to 5.21 % with Raanan having the least and farm-made diet *A* the highest. The chromic oxide concentrations in the diets ranged from 0.40 to 0.42 %. The unit cost of the diets ranged from 1.75 to GHS 5.00 with the commercial ones being more expensive than the farm-made ones. The most expensive diet was Coppens (5.00 GHS kg^{-1}) whilst the least was farm-made diet *B* (1.75 GHS kg^{-1}).

The comparison between the calculated/declared crude proteins and the analysed crude proteins of the various diets is shown in Table 4.5. The mean deviation was 3.78 ± 1.46 with farm-made diet *A* showing the highest (4.3 %) deviation whilst Coppens showed the least (1.7 %).

Table 4.5 Percentage deviation of the observed from the expected crude proteins of the various diets

Diet	Calculated/Declared CP	Analysed CP	Deviation (%)
A	30.00	31.29	4.3
B	30.00	31.53	5.1
Coppens	34.00	34.58	1.7
Raanan	30.00	31.21	4.0

4.7 Experimental Fish

The hand-sexing of the nursed experimental fish was possible when they attained sizes ranging between 19.00 and 29.00. In all, about 93 % of the population with weights ranged 19.2 to 28.7 g was found to be males. Their mean living weight (±SD) was 22.8 ± 2.1 g and mean SL (±SD) was 8.9 ± 0.3 cm. There were no significant differences (ANOVA, $p > 0.05$) among treatments.

4.8 Growth Performance of Cultured Fish

The overall values of growth performance of *O. niloticus* fed the various farm-made and commercial diets for twenty weeks is presented as mean living weight (±SD) (Appendix III) and illustrated graphically in Figure 4.4. After the second week of culture, growth was rapid in all the treatments up to the sixth week. Growth was generally slow between the sixth and eighth week. However, growth peaked after the eighth week in all the treatments, but highest in fish fed Raanan till the eighteenth week. The highest final mean weight of 187.6 g occurred in fish fed Raanan whilst the least final mean weight of 131.0 g occurred in fish fed farm-made diet *B*. There was significant difference (Tukey's MRT,

$p < 0.05$) in final mean weight between the fish fed Raanan and those fed the other diets. There was no significant difference (ANOVA, $p > 0.05$) between the final mean weights of fish fed Coppens and those fed farm-made diet *A*.

Fish fed Raanan had the highest weight gain (165.0 g) followed by those fed Coppens (125.8 g) and the least (108.2 g) were those fed diet *B* (Figure 4.5). The percentage weight gain and specific growth rate were highest for fish fed Raanan (728.8 % and 1.63 % day^{-1} respectively) and least for those fed diet *B* (466.2 % and 1.33 % day^{-1} respectively) (Table 4.6). However, there was no significant difference in specific growth rate among dietary treatments. The values for mean daily weight gain ranged from 0.77 to 1.18 g $fish^{-1}$. Fish fed Raanan had the highest daily weight gain whilst those fed farm-made diet *B* had the least. There were no significant differences among dietary treatments except between fish fed Raanan and diet *B*. Total fish yield (TFY) ranged from 0.25 to 0.38 kg m^{-2} whilst net fish yield (NFY) ranged from 0.20 to 0.33 kg m^{-2}. Both TFY and NFY were significantly higher in *O. niloticus* fed Raanan whilst there were no significant differences among the other dietary treatments. Survival ranged from 86.67 to 100.00 %. The highest survival was observed in fish fed Raanan whilst the least occurred in fish fed Coppens. However, there were no significant differences among dietary treatments. Condition factor of fish fed the various diets ranged from 2.0 to 3.2. There was no significant difference (ANOVA, $p > 0.05$) in condition factor among dietary treatments except Raanan that was significantly lower (Tukey's MRT, $p < 0.05$).

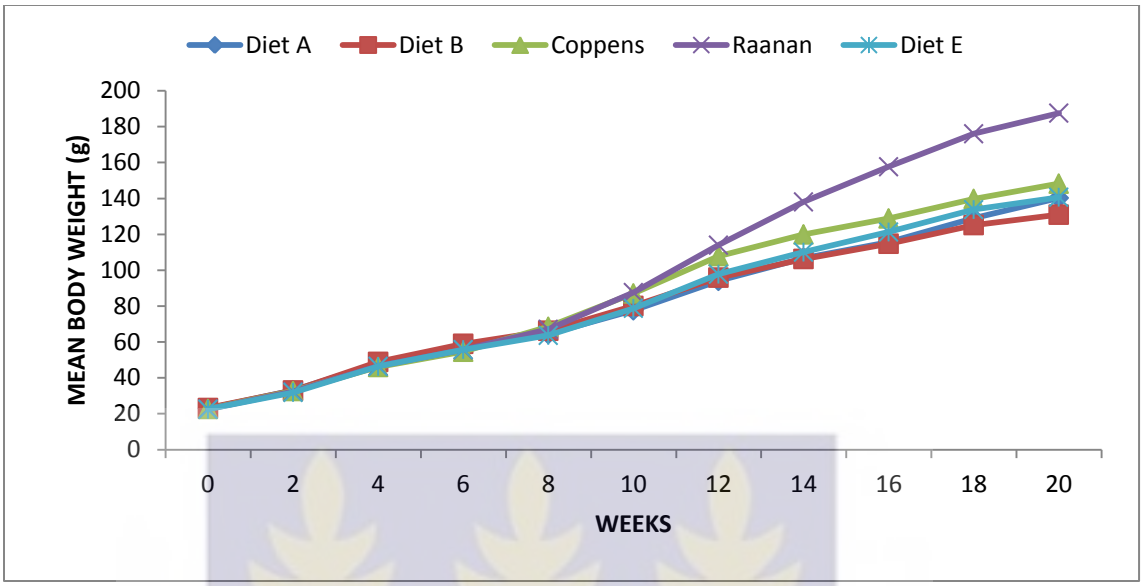

Figure 4.4 Growth performance of *Oreochromis niloticus* fed commercial and farm-made fish diets for twenty weeks

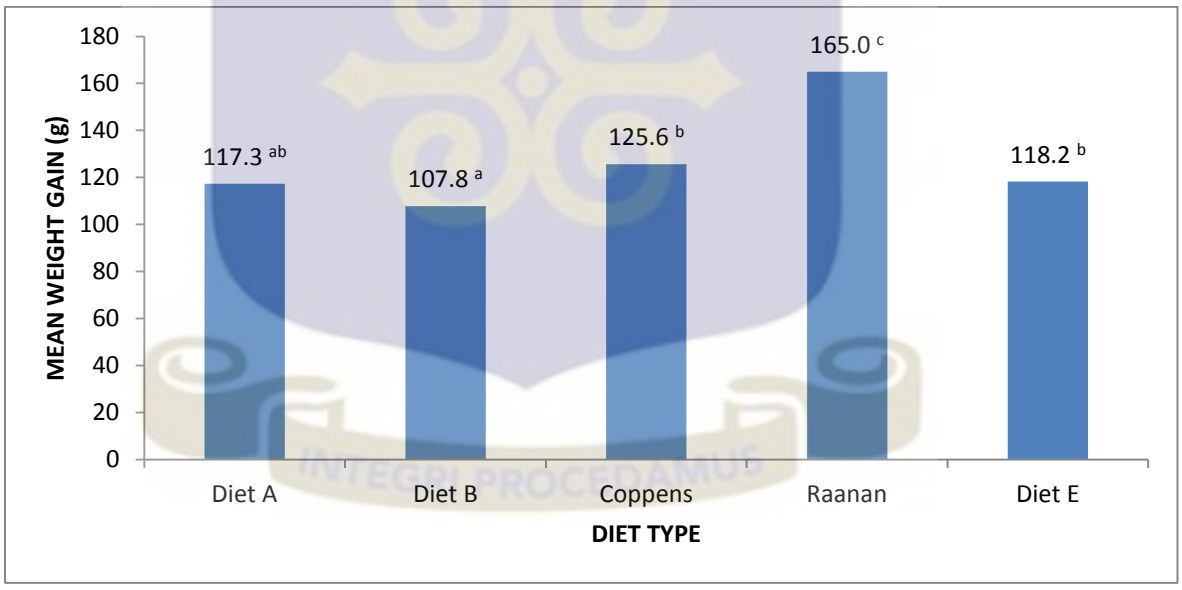

Figure 4.5 Weight gain by *Oreochromis niloticus* fed commercial and farm-made fish diets for 20 weeks. Bars with different letters are significantly different (Tukey's MRT, $p < 0.05$)

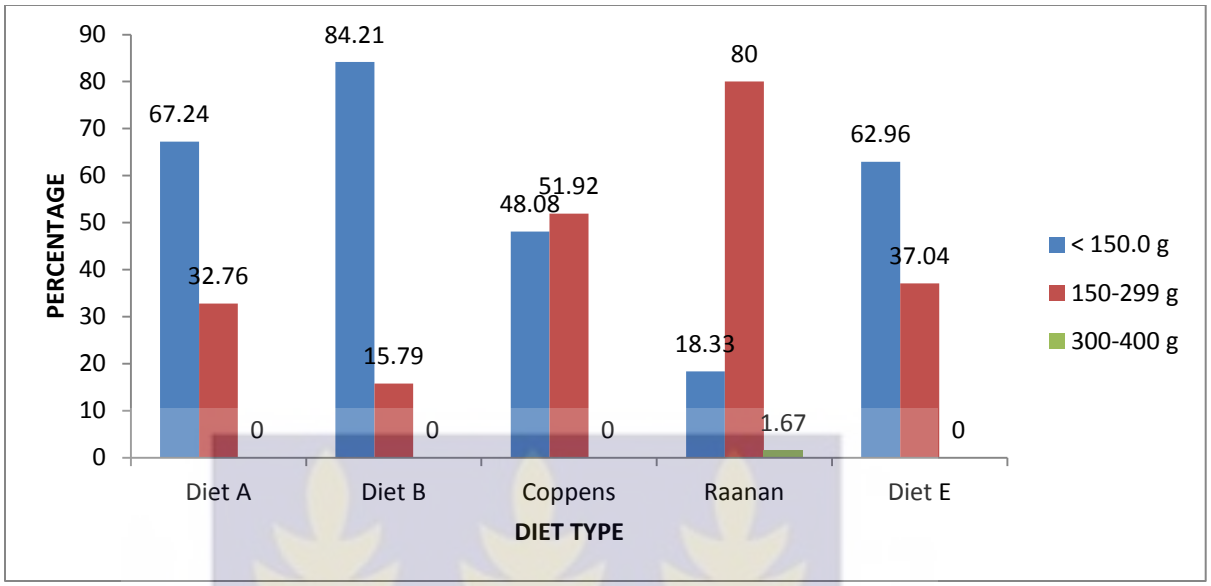

Figure 4.6 Percentage final wet weight distributions of *Oreochromis niloticus* in each dietary treatment after 20 weeks of feeding

At the end of the growth trials, only *O. niloticus* fed Raanan recorded a size range 300-400 g, and this constituted about 1.67 % of the fish fed Raanan (Figure 4.6). Besides, fish fed Raanan recorded the greatest proportion of the size range 150-299 g (80.00 %), followed by fish fed Coppens (48.08 %) whilst the least (15.79 %) of this size group was observed in fish fed farm-made diet *B*. The highest number (84.21 %) of *O. niloticus* of size below 150.0 g occurred in those fed farm-made diet *B*, followed by fish fed farm-made diet *A* whilst the least (18.33 %) was recorded in those fed Raanan.

Table 4. 6 Mean growth performance of the cultured Nile tilapia fed diets *A*, *B*, Coppens, Raanan and *E* for 20 weeks

Parameter	Diet				
	A	*B*	Coppens	Raanan	*E*
Initial Weight (g)	23.0 ± 2.0^{a}	23.2 ± 1.9^{a}	22.7 ± 1.9^{a}	22.6 ± 2.3^{a}	22.5 ± 2.2^{a}
Final Weight (g)	140.3 ± 23.4^{ab}	131.0 ± 24.4^{a}	148.3 ± 25.4^{b}	187.6 ± 42.1^{c}	140.7 ± 28.5^{b}
Initial Standard Length (cm)	89.5 ± 2.9^{a}	89.1 ± 2.5^{a}	88.3 ± 2.6^{a}	88.4 ± 2.6^{a}	88.1 ± 3.2^{a}
Final Standard length (cm)	162.6 ± 8.9^{ab}	159.9 ± 9.2^{a}	165.3 ± 8.7^{b}	177.6 ± 13.7^{c}	163.6 ± 11.2^{b}
Weight Gain (%)	511.0 ± 50.5^{ab}	466.2 ± 38.8^{a}	555.3 ± 29.0^{b}	728.8 ± 45.0^{c}	526.6 ± 36.6^{b}
Specific Growth Rate (% day^{-1})	1.39 ± 0.07^{a}	1.33 ± 0.05^{a}	1.45 ± 0.03^{a}	1.63 ± 0.04^{a}	1.41 ± 0.05^{a}
Daily Weight Gain (g/fish)	0.84 ± 0.06^{a}	0.77 ± 0.07^{a}	0.90 ± 0.08^{a}	1.18 ± 0.19^{b}	0.84 ± 0.06^{a}
Survival (%)	96.7 ± 2.89^{a}	95.0 ± 8.66^{a}	86.67 ± 5.77^{a}	100.0 ± 0.00^{a}	90.0 ± 10.00^{a}
Total Fish Yield (Kg m^{-2})	0.27 ± 0.24^{a}	0.25 ± 0.18^{a}	0.26 ± 0.15^{a}	0.38 ± 0.23^{b}	0.25 ± 0.19^{a}
Net Fish Yield (Kg m^{-2})	0.23 ± 0.24^{a}	0.20 ± 0.17^{a}	0.21 ± 0.16^{a}	0.33 ± 0.23^{b}	0.21 ± 0.17^{a}
Condition Factor	3.3 ± 0.09^{a}	3.2 ± 0.12^{a}	3.3 ± 0.08^{a}	2.0 ± 0.07^{b}	3.2 ± 0.09^{a}

Values are means ±SD of three replicates. Means within the same row with different letters are significantly different ($p < 0.05$).

4.9 Feed and Nutrient Efficiency of Cultured Fish

The data on feed and nutrient efficiency of the cultured fish is shown in Table 4.7 above. The FCR values ranged from 2.35 to 3.26 at the end of the growth study. FCRs of all the dietary treatments were not significantly different (ANOVA, $p > 0.05$) except diets *B* and Raanan that were significantly different (Tukey's MRT, $p < 0.05$) from each other with the latter being higher. Raanan was the most efficient as it gave the least FCR of 2.35 whilst diet *B* was the least efficient, with the highest FCR of 3.26. Feed efficiency was less than 50.0 % in all the dietary treatments and the values ranged from 30.10 % in diet *B* to 43.03 % in Raanan. Raanan was significantly higher than diets *A*, *B*, Coppens and *E*. Feed intake ranged from 344.83 to 388.11 g and there were no significant differences among all the diets. There was no significant difference in protein utilization efficiency among all the diets and the values ranged from 1.18 to 1.67. The protein productive value was significantly higher (Tukey's MRT, $p < 0.05$) in fish fed Raanan and there were no significant differences among fish fed diets *B*, Coppens and *E*. The percentage energy retention ranged from 8.32 to 15.32 %, with fish fed Raanan being significantly higher whilst those fed Coppens being lower.

Table 4.7 Feed and nutrient efficiency of the cultured Nile tilapia fed diets *A*, *B*, Coppens, Raanan and *E* for 20 weeks

Parameter	Diet				
	A	*B*	Coppens	Raanan	*E*
Feed Conversion Ratio	2.96 ± 0.19^{b}	3.26 ± 0.21^{ab}	2.92 ± 0.12^{b}	2.35 ± 0.13^{bc}	2.92 ± 0.07^{b}
Feed Efficiency (%)	34.02 ± 2.01^{a}	30.10 ± 2.10^{a}	33.00 ± 1.11^{a}	43.03 ± 2.00^{b}	34.04 ± 1.21^{a}
Feed Intake (g)	347.10 ± 13.28^{a}	351.32 ± 12.87^{a}	366.76 ± 14.31^{a}	388.11 ± 18.92^{a}	344.83 ± 13.63^{a}
Protein Efficiency Ratio	1.37 ± 0.84^{a}	1.27 ± 0.88^{a}	1.18 ± 0.64^{a}	1.67 ± 0.77^{a}	1.34 ± .76^{a}
Protein Productive Value (%)	24.89 ± 0.13^{a}	20.44 ± 0.34^{b}	21.15 ± 0.18^{b}	28.80 ± 0.03^{c}	22.07 ± 0.21^{b}
Energy Retention (%)	11.96 ± 0.29^{a}	10.30 ± 0.20^{b}	8.32 ± 0.18^{c}	15.32 ± 0.14^{d}	10.78 ± 0.31^{b}

Values are means ±SD of three replicates. Means within the same row with different letters are significantly different ($p < 0.05$).

4.10 Length-Weight Relationship by Diet Type

The linear least square regression of log weight (body weight, W) on log standard length (SL) (i.e. log W = b log SL + log a) computed for diets *A*, *B*, Coppens, Raanan and *E* are shown in Figures 4.7 to 4.11 below:

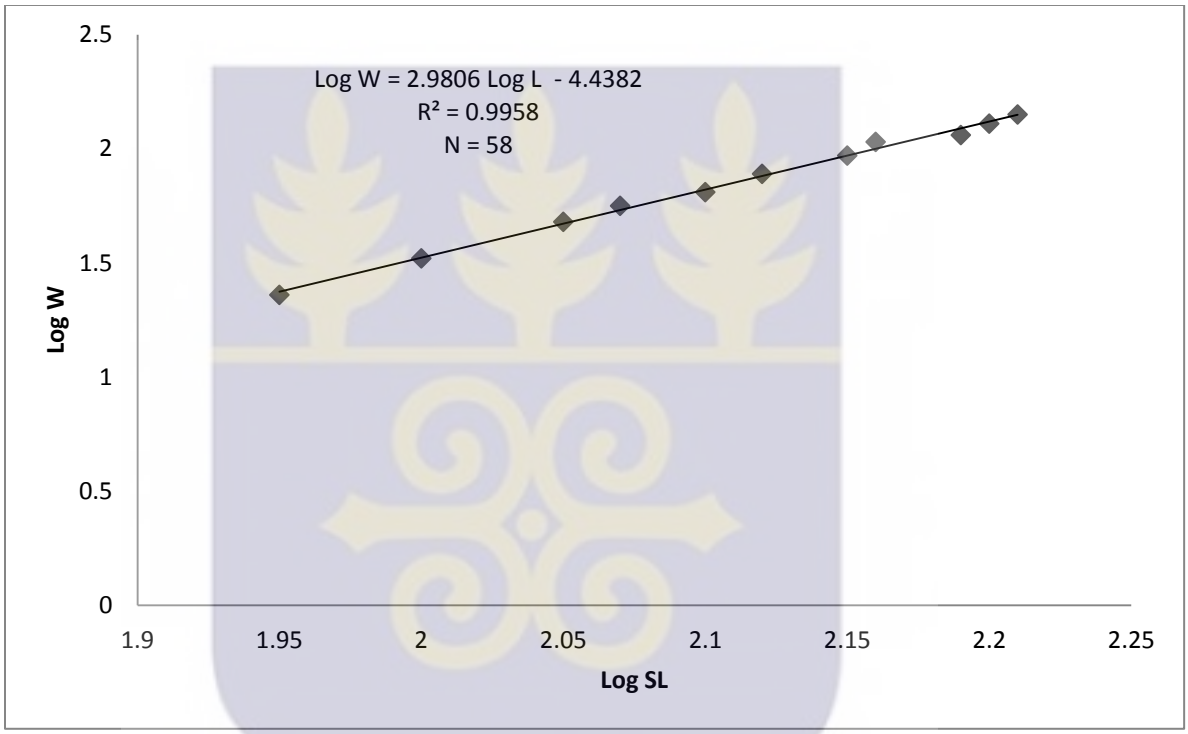

Figure 4.7 Length-weight relationship of *Oreochromis niloticus* fed farm-made diet *A*

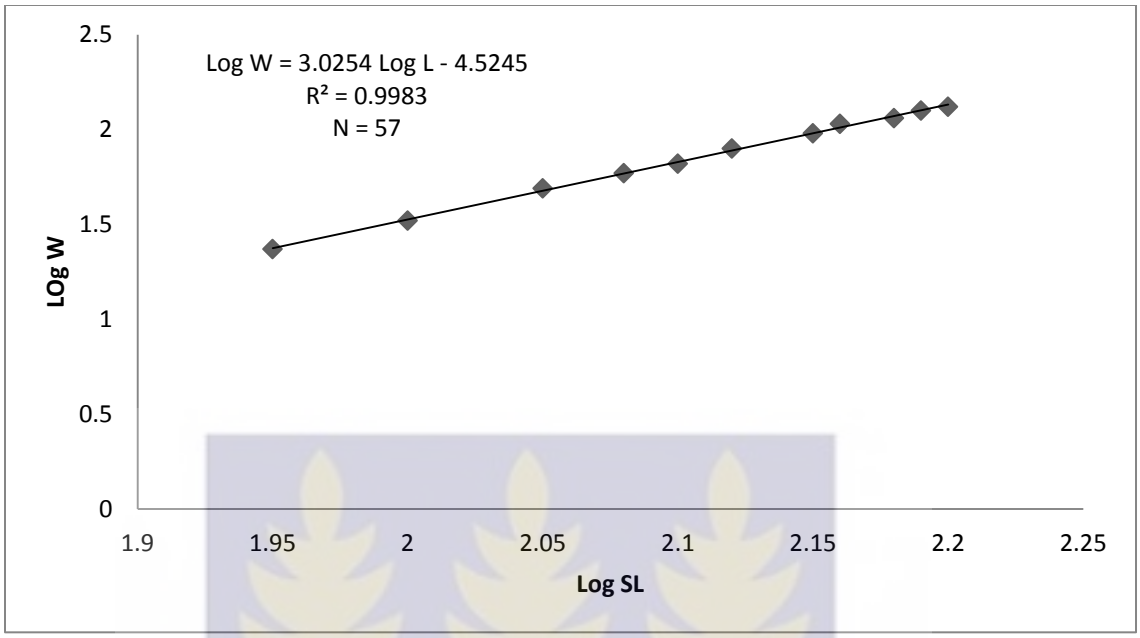

Figure 4.8 Length-weight relationship of *Oreochromis niloticus* fed farm-made diet *B*

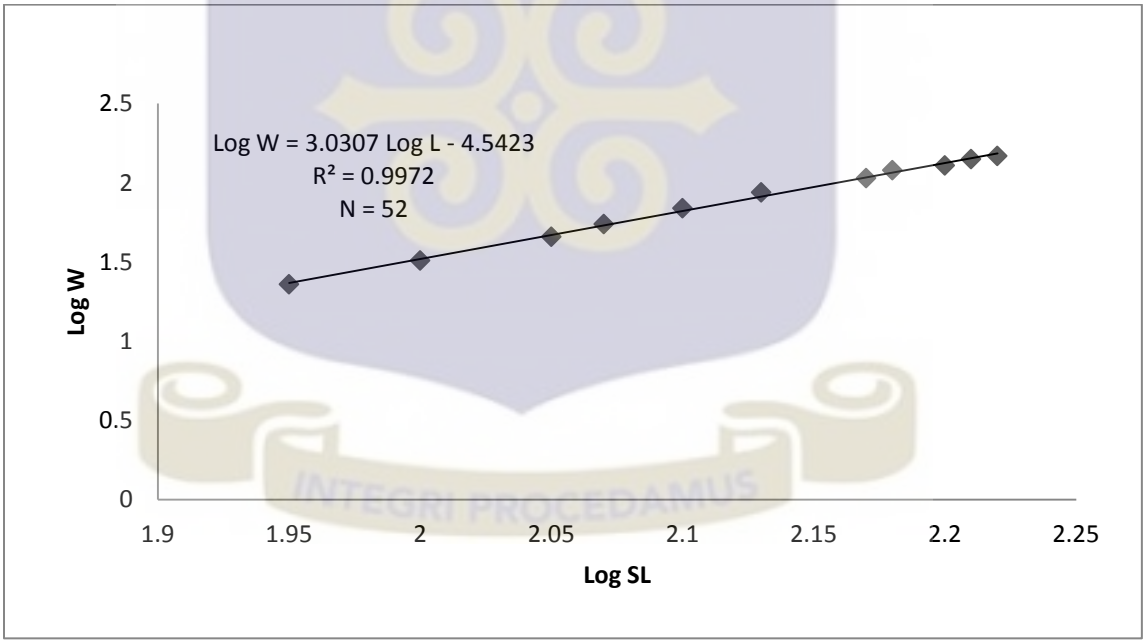

Figure 4.9 Length-weight relationship of *Oreochromis niloticus* fed Coppens

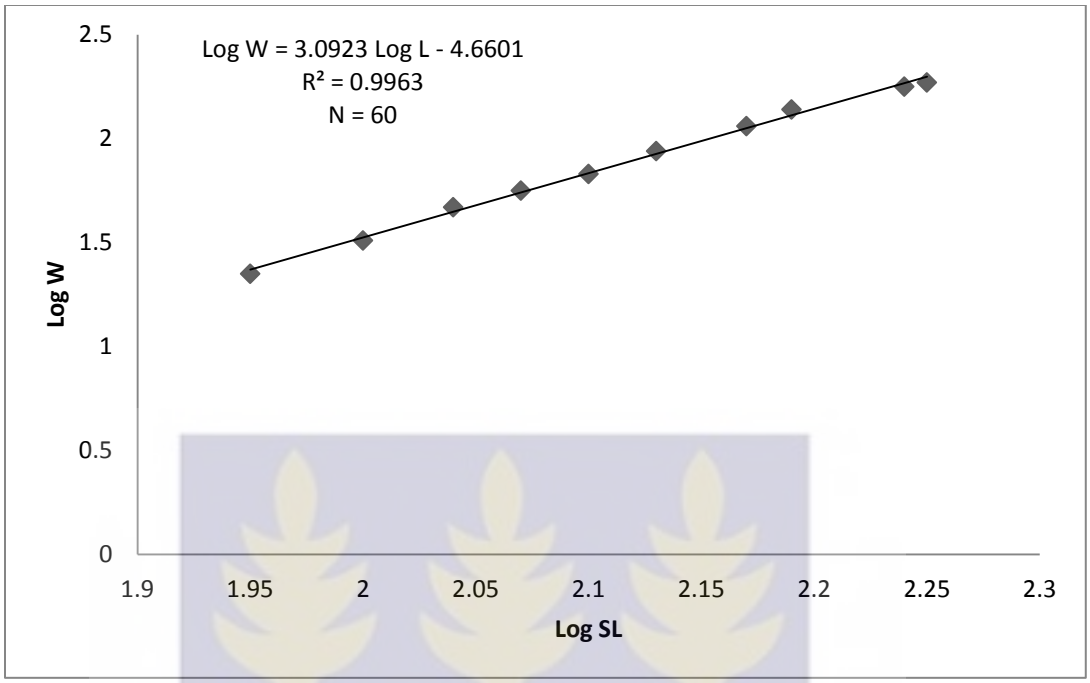

Figure 4.10 Length-weight relationship of *Oreochromis niloticus* fed Raanan

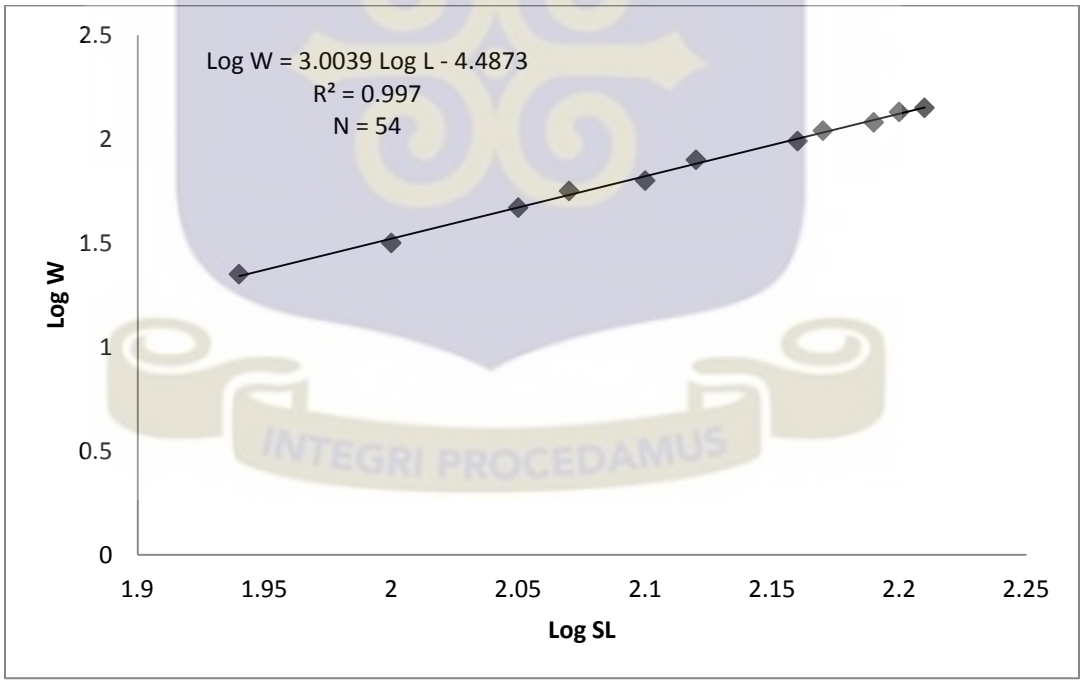

Figure 4.11 Length-weight relationship of *Oreochromis niloticus* fed diet *E*

The regression equations computed from data for each dietary treatment are as follows:

Farm-made diet ***A***: $W = 0.0000365\ SL^{2.9806}$ ($R^2 = 0.996$)

Farm-made diet ***B***: $W = 0.0000299\ SL^{3.0254}$ ($R^2 = 0.998$)

Coppens: $W = 0.0000287\ SL^{3.0307}$ ($R^2 = 0.997$)

Raanan: $W = 0.0000219\ SL^{3.0923}$ ($R^2 = 0.996$)

(Farm-made + Raanan), diet *E*: $W = 0.0000326\ SL^{3.0039}$ ($R^2 = 0.997$)

The above equations clearly indicated that the various dietary treatments exhibited differences in the value of exponent *b*. The weight gain was almost the same (approximately 3) in *O. niloticus* fed both the farm-made and commercial diets.

Table 4.8 Equation parameters of Length-weight and condition factors for *Oreochromis niloticus* fed the various diet type

Treatment	*B*	R^2	*K*
A	3.0	0.996	3.3
B	3.0	0.998	3.2
Coppens	3.0	0.997	3.3
Raanan	3.1	0.996	2.0
E	3.0	0.997	3.2

b = slope of regression line, *R* = coefficient of regression, *K* = condition factor

The values of K for dietary treatments *A* and Coppens were equal and the highest (3.3) whilst the K-value for Raanan was the least (2.0) (Table 4.8).

4.11 Health Status of *O. niloticus* according to Diet Type

There were no abnormalities observed in the eyes, fins, gills, guts, kidneys, livers, pseudobranchs, opercles or spleens in any of the fish fed the various diets. Abdominal fat covered less than half of the viscera in almost all the fish examined in the various dietary

treatments and the values ranged from 0.33 to 1.13. Generally, the least gut fat content was observed in the fish fed diet *E*. The highest gut fat content occurred in *O. niloticus* fed Coppens. However, there were no significant differences (ANOVA, $p > 0.05$) among dietary treatments, except diet *E* that was significantly lower (Tukey's MRT, $p < 0.05$). Patches of red-brown colouration were observed on the scales of about 12 % of fish fed Coppens. However, these were superficial.

4.12 Body Composition of Cultured *O. niloticus*

The whole-body proximate compositions of *O. niloticus* at the commencement and end of the growth study are presented in Table 4.9. The results showed that there was no significant difference (ANOVA, $p > 0.05$) in whole-body moisture contents among all the dietary treatments and the values ranged from 75.20 to 76.26 %, and all were lower than the initial whole-body moisture composition of the experimental fish. The crude protein contents ranged from 16.20 to 18.46 % and that of fish fed farm-made diet *A* was significantly higher (Tukey's MRT, $p < 0.05$) than those fed the other diets and the values observed in all the dietary treatments were higher than that of the initial content of the experimental fish. The crude lipid contents of *O. niloticus* fed farm-made diet *B* and Coppens were significantly higher than those fed the other diets and the values ranged from 3.04 to 4.20 %. The nitrogen free extracts (carbohydrates) content of fish fed diet *E* was significantly higher and the values for the dietary treatments ranged from 0.68 to 2.53 %. The crude fibre content of *O. niloticus* fed diet *A* was significantly higher than the other dietary treatments and all the values (0.07 to 0.23 %) observed were lower than that of the experimental fish at the commencement of the growth trials. The Ash and

Phosphorus contents of *O. niloticus* fed Coppens were significantly lower than those fed the other diets, and the values ranged from 1.33 to 1.96 % and 16.71 to 21.57 % respectively. The ash contents of *O. niloticus* in all the dietary treatments were higher than that of the fish before the commencement of the growth trials. The gross energy contents of all the fish at the end of the study ranged from 5.47 to 5.95 kJ g^{-1} and that of fish fed Coppens was significantly higher. The values recorded in all the dietary treatments were higher than that of the initial whole-body content of the experimental fish. The values of hepatosomatic index of the various dietary treatments ranged from 1.41 to 2.17 and *O. niloticus* fed Coppens was significantly higher than those fed the other diets whilst those fed farm diet *B* was significantly lower.

Table 4.9 Whole body proximate composition (%) gross energy (kJ g^{-1}) and hepatosomatic index of cultured Nile tilapia (mean ± SD)

Constituent	Initial	*A*	*B*	Coppens	Raanan	*E*
MC	81.21 ± 0.16	75.20 ± 0.53^{a}	75.61 ± 1.06^{a}	75.89 ± 0.19^{a}	75.65 ± 0.60^{a}	76.26 ± 0.23^{a}
CP	12.49 ± 0.42	18.46 ± 1.04^{a}	16.37 ± 5.18^{b}	17.76 ± 2.19^{c}	17.87 ± 2.96^{c}	16.20 ± 4.63^{b}
CL	3.51 ± 0.06	3.53 ± 0.55^{b}	4.20 ± 0.37^{a}	4.13 ± 0.67^{a}	3.14 ± 0.40^{b}	3.04 ± 0.59^{b}
NFE	0.94 ± 0.63	0.68 ± 1.22^{c}	1.73 ± 5.22^{bcd}	0.71 ± 1.70^{a}	1.42 ± 2.94^{c}	2.53 ± 4.33^{cde}
CF	1.10 ± 0.13	0.23 ± 0.04^{a}	0.13 ± 0.05^{b}	0.18 ± 0.01^{c}	0.07 ± 0.01^{d}	0.07 ± 0.01^{d}
Ash	0.75 ± 0.36	1.90 ± 0.18^{cd}	1.96 ± 0.26^{cd}	1.33 ± 0.20^{a}	1.85 ± 0.28^{cde}	1.90 ± 0.28^{bcd}
P	16.85 ± 119.24	21.37 ± 11.98^{c}	21.57 ± 8.37^{cd}	16.71 ± 7.27^{a}	18.75 ± 7.74^{b}	21.25 ± 7.42^{c}
GE	4.50 ± 0.03	5.88 ± 0.21^{c}	5.83 ± 0.31^{cde}	5.95 ± 0.13^{a}	5.71 ± 0.12^{c}	5.47 ± 0.21^{bc}
HIS		1.62 ± 0.46^{bc}	1.41 ± 0.40^{abc}	2.17 ± 0.73^{cd}	1.71 ± 0.34^{bc}	1.81 ± 0.53^{c}

MC = moisture content, CP = crude protein, CL = crude lipid, NFE = nitrogen free extracts, CF = crude fibre, P = phosphorus, GE = gross energy, HSI = hepatosomatic index. Values are means ± SD of three replicates. Values within the same row with dissimilar letters are significantly different (Tukey's MRT, $p < 0.05$).

4.13 Cost Effectiveness of the Diets

The costs per kilogramme of the commercial diets were higher compared to the farm-made ones (Table 4.10). Coppens was the most expensive (GHS 5.00 kg^{-1}) and the least (GHS 1.93 kg^{-1}) was farm-made diet *B*. The cost analyses showed that it was more expensive (GHS 12.35) to use Coppens to produce a kilogramme of tilapia than any of the other diets whilst the farm-made diet *A* cost least (GHS 5.12). The highest profit was made by the use of farm-made diet *A*, followed by farm-made diet *B* whilst the least was made by the use of Coppens. The results of this study also revealed that it was more profitable to use farm-made diet *B* alone than mixing it in equal proportions with Raanan.

Table 4.10 Cost effectiveness of diets fed to Nile tilapia

Diets	Cost per kg of feed (GHS)	Feed input (kg)	Cost of feed used (GHS)	Harvested biomass (kg)	Estimated value of biomass (GHS)**	Incidence Cost (GHS/kg)	Profit Index
*A**	2.07	20.12	41.65	8.14	52.03	5.12	1.25
*B**	1.93	19.93	38.46	7.46	47.00	5.16	1.22
Coppens	5.00	19.05	95.25	7.71	50.07	12.35	0.53
Raanan	3.25	23.29	75.69	11.26	75.04	6.72	0.99
E	2.59	18.59	48.15	7.60	48.83	6.34	1.01

*Cost per kg of feed include labour, constituting 10 % of the cost of producing the feed, **Sale of fish: < 150 g = GHS 6.20, 150-299 g = GHS 6.70, 300-400 g = GHS 7.50

4.14 Water Quality

The detailed value range of water quality parameters in hapas for the various dietary treatments and the open pond water during the growth trials are shown in Appendix IV whilst the summary of statistical result range (maximum and minimum), mean and standard deviation values are shown in Table 4.11. Generally, all water quality parameters were within the suitable range for Nile tilapia (Nabil and Gamal, 2010; Swann, 2007; Hussain, 2004; Suresh, 2003; Popma and Masser, 1999; Stickney, 1979).

Table 4.11 Summary of statistical analysis of water quality parameters for the various dietary treatments and the open pond water for a period of 140 days

Parameter	Maximum	Minimum	Mean	Standard Deviation
Temperature (^{0}C)	29.83	27.58	28.90	0.02
Dissolved Oxygen	3.30	1.15	2.16	0.15
Salinity (ppt)	0.04	0.03	0.04	0.00
Conductivity (µS cm^{-1})	100	61	86	2
pH	7.62	5.79	6.39	0.05
Phosphate (mg L^{-1})	2.55	0.10	0.29	0.11
Nitrate (mg L^{-1})	6.60	0.40	1.28	0.21
Nitrite (mg L^{-1})	0.113	0.001	0.008	0.003
Ammonia (mg L^{-1})	0.52	0.07	0.35	0.01
Alkalinity (mg L^{-1})	73.0	52.0	61.0	0.8
Total Suspended Solids (ppt)	85	18	39	3
Total hardness (mg L^{-1})	4.98	2.05	3.55	0.10

During the experimental period, the temperatures recorded varied in the range 27.58-29.83 ^{0}C in the various dietary treatments and the open pond water (Table 4.11). Both temporal and spatial fluctuations in temperature were observed in all the treatments. The highest maximum value (29.83 ^{0}C) was recorded in dietary treatment *A* whilst the least minimum value (27.58 ^{0}C) was observed in treatment *E*. There were no significant differences (ANOVA, $p > 0.05$) among the mean values of all the treatments.

The dissolved oxygen (DO) recorded in all the treatments and the open pond waters during the study varied in the range 1.15-3.30 mg L^{-1}. Both temporal and spatial

fluctuations in DO were observed in all the treatments. Both the highest maximum value (3.30 mg L^{-1}) and least minimum value (1.15 mg L^{-1}) were recorded in dietary treatment *A*. There were no significant differences (ANOVA, $p > 0.05$) among the mean values of all the treatments.

The recorded salinity in all the treatments and the open pond waters during the study were 0.03 and 0.04 ppt. Both the maximum value (0.04 ppt) and the minimum value (0.03 ppt) were the same in all the treatments during the study period. All the treatments and the open pond waters recorded the same mean value (0.04 ppt). The values of conductivity recorded in all the treatments and the open pond waters varied in the range 100-61 µS cm^{-1}. There were both temporal and spatial variations in conductivity values. The highest maximum value (100 µS cm^{-1}) occurred in the open pond waters whilst the least minimum value (61 µS cm^{-1}) was recorded in dietary treatment *E*. There were no significant differences (ANOVA, $p > 0.05$) among the mean values of all the treatments.

The pH-values in all the treatments and the open pond waters were similar. The values varied in the range 5.79-7.62. There were slight temporal and spatial variations, but there were no significant differences among them. Both the highest maximum pH-value (7.62) and least minimum value (5.79) were recorded in dietary treatment *A*. There were no significant differences (ANOVA, $p > 0.05$) among the mean values of all the treatments.

The phosphate values varied in the range 0.10-2.55 mg L^{-1}. There were both spatial and temporal variations in all the treatments and the open pond waters during the study period. The highest maximum value (2.55 mg L^{-1}) was recorded in dietary treatment *B*

and the least minimum value (0.10 mg L^{-1}) was in Coppens. Values recorded in dietary treatment *B* were significantly higher (Tukey's MRT, $p < 0.05$).

The nitrate values varied in the range 0.40-6.60 mg L^{-1}. There were both spatial and temporal variations in all the treatments and the open pond waters during the study period. The highest maximum nitrate value (6.60 mg L^{-1}) was recorded in Raanan dietary treatment and the least minimum value (0.40 mg L^{-1}) was observed in all the dietary treatments except in *E* and the open pond waters that recorded higher values (0.60 and 0.50 mg L^{-1} respectively). Values recorded in the open pond waters were significantly lower (ANOVA, $p > 0.05$).

The nitrite values recorded during this study varied in the range 0.001-0.113 mg L^{-1}. There were both spatial and temporal variations in all the treatments and the open pond waters during the study period. The highest maximum nitrite value (0.113 mg L^{-1}) was recorded in Raanan dietary treatment and the least minimum value (0.001 mg L^{-1}) was observed in all the dietary treatments except in *E* and the open pond waters that recorded 0.002 and 0.003 mg L^{-1} respectively. Values recorded in diet *A*, Coppens and Raanan dietary treatments were significantly higher (Tukey's MRT, $p < 0.05$).

The ammonia values varied in the range 0.07-0.52 mg L^{-1}. There were both spatial and temporal variations in all the treatments and the open pond waters during the study period. The highest maximum ammonia value (0.52 mg L^{-1}) was recorded in Coppens dietary treatment and the least minimum value (0.07 mg L^{-1}) was observed in dietary

treatment *E*. There was no significant variation between values recorded in the open pond waters and the various dietary treatments.

The alkalinity values varied in the range 52.0-73.0 mg L^{-1}. There were both spatial and temporal variations in all the treatments and the open pond waters during the study period. The highest maximum alkalinity value (73.0 mg L^{-1}) was recorded in Coppens dietary treatment and the least minimum value (52.0 mg L^{-1}) was observed in dietary treatment *E*. There was no significant variation between alkalinity values recorded in the open pond waters and the various dietary treatments.

The total suspended solids (TSS) values varied in the range 18-85 ppt. There were both spatial and temporal variations in all the treatments and the open pond waters during the study period. The highest maximum TSS value (85 ppt) was recorded in the open pond waters and the least minimum value (18 ppt) was observed in dietary treatment *E*. TSS values recorded in the open pond waters were significantly higher (Tukey's MRT, $p < 0.05$) than that of the various dietary treatments.

The total hardness (TH) values varied in the range 2.05-4.98 mg L^{-1}. There were both spatial and temporal variations in all the treatments and the open pond waters during the study period. The highest maximum TH value (4.98 mg L^{-1}) was recorded in Coppens dietary treatment and the least minimum value (2.05 mg L^{-1}) was observed in dietary treatment *E*. TH values recorded in dietary treatment A was significantly lower than the pond waters and the other dietary treatments.

4.15 Apparent Digestibility Coefficients of Nutrients in the Diets

The proximate compositions of the faecal samples of *O. niloticus* fed the farm-made and commercial diets are shown in Table 4.12 below. There was a general reduction in all the parameters except the Ash as compared to those of the diets.

Table 4.12 Proximate composition (%) of faecal samples of *Oreochromis niloticus* fed the various diets

Parameter	*A*	*B*	Coppens	Raanan	*E*
Dry matter	67.59	68.98	65.72	71.11	66.48
Crude protein	21.22	17.80	20.13	13.79	20.56
Crude lipid	2.12	2.33	2.64	2.51	2.95
Nitrogen free extract	27.62	32.47	28.63	40.38	27.46
Crude fibre	3.39	3.37	3.38	2.95	3.03
Ash	12.70	13.01	10.94	11.48	12.48
Gross energy	10.60	10.70	10.71	11.18	10.74
Phosphorus	0.76	0.76	1.24	1.09	1.37
Chromic oxide	1.41	1.14	1.84	1.19	1.08

The apparent digestibility coefficients (ADCs) of the nutrients and other components in the various diets fed to *O. niloticus* are shown in Table 4.13. There were significant differences (Tukey's MRT, $p < 0.05$) in the ADCs of all the parameters in all the dietary treatments. The ADCs of protein, lipid and phosphorus were similar for farm-made diets *A* and *B*. On the whole, the ADCs of all parameters for farm-made diet *A* were higher than those of *B*. The ADCs of lipid and phosphorus for the farm-made diets were higher than those of the commercial diets. The digestibility of protein was significantly higher in the commercial diets than in the farm-made diets. Digestibility of crude fibre in all the diets except in Coppens was higher than carbohydrate. Generally, ADCs of the nutrients were highest for Coppens followed by farm-made diet *A* whilst the least ADCs were observed in diet *E*. (i.e. a 1:1 mixture of farm-made diet *B* and Raanan). ADC of Ash was the least of ADCs of all the other parameters in all the dietary treatments.

Table 4.13 Apparent digestibility coefficients (%) of dry matter, crude protein, crude lipid, nitrogen free extract, crude fibre, ash, gross energy and phosphorus in the various diets fed to *Oreochromis niloticus*

Parameter	*A*	*B*	Coppens	Raanan	*E*
Dry matter	70.23 ± 0.47^{a}	64.20 ± 0.50^{b}	77.70 ± 0.50^{c}	64.53 ± 0.58^{b}	63.10 ± 0.66^{b}
Crude protein	79.79 ± 0.30^{a}	79.68 ± 0.28^{a}	87.02 ± 0.31^{b}	84.40 ± 0.30^{c}	77.49 ± 0.29^{d}
Crude lipid	93.90 ± 0.29^{a}	93.23 ± 0.41^{a}	91.52 ± 0.50^{a}	81.46 ± 0.13^{b}	89.09 ± 0.86^{a}
Nitrogen free extract	75.75 ± 0.03^{a}	65.44 ± 0.02^{b}	85.94 ± 0.02^{c}	65.28 ± 0.05^{b}	69.97 ± 0.04^{d}
Crude fibre	77.52 ± 0.01^{a}	72.80 ± 0.04^{b}	83.18 ± 0.06^{c}	73.37 ± 0.02^{b}	72.04 ± 0.04^{b}
Ash	56.94 ± 0.05^{a}	44.23 ± 0.06^{b}	52.70 ± 0.02^{c}	57.10 ± 0.02^{d}	42.40 ± 0.02^{e}
Gross energy	81.75 ± 0.42^{a}	78.78 ± 0.18^{b}	87.23 ± 0.37^{c}	75.80 ± 0.53^{d}	77.61 ± 0.27^{b}
Phosphorus	97.95 ± 0.03^{a}	97.86 ± 0.04^{a}	95.78 ± 0.17^{b}	95.49 ± 0.26^{b}	93.28 ± 0.16^{c}

Values within the same row with dissimilar letters are significantly different (Tukey's MRT, $p < 0.05$).

CHAPTER 5.0 DISCUSSION

5.1 Use of Fish Feed Ingredients

Both feed ingredients and supplements/additives were being used by small-scale pond fish farmers in all the regions (Ashanti, Brong Ahafo, Central, Volta and Western) surveyed to produce fish diets. Since Ghana is mainly an agro-based country, the ingredients surveyed in the present study were mainly agricultural crops and by-products and most were available in most parts of the country and throughout the year. Some of the ingredients used by fish farmers as fish feed or in fish diet production were cultivated by the farmers themselves as most of them practised integrated culture system.

Of the 32 ingredients and 5 feed supplements/additives surveyed, most of them were being utilized in at least three of the regions, whilst some were more localised. This was also reflected in the cost per kilogramme of the various ingredients, in that within regions where particular ingredients were localised, such ingredients were cheaper than regions where they were least available. This suggests that it would be cheaper to produce a kilogramme of fish diet in a region where the ingredients used are localised and less expensive than in others where such ingredients are not readily available and hence could be more expensive.

Availability and price are key determinants for an ingredient to be used. For availability, volume, time of availability, (e.g. is it available every day or week or is it only available during one season each year), source (e.g. is it available everywhere or only in a particular city or region) and accessibility (i.e. supply chain mechanism) are all important

determinants (Glencross *et al*, 2007). Ingredient pricing is obviously critical, and factors that drive price change have to be considered. Weather (especially droughts) affects supply and price of grains and other agricultural products as in the changing pattern for the demand of ingredients for other purposes.

In the present survey, the costs of fish meal were generally high in all the 5 regions. This is consistent with observations made by Munguti *et al*. (2012) that the costs of feed ingredients of animal origin were generally high and unlikely to be economically viable for semi-intensive culture of *O. niloticus* and *C. gariepinus* when their percentage inclusion in the diet formulations is over 25 %. Although most of the ingredients have a high potential for inclusion in fish diets due to their nutritional compositions and lack of competition as human food, they may still suffer the limitation of competition as such ingredients are utilized in poultry and livestock feed producing industries.

During the survey, ingredients such as bean (*Phaseolus vulgaris*) husks and leaves, dead poultry, brewery waste, cassava (*Manihot esculenta*) leaves, kitchen wastes and potato (*Solanum tuberosum*) leaves were sourced by fish farmers at no cost. These ingredients would attract cost and may become unaffordable when their demand and use in farm-made fish diets increase. The inter- and intra- regional differences in the unit costs of most of the ingredients used suggests that there will be remarkable differences in the cost of a kilogramme of farm-made fish diet production from region to region using the same ingredients. Hence, it will be more profitable to produce and use farm-made fish diets in some regions than others using the same ingredients. Therefore, ingredients used in farm-

made fish diets need to vary from region to region based on availability, cost and nutritional value. It also suggests that there should be variations in ingredients use within the same region.

5.2 Use of Commercial Fish Diets

In this study, Raanan was found in all the five regions surveyed. This could possibly be due to the fact that Raanan is the only major commercial fish diet currently being produced in commercial quantities in Ghana. During the present study, besides Raanan, only two main brands of commercial tilapia diets (Coppens and Biomar) were observed being used by small-scale pond fish farmers in the five selected regions for the study whilst over 16 different brands were recorded in the Eastern region particularly in the Asuogyaman District where intensive cage fish culture is commonly practised due to the presence of the Volta River. This could possibly due to the low demand of these complete diets which are designed particularly for intensive fish culture as against the semi-intensive culture being practised by the small-scale pond fish farmers in the five surveyed regions in the present study. *Artemia* was unique to Ashanti and Western Region where it was used to feed the post larval African catfish, *Clarias gariepinus*. Hence, *Artemia* was not being used by farmers who spawned tilapia only.

The higher cost of commercial diets with higher crude protein contents is due to the fact that protein is the most expensive component of fish diet (Borghesi *et al*., 2007; Lovell, 1989). Much of the costs of fish diet production are due to the extensive use of fish meal in the diet (De-Silva *et al*., 2011; Tacon and De-Silva, 1997; Tacon, 1995). Generally,

commercial fish diets tend to be very high in protein (Lovell, 1989). Diets for fry and fingerlings frequently exceed 50 % crude protein. As growth rate decreases and fish age, protein levels in diets are decreased accordingly. Protein levels on grow-out diets often approach or exceed 40 % crude protein, while maintenance diets may contain as little as 25-35 %. In addition to decreasing the protein content of the diet as fish grow, the particle size must increase. Commercial fish diets are manufactured as either extruded (floating or buoyant) or pressure-pelleted (sinking) feeds. Extruded feeds are more expensive due to the higher manufacturing costs (Lovell, 1989). Commercial fish diets are available in a variety of sizes ranging from fine crumbles for fry and fingerlings to large (6.00 mm) pellets.

The cost of any particular brand of the commercial diet was also influenced by location. The farther the location from the main retailers, the more expensive it was. This was due to additional cost added to the original price of the diet to cover transportation. Hence, farmers who were remote from the main retailers or dealers would spend more money on fish diets and feeding. This suggests that the production cost of such farmers would increase greatly. Fish feed has been projected to account for at least 60 % of the total cost of fish production (Gabriel *et al*., 2007).

5.3 Use of Fish Diets in the Five Regions

The highest usage of commercial fish diets was observed in the Western region whilst the least was in the Ashanti region. This was mostly due to the fact that most fish farmers in the Western region could easily afford the cost of the commercial ones as most of these

farmers were found to have other lucrative businesses aside from fish farming compared to farmers in the other regions. Besides, most farmers in the Western region lacked the technical know-how in the preparation of farm-made fish diets. Farmers who utilized commercial diets in the Western region were of the view that they could not prepare diets whose quality could be comparable with that of the commercial ones. Most of them also expressed lack of time as a reason for not producing their own fish diets. Some also attributed their inability to produce their own fish diets to unavailability of required equipment and the necessary feed ingredients. Hence, they must of necessity patronise the commercial diets. On the contrary, the least of fish farmers in the Ashanti region used commercial fish diets only whilst they were not solely used by any farmer in the Volta region.

The largest number of producers and users of farm-made fish diets was found in the Ashanti region. These farmers appeared to have a fair knowledge in fish diet preparation which most of them claimed they acquired through expert training and on the job experience. However, the diets were found not to be nutritionally balanced as the producers did not follow feed formulation protocol so as to produce balanced diets that meet the nutritional requirements of the target fish. The largest portion of farmers who used both the commercial and farm-made fish diets in their production was also observed in the Ashanti region. This practice was to reduce cost of fish production. Some of the farmers who used the two types of diets either fed them to the fish alternatively or fed them with each type at different stages of the culture period. Others also mixed the farm-made and the commercial diets in varying proportion to feed their fish. Those who used

the two types of diets at different stages of the culture period, used the expensive commercial ones as starter diet (i.e. feeding them to the fish at the fry/fingerling stage) and used the farm-made diets as the finisher (i.e. at the juvenile/grower stage till the fish are ready for harvest).

Some farmers used the farm-made diets throughout the culture period as they could not afford the commercial ones. This practice was very prevalent in the Ashanti region. As most times the diets were not nutritionally balanced, the fish could take longer period to reach the harvestable size. Most of the farm-made diets consisted of ingredients that were not combined in a specified proportion. Some were raw agricultural wastage that was directly fed to the cultured fish. This could impact on water quality negatively and affect fish growth. Evidently, many farmers producing farm-made diets are often unaware of the nutrient requirements of their farmed species, notably dietary protein and energy levels and how these change over the production cycle (White, 2013). Formulations are often based on past experience (what the farmers themselves have found to work), feed ingredient availability and cost, and advice from other farmers, feed ingredient suppliers and occasionally Fisheries Extension Officers.

The practice of extensive culture was highest in the Volta region. About 33.3 % of the respondents fed their fish with neither commercial nor farm-made diets at any given time. These farmers were observed to maintain large earthen ponds/reservoirs. However, they periodically put into the systems agricultural wastes particularly during the seasons of harvesting their crops or when some of their farm produce gets rotten.

5.4 Proximate Compositions of Ingredients Used in Diet Formulation and Preparation

Of the ingredients used in the present study, the analysed crude protein content of fishmeal (Tuna) was found to be higher than those of the ingredients of plant origin. The result is in agreement with other researchers who concluded that feed ingredients of plant origin often contain less protein than those of animal origin (Wu *et al*., 2006; Sullivan and Reigh, 1995; Wilson, 1991). Fishmeal had relatively high crude fibre (5.73 %). The fishmeal used in this study was produced from tuna wastes (fillet remains) obtained from processed and canned tuna. Most often such fish wastes consist of trimmings, belly flaps, heads, frames, fins, skins and viscera (Choudhury and Bublitz, 1996). The result is consistent with the findings of Munguti *et al*. (2012) who observed that the fibre contents of fillet remains of tilapia (*Oreochromis spp*) and those of North African catfish (*Clarias gariepinus*) were high and ranged from 6.7 to 7.3 % (Munguti *et al*., 2012).

Plant proteins are less expensive than animal sources; however, their deficiency in methionine and lysine limits their use as main protein sources in fish diets (Francis *et al*., 2001). Of all the plant protein feed ingredients, soybean meal is considered to be the most nutritious and is used as the major protein source in many fish diets to partially or totally replace fish meal (Lovell, 1988). It is a by-product after the removal of oil from Soya beans (*Glycine max*). The crude protein level depends on the soybean meal quality. Soybean has one of the best amino acid profiles of all vegetable oil meals (Agbo, 2008; New, 1987). The limiting amino acids in soyabean meal are lysine, methionine and threonine whilst arginine and phenylalanine are in good supply (Jauncey, 1998).

Antinutritional factors in soybean meal, including trypsin inhibitors (Arndt *et al*., 1999; Krogdahl *et al*., 1994), insoluble carbohydrates (Arnesen *et al*., 1990) saponins (Bureau *et al*., 1998), and proteins that cause an immune response (Rumsey *et al*., 1994) have been sighted as causes for this common effect.

The proximate compositions of white maize, soybean meal and wheat bran in the present study were in the same range as indicated by results of previous studies in Ghana (Nelson and Wallace, 1998). Crude fibre content of wheat bran was high and it is considered a limiting factor in its use in fish diet. Nutrient composition of feed ingredients depends on the origin, state and processing methods used (Lovell, 1998). From literature, it is indicated that agricultural by-products in general contain components which may affect their nutritive value. About 6.0 % of the total protein of soybeans reduces activities of trypsin and chymotrypsin, which are pancreatic enzymes and involved in protein digestion (Yen *et al*., 1977). The activity of trypsin inhibitor is not fully understood, but is responsible for the poor performance of certain fish species (Balogum and Ologhobo, 1989; Alexis *et al*., 1985). In case of cassava, a toxic component known as Linamarin has to be considered. Linamarin cause cyanide poisoning, but the toxicity may be removed by boiling and/or sun drying (Tewe, 1991).

5.5 Proximate Compositions of Farm-Made and Commercial Diets

A good fish diet should contain protein, lipids or fats, ash (minerals), fibre, moisture, nitrogen free extracts (carbohydrates) and vitamins in the right proportion and formulated in a balanced ration which will be acceptable, palatable and durable to the fish for its

optimum growth (Ayuba and Iorkohol, 2013). Protein is the main growth promoting factor in fish diet. Protein requirement of fish is influenced by factors such as fish size, water temperature, feeding rate, availability and quality of natural foods and overall digestible energy content of the diet (Ayuba and Iorkohol, 2013; Satch, 2000; Wilson, 2000). The values for chemical analyses of the farm-made and commercial diets were similar to the calculated/declared crude proteins. In all cases, the analysed values were higher. These findings were in disagreement with those values of analysed crude protein levels of four commercial diets (Adolf calyx, Coppens, Dizengoff and Durate) by Ayuba and Iorkohol (2013). These researchers observed that all the analysed values on crude protein were less than the producers' declared values. The values of the analyses ranged from 0.7 to 38.4 % less than they expected. On the other hand, similar analyses carried out by Opiyo *et al*. (2014) indicated that three commercial fish diets which were indicated to contain 26.0 % crude protein, proximate analyses showed that diets 1, 2 and 3 had crude protein levels of 32.7 %, 16.0 % and 28.0 % respectively. In the present study, the crude proteins of the farm-made and commercial diets ranged from 1.71 to 5.1 % greater than the expected with the greatest deviation occurring in farm-made diet *B*. However, all the analysed crude protein levels for both the farm-made and commercial diets were within the recommended range for juvenile and adult *O. niloticus* (El-Sayed, 2006; Lim and Webster, 2006; Fitzsimmons, 2005; Shiau, 2002; NRC, 1993). The differences between the analysed values and indicated values of crude protein in the diets could be an indication of lack of proper proximate analysis of ingredients before feed formulation and production (Opiyo *et al*., 2014). Variations in feed ingredients might occur due to regionalism and seasonality in availability of the ingredients (Munguti *et al*.

2012). For this reason, feed producers need to carry out routine proximate analyses particularly when a new batch of fish feed ingredients is procured.

Lipids are primarily included in formulated diets to maximize their protein sparing effect by being a source of energy (Hasan, 2001). Dietary lipids facilitate the absorption of fat soluble vitamins, play an important role in membrane structure and function, serve as precursors for steroid hormones and prostaglandins, and serve as metabolizable sources of essential fatty acids. The observed lipid levels of the two commercial diets, Raanan and Coppens were below the minimum recommended values of 10-15 % (El-Sayed, 2006; Lim and Webster, 2006; Fitzsimmons, 2005 and Shiau, 2002). However, Luquet (2000) also stated that dietary lipid levels of 5 to 6 % are often used in tilapia diet.

Fibre provides physical bulk to the diet. An appreciable amount of fibre in the diet permits better binding and moderates the passage of feed through the alimentary canal. However, De Silva and Anderson (1995) noted that it was not desirable to have fibre content above 8-12 % in diets for fish, since the increase in fibre content would consequently result in the decrease of the quality of usable nutrient in the diet. A high fibre and ash content reduces the digestibility of other ingredients in the diet resulting in poor growth of the fish. The analysed crude fibre contents of all the diets evaluated were within the dietary requirement for *O. niloticus*.

The percentage phosphorus contents of all the diets were within range for complete fish diets (Lovell, 1989). Although farm-made diet *E* was prepared by mixing equal portions

of farm-made diet *B* and Raanan, the values obtained for the chemical analyses of *E* were not equal to those of the mean of the two mixed diets. However, all the parameters were similar to those of the other diets.

5.6 Growth Performance of the Cultured *O. niloticus*

The growth performance and feed utilization efficiency of juvenile *O. niloticus* are affected by food quantity and quality, genetic make-up, sex of the fish and their interaction (Noor *et al*., 2010; Gjedrem, 1997). The initial body weights and body lengths of the experimental fish recorded at the commencement of the experiment were similar and were not significantly different (ANOVA, $p > 0.05$). Hence, the performance differences observed among treatments at the end of the growth trial was due mainly to dietary effect.

The results of the present study showed that all the experimental diets were accepted to varying degrees by the cultured fish. Hence, the constituents of both the farm-made and the commercial diets affected the palatability of the diets. The differences in the quality of the diets could be due to the composition and the processing technique employed in their production which might have enhanced the palatability and nutrient digestibility of the different diets to varying extent. The extrusion of the commercial diets during their production compared to the farm-made ones might have improved the performance of the former. Heat treatment involved in typical moist extrusion processing used for fish diet may be sufficient to inactivate most of the trypsin inhibitor activity in unheated soybean meal, and to increase digestibility of the protein in untoasted defatted soybean meal

(white flakes) to approximately the same level as found for soybean meal and fish meal (Romarheim *et al.*, 2005). The growth performance and feed efficiency of animals fed extruded diets is thought to improve. Different processing techniques can reduce anti-nutritional factors and thereby increase palatability (Workagegn *et al*., 2013; Azzaza *et al*., 2008).

Extrusion conditions might significantly affected final weight, feed efficiency, protein productive value and energy retention particularly of *O. niloticus* fed Raanan in this study. Similar results were reported for rainbow trout (Barrows *et al*., 2007), channel catfish (Peres *et al*., 2003) and carp (Viola *et al*., 1983). A beneficial effect of heating of soyabean meal on weight gain, feed intake and feed efficiency of channel catfish was observed (Peres *et al*., 2003). Growth rates of carp were reduced when fed diets containing under-heated soybean meal (Viola *et al*., 1983). The variations in growth performance and feed utilization efficiency in this study could also be attributed to differences in the quality of the various diets in terms of nutrient composition (Workagegn *et al*., 2014).

Even though Coppens had the highest crude protein content, this was not reflected in the growth performance and feed efficiency of the *O. niloticus* it was fed with. This could possibly be due to the fact that the diet lacked sufficient essential amino acids to support fish growth. This supports the observation made by Santiago and Lovell, (1988) that fish do not have a specific requirement for crude protein per se, but rather they need the right combination of essential amino acids. Essential amino acid requirements can be met by

the use of a balance of both plant and animal proteins, and if necessary, by the inclusion of synthetic amino acids in the complete diet (Jauncey *et al*., 1983). An indispensable amino acid deficiency may cause reduced growth and poor feed conversion (Halver and Hardy, 2002; Wilson and Halver, 1986). Therefore, satisfying the indispensable amino acid requirements of a species is outmost importance in preparing well-balanced diets. This observation suggests that *O. niloticus* performs better when fed a diet containing the complete requirements of amino acids for tilapia (Santiago *et al*., 1988).

The low ash content of Coppens could also be responsible for the poor growth performance of the fish it was fed with. In experimental diets, ash is a source of calcium and phosphorus (Abowei and Ekubo, 2011). Hence, essential mineral elements such as calcium and phosphorous that promote growth in fish were insufficient in Coppens. Ali and Jauncey (2004) noted a better growth performance of *C gariepinus* on diet containing 9.3 % ash content, whilst Alam *et al*. (2012) opined that ash content in the feed of *C. gariepinus* should not be less than 8.0 %. High ash content of > 12.0 has been reported to produce better growth performance in *Clarias* species (Corn Elio *et al*., 2014; Kiriratnikom and Kiriratnikom, 2012).

The results of the present study contradict that of other researchers in comparing Coppens with farm-made fish diets. Mustapha *et al*. (2014) observed that *C. gariepinus* gave significantly better growth performance when fed Coppens than when fed farm-made diet. Coppens has been reported to produce better growth performance in various species of fish when compared with local fish diets. These include the work of Shapawi *et al*.

(2011) who compared growth performance of humpback grouper *Cromileptis altivelis* fed farm-made diets and Coppens, and Ahmed *et al*. (2012) who showed that commercial fish diets enhanced better growth performance of the fingerlings of *Labeo rohita*. The comparable performance of the farm-made diets to Coppens in the current study could be attributed to the quality of the former.

5.7 Feed and Nutrient Efficiency of the Cultured *O. niloticus*

The most efficient feed conversion was observed in fish fed Raanan diet whilst the least occurred in fish fed farm-made diet *B*. Fish fed farm-made diet *B* (diet without supplements), showed higher feed conversion ratio (FCR), lower protein efficiency ratio (PER) and lower protein productive value (PPV %) (3.26, 1.27 and 20.44 % respectively) when compare with on-farm diet *A* (2.96, 1.37 and 24.89 respectively). These findings are comparable to those of various researchers who reported improved growth of fish with amino acid incorporation at similar inclusion levels of plant protein (Furuya *et al*., 2004; El-Saidy and Gaber, 2002; Mukhopadhyay and Ray, 2001; Polat, 1999).

The results of this study are also in agreement with that of Zhou *et al*. (2006). PER increased with increasing dietary level of methionine from 0.61 % to 1.05 % and decreased with further increase (1.68 %). Luo *et al*. (2005) from their study on methionine requirement of juvenile grouper, they observed the poorest FCR (2.38), the lowest PER (0.93) and low PPV % (16.3 %) in fish fed the diet containing least (0.55 %) methionine. These parameters improved proportionally with the methionine supplementation up to 1.34 % and showed no significant difference for fish fed the

dietary methionine level ranging from 1.34 % to 1.81 %. Significant improvement in PPV % was observed when level of methionine supplementation increased to 1.34 and 1.81 % to be 28.8 and 31.6 % respectively. Also, Mai *et al*. (2006) from their study on dietary methionine requirement of large yellow croaker, they found that the PER of fish were significantly improved by supplementation with methionine. Methionine deficiency resulted in reduced growth and feed efficiency, as well as in cataract of salmon (Cowey *et al*., 1992; Rumsey *et al*., 1983; Walton *et al*., 1982).

Supplementing crystalline amino acids in fish diets has had variable success (Agbo, 2008). Shiau *et al*. (1989) observed that male tilapia (*O. niloticus* x *O. aureus*) fed diets in which 100 % of the fish meal was replaced with soyabean meal (SBM), either with or without methionine supplementation had significantly lower weight gain, FCR and protein digestibility than in groups fed diets containing fish meal as the sole source of protein. Andrews and Page (1974) stated no improvement in growth of channel catfish when L-methionine was supplemented to a soybean meal based diet and also Teshima and Kanazawa (1988) did not observe improvement in fish growth when they supplemented SBM with the deficient essential amino acid, and therefore concluded that it was unnecessary. In the present study, there was no significant difference between fish fed diet supplemented with amino acids and the one that was not. Bai and Gatlin (1994) also reported that addition of supplemental L-lysine to a diet with 25 % crude protein from soy did not improve growth of channel catfish.

Studies in Israel have suggested that despite the essentiality of vitamins in dietary formulations, tilapia grown in ponds, cages or concrete tanks at densities as high as 100

fish m^{-2} and yield up to 20 tonnes/ha did not show any beneficial effects from the addition of dietary vitamin supplements (Viola, 1989). Many farmed fish species, including Indian major carps, are filter-feeders and derive much of vitamin and mineral requirements by consuming fine particulate matter (phytoplankton, zooplankton, bacteria and detritus) (Coleman and Edwards, 1987). These findings were in agreement with the present study as the addition of mineral and vitamin premixes did not increase growth performance and feed efficiency significantly.

The unexpected poor growth performance and feed efficiency observed in fish fed diet *E* (a 1:1 mixture of farm-made diet *B* and Raanan) could be due to the adulteration of the Raanan diet. Diet *B* was not supplemented with essential amino acids, it contained high level of antinutritional factors by virtue of the ingredients used in its preparation and besides, it was not processed by any means (particularly heating). Hence, the mixing of *B* with Raanan in a ratio of 1:1 diluted the latter to the extent that there was reduction in nutrient availability as confirmed by Azzaza *et al*., 2011; Aderibigbe *et al*., 1997; Hajos *et al*., 1995; Reddy and Pierson, 1995, who reported that diets with higher concentration of antinutritional factors reduces the availability of nutrients which in turn reduces the growth performance of fish. Also, Lim and Dominy (1991) reported that reduced growth response and feed utilization in various warm-water aquaculture species fed diets in which fish meal was replaced with oilseed meals have been explained by sub-optimal amino acid balance, inadequate levels of phosphorus, inadequate energy, low feed intake caused by poor palatability, presence of endogenous antinutrients or dietary level of fish oil (Lim and Dominy, 1991). The poor performance of diet *E* could be due to any of these

factors. Also, De Silva *et al.* (1989) observed that acceptability of feed by fish could be affected by increasing levels of plant material since the texture and taste of the diets are bound to differ.

In this study, the highest survival rate was achieved in fish fed Raanan and the least in Coppens. However, there were no significant differences among dietary treatments. Most of the mortality observed during the growth trials could not be due to dietary treatment as mortality was mostly experienced a day after measurements of fish growth. Hence, mortalities could be attributed to handling stress. This observation was in agreement with findings of Attipoe *et al*. (2009). These researchers reported a survival of 86.50 to 87.43 % in earthen ponds when Nile tilapia was fed with three different diets formulated from local agro-industrial by-products. They also attributed part of the mortality to predation particularly by predatory birds. In the current study, bird predation did not occur as the hapas used in culturing the fish were fully covered with nylon nets. Besides handling stress, another factor that contributed to mortality in this study was escape of fish from some of the replicates (hapas) as they were being taking out of the culture system to measure growth during the study period.

Although specific feeding trial durations are not universally specified, they generally need to last long enough for any potential significant differences among the diets to materialize (Weatherup and McCracken, 1999). In a study by De Francesco *et al*. (2004), differences in trout growth performance between fish meal and plant-based diets became apparent after 12 weeks. In the present study significant differences occurred after 16

weeks. In a study by Barnes *et al*. (2012) in which fish meal was replaced with high protein distillers dried grain (HPDDG) in juvenile rainbow trout diets, the experiment lasted over 10 weeks for significant differences to occur.

5.8 Length-Weight Relationship of the Cultured *O. niloticus*

The present work revealed that *O. niloticus* followed the cube law completely in all the dietary treatments except in Raanan where there was a positive departure by 0.1. Statistical analysis of the LWR of the current study showed that *O. niloticus* fed both the farm-made and commercial diets showed isometric growth. These results are comparable with the findings of other researchers who worked on other species of tilapia. Mgaya *et al*. (2005) recorded values of *b* in fresh water floodplain lakes in Ruwe ponds for *O. urolepis* ranged from 2.7-3.0. Haruna (2006) recorded a *b* value in *T. zillii* of 2.7 and 3.2 for wet and dry seasons respectively. The values obtained by these researchers are in agreement with the findings of this study. The values of *b* in this study were within the range of 2 - 4 recommended by (Bagenal and Tesch, 1978; Martin, 1949; Hile, 1936) as ideal for fresh water fishes and an ideal fish maintain the shape $b = 3$ (Golam and Al-Misned, 2013). Values of *b* above 3 are possible in some conditions such as stress free environments (Prasad and Anvar, 2007). The good water quality parameters recorded in all the dietary treatments coupled with food availability and feeding characteristics could account for the high b values obtained in the present study.

5.9 Condition Factor of the Cultured *O. niloticus*

In the present study, the *K* values of *O. niloticus* in all the dietary treatments were greater than 1. A condition factor higher than one suggests good fish health condition and indicates an isometric growth, which is desirable in a fish farm (Ayode, 2011). There may be differences in the condition factor due to sex (Olurin and Aderibigbe, 2006). This was not applicable to the results of the present study as all-male *O. niloticus* were utilized in all the dietary treatments. In this study the LWR was found to be in a linear form conforming to the general formula expressing the relationship between the length and weight of fishes. This could be attributed to the good water quality maintained and the quality of diets that contributed to the steady increase in their weight and length. The fish from all the treatments were in good condition and healthy. This suggests that all the fish diets used in this study will be suitable for commercial production of *O. niloticus*.

5.10 State of Health of the Cultured *O. niloticus*

Harvested fish from all dietary treatments at the end of the experiment were in good health condition with no physical deformities. No abnormalities occurred in the eyes, fins, gills, guts, kidneys, livers, pseudobranchs, opercles or spleens in any of the fish fed the various diets including farm-made diet *B* which was not supplemented with vitamin and mineral premixes, and essential amino acids. These results support the findings of other researchers who reported that vitamin supplementation is not necessary for optimum growth and health of tilapia in semi-intensive farming systems where natural foods are available (El-Sayed, 2006; Lim and Webster, 2006).

Vitamins are important nutrients in the supplementary diets of most fish species (Dabrowski and Blom, 1994). The absence or relative deficiency of vitamins in the diets leads to decrease fish appetite, metabolic activities and consequently to the onset of diseases (Abdelghany, 1998). Several vitamin requirements of tilapia are known to be affected by other dietary factors. For example, the vitamin E requirement is influenced by dietary lipid level with Nile tilapia requiring 50-100 mg/kg when fed diets with 5 percent lipid and increased to 500 mg/kg diet for diets with 10-15 percent lipid (Lim and Webster, 2006). Vitamin deficiency symptoms of tilapia under controlled culture conditions have been extensively reviewed by Jauncey (2000), El-Sayed (2006) and Lim and Webster (2006). Under culture conditions, vitamin deficiency signs are not a common occurrence in tilapia. In fact, several studies have reported on the "non-essentiality" of adding vitamin premixes to tilapia diets (Jauncey, 2000). Vitamins obtained from natural food in fertilized ponds, endogenous vitamins present in feed ingredients used in tilapia feeds and the microbial biosynthesis of some vitamins in the gut are all likely to contribute significantly to the vitamin requirements of tilapia.

Mineral deficiencies are difficult to assess in tilapia as most trace elements are obtained both from the dietary ingredients and from the culture water (Dabrowska *et al*., 1989). Besides, tilapia could absorb minerals from the culture water and there are also minerals in feed ingredients (Stickney, 1997). Deficiency signs of farmed tilapia may occur when fish are fed nutrient deficient diets or raised in a low nutrient-input culture system (Dabrowska *et al*., 1989). Since no deficiency signs were observed in any of the fish of

the various dietary treatments in the present study, it suggests that none of the diets was deficient in nutrient.

Also, histopathological examination of the intestines and liver did not reveal any morphological abnormality. Since the Nile tilapia fed the unsupplemented amino acid and vitamin-mineral premix diet did not show any disease condition, it suggests that the various ingredients used in the diet formulation, contributed significant amount of essential amino acids, vitamin and minerals to the prepared diet. A similar observation made by Agbo (2008) stated that a careful selection of different plant protein sources in various combinations could be a means of compensating for essential amino acid deficiency in any single protein source and also prevent a high inclusion level of any single antinutritional factor in the diet.

Absence of both external and internal abnormalities in *O. niloticus* in all the dietary treatments could also be attributed to the quality control measures that were applied to the diets during the current study, which prevented the diets from being infested with aflatoxin. Cha `vez-Sa `nchez *et al*. (1994) reported that *O. niloticus* fingerlings were able to tolerate the immediate effect of aflatoxin but later the fish developed external and internal abnormalities. Different external manifestations of abnormality in fish fed with aflatoxin contaminated feeds were eye opacity leading to cataract and blindness, lesions on the body surface, fin and tail rot, yellowing of the body surface of the fish, abnormal swimming, feeble and stationary on one place, and reduced appetite (Cha `vez-Sa `nchez *et al*. 1994). These manifestations became more intense as aflatoxin level in the feed

increased. Observed manifestations of aflatoxin in the liver of fish were abnormal enlargement and yellowing as well as collapsed liver in newly dead fish (Royes and Yanong, 2002; Wu, 1998; Ferguson, 1989; Roberts, 1978). Joner (2000) described the effect of aflatoxin in the liver as follows: first, aflatoxin is absorbed from the diet in the alimentary canal and is passed to different organs. The principal target organ for aflatoxins is the liver. After the invasion of aflatoxins into the liver, lipids infiltrate hepatocyte and leads to necrosis or liver cell death. The main reason for this is that aflatoxin metabolites react negatively with different cell proteins, which leads to inhibition of carbohydrate and lipid metabolism and protein synthesis. In relation with the decrease in liver function, there is a derangement of the blood clotting mechanism, jaundice, and a decrease in essential serum proteins synthesized by the liver.

5.11 Whole Body Composition of the Cultured *O. niloticus*

In this study, dietary treatments affected whole body composition. Among all the parameters, it was only moisture content that was not significantly affected by dietary treatment. Comparing the *O. niloticus* fed the farm-made diet supplemented with amino acids (diet *A*) and those fed diet *B*, the former had a higher final body crude protein and reduced fat content. This was in agreement with observation made by Cheng *et al*. (2003) that lysine supplementation in plant protein-based diets increased crude protein and reduced fat in fish body. Rodehutscord *et al*., (2000) found that the crude protein of trout body increased linearly with increased dietary lysine supplementation disregarding dietary crude protein levels and fat decreased linearly with increased lysine supplementation. Schwarz *et al*. (1998) in their study on carp (*Cyprinus carpio* L.) found

that whole body protein and lipid content were significantly affected by dietary methionine levels ($p < 0.01$), the whole body protein increased significantly from 14.7 % T-I to 16.3 % T-IV with increasing dietary methionine levels, whilst fat decreased from 13.9 to 11.5 % T-V with increasing dietary methionine levels, (Where T-I to T-V are treatments with ascending methionine levels 0.49, 0.61, 0.79, 1.08 and 1.34 %). Luo *et al*. (2005) from their study on methionine requirement of juvenile grouper, they observed that carcass protein content showed an increasing trend with increasing dietary methionine levels but moisture content decreased.

There was significant increase in crude protein content of the cultured fish in all the dietary treatments in comparison with that of the initial carcass composition of the experimental fish. Similar results were reported by El-Saidy and Gaber (2002) in Nile tilapia, Mukhopaddhyay and Ray (2001) in rohu and Polat (1999) in *T. zillii*.

Hepatosomatic index (HSI) is positively related to carbohydrate levels in the diet (Kim and Kaushik, 1992; Daniels and Robinson, 1986). Hence, it was not surprising that in this study, fish fed coppens had significantly higher HSI. It was also expected that fish fed farm-made diet *B* should have a high HSI since they had the least growth rate and lowest feed efficiency although they were not significantly different from the other treatments except for the feed efficiency, which was significantly lower than that of fish fed Raanan. Higher HSIs have also been associated with slower growth rates and decreased feed efficiency (Takeuchi and Watanabe, 1982) both of which describe the fish fed farm-made diet *B*. The findings of the current study are in agreement with that of Barnes *et al*.

(2012), who reported that there were no significant differences in HSI among treatments when diet containing different levels of Distillers Dried Grains with Solubles (DDGSs) were fed to juvenile rainbow trout (*Onchorynchus mykiss*). The hepatosomatic index either slightly decreased or showed no effect, from dietary DDGS in tilapia (*O. niloticus*) (Schaffer *et al*., 2010, 2009) and was also unaffected by dietary protein in common carp (*Cyprinuc carpo*) (Fine *et al*., 1996).

5.12 Effect of the Diets on Water Quality

All the diets had similar effect on the quality of hapa water and all recorded values were within the suitable ranges for *O. niloticus* (Swann, 2007, Hussain, 2004; Suresh, 2003; Popma and Masser, 1999; Stickney, 1979). The suitable water quality maintained in all the dietary treatments during the present study could be attributed to prevention of diet waste during the feeding process as appropriate pellet sizes that the fish could ingest were administered. Besides, the diets were free of fines avoiding poor ingestion by the fish as well as dispersion of the fines within the water column. These prevented the diets from sinking and accumulating at the bottom of the hapas to impact negatively on water quality. This observation is in accordance with the findings of Ofori (2001) who reported that the risk of water quality deterioration and an associated reduction in fish growth is ameliorated when the accumulation of organic matter is minimized.

5.13 Apparent Nutrient Digestibility of Diets

The general reduction in the nutrients of the faeces compared to that of both the farm-made and commercial diets fed to *O. niloticus* observed is in agreement with other

researchers (Jimoh *et al*., 2010; Adeparusi and Jimoh, 2002). This suggests that some amount of nutrients in all the diets were absorbed and made available for metabolism in the fish. Nutrient digestibility as well as its absorption and retention in the body determine growth performance and feed utilization efficiency in fish (Aanyu *et al*., 2014; Deganp and Yehuda, 1999; Guillaume and Choubert, 1999). The nutritive value of a diet depends not only on its nutrient content but also on the capacity of the animal to digest and absorb the nutrients (Rust, 2003; Cook *et al*., 2000). Nutrients absorbed in the digestive system are first used for maintenance of body functions and the surplus is retained in the body. Excess protein is deposited in the body for growth whilst excess energy is stored as fat (Cook *et al*., 2000; Jobling, 1994). In the present study, a higher crude protein deposition and lower fat content were observed in the carcass of fish fed farm-made diet *A* and Raanan. The results suggest that farm-made diet *A* and Raanan were the most efficiently assimilated. Deposition of protein in fish is known to result in fish growth. The higher the protein deposition, the higher the weight gain (Aanyu *et al*., 2014; Lupatsch *et al*., 2003; Sveier *et al*., 2000).

The variations in apparent digestibility coefficients (ADCs) of the various components in the diets used in this study could be explained by differences in the chemical compositions and processing of the diets. In general, the ADCs of all the parameters except ash in all the diets were high (above 60 %). This could primarily due to the relatively low fibre and ash contents of the diets. Furulehi and Yone (1982) observed that low levels of dietary fibre improved digestibility of nutrients through increased gut transit time and enzymatic activity. The digestibility of the commercial diets was further

enhanced by extrusion compared to the farm-made ones which were just pelleted. Mild extrusion cooking conditions can enhance digestibility of plant protein (Hakansson *et al*., 1987; Srihara and Alexander, 1984). As a result, extrusion normally improves nutrient digestibility, palatability, pellet durability, water stability and pellet storage life (Barrows and Hardy, 2001).

Protein quality of dietary protein sources depends on the amino acid composition and their digestibility (Halver and Hardy, 2002). Deficiency of essential amino acid leads to poor utilization of the dietary protein and consequently reduces growth and decreases feed efficiency. Therefore, this could explain why Coppens performed relatively poorly in terms of growth performance and feed efficiency, regardless of its high apparent protein digestibility in the present study. The digestion coefficients for protein-rich feedstuffs are usually in the range of 75 to 95 % (NRC, 1983). The apparent digestibility of protein (77.49 % - 87.02 %) of both the farm-made and commercial diets in this study is within this range. Apparent protein digestibility tends to be depressed as the concentration of dietary carbohydrate increases (NRC, 1993). This was not observed in this study and the findings were in agreement with that of Agbo (2008). The higher apparent digestibility of protein in the fish fed the extruded diets (Coppens and Raanan) compare with those fed the un-extruded ones (farm-made diets) are in agreement with the findings of Ma *et al*. (2015).

The higher crude fibre digestibility coefficient than that of crude carbohydrate observed in this study could be due to the natural feeding habit of tilapia that consists mainly of

plant material (Pullin, 1983). *O. aureus* was observed to digest highly fibrous feedstuffs such as alfalfa meal (Mgbenka and Lovell, 1987). Crack and cook processing method improved the digestibility of crude fibre (Jimoh *et al*., 2010; Adeparusi and Jimoh, 2002). Fibre digestibility of *O. niloticus* fed lima bean diet was improved with toasting and autoclaving (Adeparusi and Jimoh, 2002). Hence, it was expected in the current study that Raanan like Coppens should have yielded higher crude fibre ADC than what was observed. This might probably be due to the higher ash content of Raanan (Table 4.4). The same reason could explain why the apparent dry matter digestibility coefficient of Raanan was significantly lower than that of Coppens although both diets were extruded. High ash content of diet is known to decrease dry matter ADCs (Bureau *et al*., 1999). The comparatively low ADCs of ash recorded in all the dietary treatments could be due to the fact that fish do not need high quantity of minerals from their diets (Adeparusi and Komolafe, 2006).

Lipid digestibility in all the dietary treatments was high (81.46 % - 93.90 %) and the values were found to be in line with what were reported by Jimoh *et al*. (2010) for *O. niloticus* and Hossain *et al*. (1992) for rainbow trout. Andrew *et al*. (1978) reported that the ability to digest fat appears to be influenced by temperature and the level of fat in the diet. The high lipid digestibility by *O. niloticus* in the farm-made diets shows that the palm oil used in the formulation and production of the diets was well utilized. This is a good phenomenon since lipid can also have a sparing effect on protein. It also suggests that plant oil which is cheaper could be a better alternative to animal oil in tilapia diet.

The high apparent carbohydrate digestibility coefficients (65.44 % - 85.94 %) recorded in this study were in agreement with the observation of Popma (1982) that warm water fish like *O. niloticus* absorbs 60 % or more of raw corn starch . The result however deviated from the low carbohydrate digestibility recorded by Jimoh *et al*. (2010) as well as Adeparusi and Jimoh (2002) for *O. niloticus* fed lima bean diets. The digestibility of carbohydrates has been shown to vary with their complexity, source, treatment and level of inclusion in the diet (Jimoh *et al*., 2010; Cho and Slinger, 1979; Lovell, 1977; Phillip, 1972). The result of the present study agrees with the observation of Lovell (1988) that tilapia have ability to digest carbohydrate relatively well in feedstuff but not as well as fat or protein. In this study, the ADCs of fat and protein for all the dietary treatments were higher than their corresponding values for carbohydrate. Digestibility of carbohydrate was high in *O. niloticus* fed farm-made diet *A*, although highest in Coppens. This would lead to maximum utilization of available protein as a result of protein sparing-action of carbohydrate. This could probably explain why the final carcass protein deposition of *O. niloticus* fed farm-made diet *A* was significantly high.

The apparent digestibility coefficients of gross energy recorded in this study except in Raanan were higher than the values observed by Jimoh *et al*. (2010) and Fagbenro (1998) of jackbean meal diets fed to *O. niloticus*. Lovell and Durve (1982) observed that cooking improved gross energy digestibility. However, this was not shown in the Raanan diet, as the non-heat treated farm-made diets recorded higher values than the former. The least digestibility of energy in Raanan in this study could be due to the low energy content of the diet as indicated by analysis. The extrusion of the commercial diets was expected to

improve their digestibility compare to the farm-made ones which were not heat-processed in any form.

The apparent digestibility coefficients of dry matter, carbohydrate, fibre, ash and gross energy of farm-made diet *A* were higher than those of farm-made diet *B*. This could possibly due to the inclusion of lysine and methionine in diet *A*.

5.14 Cost Effectiveness of Diets

The cost-effectiveness analyses of the various diets in this study indicated that the farm-made diets were more profitable than the commercial ones, and the amino acid supplemented diet was the most profitable whilst Coppens was the least profitable. These findings are consistent with other studies which indicated that nutritionally balanced farm-made fish diets were cost-effective in the production of *O. niloticus* in semi-intensive fertilized ponds (Opiyo *et al*., 2014; Gabriel *et al*., 2007; Liti *et al*., 2005). However, the results of the present study are in disagreement with that of Nguyen (2013) who observed that although using farm-made diets appears to be the cheaper option, and switching to them reduces production costs, they are less efficient in terms of growth and FCR; thus, in terms of real production costs (cost/kg fish produced), they are more expensive to use. His study demonstrated that the total cost of production using farm-made diets was US$0.88/kg fish, whereas it was US$0.79/kg fish for farmers using commercially manufactured diets or a combination of commercially manufactured and farm-made diets (Nguyen, 2013). The findings of the current study also contradict that of

this researcher, who reported that although reverting to farm-made diets may reduce diet costs, farmers need to recognize that there will be a concomitant reduction in profits.

In the present study, even though the Raanan was highest in extrapolated fish yield (7, 920 kg ha^{-1} yr^{-1}) it was 26.26 % less profitable than farm-made diet *A* (5, 407.99 kg ha^{-1} yr^{-1}) and 23.23 % less profitable than farm-made diet *B* which gave the least yield (4, 856.00 kg ha^{-1} yr^{-1}). Diet *A* was 135.85 % more profitable than Coppens (5, 096 kg ha^{-1} yr^{-1}) and diet *B* was 130.19 % more profitable than Coppens. The least profit of Coppens was likely due to the high cost of the diet without commensurate increase in yields when compared to Raanan. It was more profitable to feed Nile tilapia with either the supplemented or unsupplemented amino acid or vitamin/mineral premixes diet than an equal mixture of the unsupplemented diet and Raanan. In this study, there were no significant differences between the growth rate and feed efficiency of the farm-made diets and the Coppens which was the most expensive diet among all. Hence, the use of the two types of diets to raise a fish to market size of 200 g by Ghanaian standards (Agbo, 2008) may last over the same culture period. This suggests that using the farm-made diets will reduce the production cost of Nile tilapia and consequently increase the profit margin of the fish farmer. This will immensely benefit the small and medium scale semi-intensive farmers who constitute the majority of fish farmers in Ghana.

CHAPTER 6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The results of this study showed that in all, 32 feed ingredients and 5 feed supplements/additives were being used by small-scale pond fish farmers in Ashanti, Brong-Ahafo, Central, Volta and Western Region to produce farm-made fish diets. Some of these ingredients were being used in all the regions surveyed whilst others are peculiar to one or two regions. There were both inter- and intra- regional differences in the price per kilogramme of almost all the ingredients. Ingredients such as Bean (*Phaseolus vulgaris*) husks, Bean (*Phaseolus vulgaris*) leaves, Birds (dead poultry), Brewery waste, Cassava (*Manihot esculenta*) leaves, Kitchen wastes and Potato (*Solanum tuberosum*) leaves were being sourced at no cost.

The largest usage of farm-made fish diets was found in the Ashanti Region. However, the diets were found not to be nutritionally balanced as the producers did not follow standard feed formulation protocol so as to produce balanced diets that meet the nutritional requirements of the target fish. Of the 138 farmers using fish diets in all the regions surveyed, 37.7 % used commercial diets, 26.8 % used farm-made diets whilst 35.5 % used both.

Only 3 major commercial fish diets (Raanan, Coppens and Biomar) out of about 16 commercial fish diets (Agricare, Alleraqua, Aquafeed, Aquaxcel, Beacon Hill, Bioaqua, Biomar, Coppens, Multi Feed, Nicoluzzi, Pirá, Proaqua, Raanan, Skretting, Tilalia and Zeigler) currently available in the country were being used in the five regions (Ashanti,

Brong-Ahafo, Central, Volta and Western) surveyed. Raanan was most used and it constituted about 86.2 % of all used commercial diets. Biomar was least used (about 2.0 %). The price per kilogramme of the commercial fish diets was influenced by brand, crude protein content and location. Those with higher crude proteins were more expensive although of the same brand. The highest usage of commercial fish diets was observed in the Western Region whilst the least was in the Ashanti Region.

The largest (48.2 %) portion of farmers in Ashanti used both commercial and farm-made fish diets in their production. Some of the farmers who used the two types either fed them to the fish alternatively or fed them at different stages of the culture period. They used the expensive commercial ones as starter diet (i.e. feeding them to the fish at the fingerling stage) and used the farm-made diets as the finisher (i.e. at the juvenile till the fish are ready for harvesting). Some farmers for un-affordability of the commercial fish diets used the farm-made diets throughout the culture period. This practice was very prevalent in the Ashanti. Most of the farm-made diets consisted of ingredients that were not combined in a specified proportion to produce diets. Some were raw agricultural wastage that was directly fed to the cultured fish. The practice of extensive culture system was highest in the Volta. About 33.3 % of the respondents in the region fed their fish with neither commercial nor farm-made diets at any given time. These farmers were observed to maintain large earthen ponds/reservoirs.

The proximate compositions analyses of the two most commonly used commercial fish diets in the present study together with results from other researchers revealed that not all

commercial fish diets available on the Ghanaian market are good enough to enhance good growth of *O. niloticus* as the chemical analyses of the nutritional compositions indicated that some of the parameters were different from what the producers declared on the labels of their feed bags.

The costs associated with the use of commercial fish diets by small-scale pond fish farmers are high, and in terms of fish growth and economic returns, the use of appropriately prepared farm-made diets will be a better alternative. The most obvious observation was the relatively poor performance of Coppens although it was the most expensive. Therefore, cost of commercial fish diets cannot necessarily be translated into good quality. The farm-made diet *A* which was supplemented with amino acids, vitamin/mineral premixes has the best prospects based on growth performance, nutrient utilization and economic benefits. Amino acids unsupplemented farm-made diets could be used to produce acceptable fish growth and feed conversion ratios of Nile tilapia in semi-intensive production systems, where autotrophic and heterotrophic food material may supply the deficient amino acids. Simple heat processing of the unsupplemented diet (*B*) under field conditions as suggested by Agbo (2008) will improve on the performance of the diet and thereby reducing the cost of fish diet production since the additional cost of including supplements will be eliminated.

The highest (165.0 g) weight gain was observed in the fish fed Raanan whilst the least (107.8 g) occurred in fish fed farm-made diet *B*. There was no significant difference in specific growth rate among all dietary treatments. The feed conversion ratio (FCR)

ranged from 2.92 to 3.26, with Raanan recording the least and farm-made diet *B* the highest. There were no significant differences in feed intake and protein efficiency ratio among treatments. Energy retention ranged from 8.32 to 15.32 % with fish fed Raanan being significantly higher and those fed Coppens being significantly lower. The crude protein of whole body proximate analyses of the harvested fish from the dietary treatments ranged from 16.20 to 18.46 % and analyses indicated that fish fed farm-made diet *A* was significantly (ANOVA, $p < 0.05$) higher whilst there was no significant difference between fish fed farm-made diets *B* and *E*. The fat contents of the treatments ranged from 3.04 to 4.20 % with diet *B* and Coppens being significantly higher. The gross energy of all the dietary treatments was similar and they ranged between 5.47 to 5.95 kJ g^{-1}.

The apparent digestibility coefficients of the nutrients in both the farm-made and commercial diets in this study were high (> 60.0 %). Digestibility was found to be affected by the chemical composition of the diets and their treatments. Digestibility of nutrients was relatively lower in diets with relatively high ash content. Digestibility of nutrients in the farm-made diet supplemented with amino acids was higher than the unsupplemented diet. Digestibility of protein was highest in the commercial diets due to the extrusion of the diets since extrusion or heat processing in general is known to increase digestibility of nutrients. Among the nutrients, the apparent digestibility coefficients of lipid were found to be the highest in all the treatments whilst carbohydrate was found to be the least.

In the present study, even though the farm-made diet *B* had the least yield of 4, 856.00 kg ha^{-1} yr^{-1}, it was about double the productivity of 2, 500 kg ha^{-1} yr^{-1} by Ghanaian small-scale fish farmers (Awity, 2005). This was against the background that the current study was carried out in hapas with a stocking density of 2 fish m^{-2}. Hence, under semi-intensive culture systems commonly practised in earthen ponds in Ghana where fish stocking could be up to 4 fish m^{-2}, the performance of diet *B* could be up to about four times the current production levels of small-scale pond fish farmers in the country. Further, farmers could increase yield and their profit margin by combining feeding with fertilizing.

The use of the farm-made and commercial diets to feed *O. niloticus* did not result in any disease condition in the present study. All the external and internal organs and structures observed in the harvested fish were without any abnormality and the fish were in good health and condition. Hence, all the diets used in the present study will be suitable for commercial production of *O. niloticus*. The diets did not have any negative impact on water quality. All the measured water quality parameters monitored during the study were found to be within acceptable range for tilapia.

The results of the present study have revealed that selection of appropriate ingredients to formulate and prepare nutritionally balanced farm-made fish diets is cost effective and will boost growth of aquaculture in rural areas where semi-intensive aquaculture is mainly practised in Ghana. In the current study, the production cost of a kilogramme of the two farm-made fish diets were 1.93 and GHS 2.07 whilst a kilogramme of the two

commercial ones were 3.25 and GHS 5.00. In this study, the use of farm-made diets in tilapia production was between 23.23 to 135.85 % more profitable than the use of commercial diets. The least growth performance of fish fed commercial diet over those fed farm-made diet was 5.92 % whilst the highest was 33.71 %. The findings are also in agreement with other studies which indicated that local production of fish diets is very critical to the development and sustainability of aquaculture in sub-Saharan Africa.

It was more profitable to feed Nile tilapia with farm-made diets not supplemented with amino acid and vitamin/mineral premixes than mixing an equal amount of it with Raanan. In the present study, the use of the unsupplemented diet gave a higher profit index (1.22) than (1.01) when it was mixed with Raanan in a ratio of 1:1. Hence, farmers will make a higher profit and cut back on production cost when they use appropriately prepared farm-made diets than mixing a prepared diet with a commercial one as it was observed during the regional survey.

6.2 Recommendations for Research and Policy

The following recommendations are being made based on the findings of the present study:

6.2.1 Research

1. A nationwide survey should be conducted to cover all the 10 Regions in the country to identify potential fish feed ingredients apart from what are being used currently. This should be based on their availability, price and nutritional value.

2. Other alternatives of animal origin with high crude protein levels and relatively low cost such as blood, meat and bone meal, offal and other slaughter wastes as well as bran of various feed ingredients which are not consumed by humans must be given serious consideration.

3. Further research into the possibility for including different kinds of locally available feed ingredients preferably those unsuitable for direct human consumption so as to meet the growing demand of fish diets for aquaculture expansion in the country.

4. Future studies should investigate the nutrient compositions of all commercial fish diets available on the Ghanaian market and compare the values with those declared by the manufacturers.

5. In the present study, growth trials of the experimental fish were carried out in hapas as against the semi-intensive system commonly practised in earthen ponds by small-scale fish farmers in Ghana. Hence, similar study should be carried out under field conditions in earthen ponds. Under the pond condition the stocking density could be increased to 4 fish m^{-2} as against 2 fish m^{-2} that was used in this study.

6. The growth performance of Nile tilapia should be evaluated when fed with the farm-made fish diets in fertilized earthen ponds as well as unfertilized earthen ponds.

7. The growth performance of Nile tilapia should also be evaluated when fed with the farm-made and the commercial fish diets used in the current study to culture fish in fish cages.

8. The farm-made fish diets, particularly the one which was not supplemented with essential amino acids and vitamin/mineral premix should be processed by heating before being fed to Nile tilapia. The diets may also be extruded if possible so as to assess their performance.

6.2.2 Policy

1. As the costs of most of the ingredients used in farm-made fish diets were cheaper during the rainy season, farmers should acquire such ingredients in bulk when they are in season. Hence, there is an urgent need to improve the storage methods employed by feed ingredient dealers, diet manufacturers and farmers so as to preserve the nutrient quality and content of ingredients prior to usage and fish diets prior to feeding.

2. Fish farmers should cultivate some of the needed ingredients so as to reduce the cost of farm-made fish diet production.

3. For fish farmers to produce good quality farm-made fish diets, there should be regular training of fish farmers on how to formulate and produce nutritionally balanced high quality fish diets.

4. To increase aquaculture production and make it more attractive to prospective fish farmers, the government must assist fish farmers by subsidizing the cost of locally fabricated feed manufacturing machines (particularly extruding and pelleting machines) so as to make it affordable to fish farmers.

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APPENDIX I

INFORMED CONSENT FORM

STUDY TITLE: Evaluation of Farm-Made and Commonly Used Commercial Fish Diets by Small Scale Pond Fish Farmers in Five Selected Regions of Ghana, for Nile Tilapia (*Oreochromis niloticus* L.)

INVESTIGATOR: Francis Assogba Anani

ADDRESS: CSIR-Water Research Institute, ARDEC, Akosombo. P.O. Box AB 139 Akosombo.

PURPOSE: The survey is to gather information on types of commercial fish feeds used by small-scale pond fish farmers in Ghana and fish feed ingredients they use in compounding on-farm fish feeds.

DESCRIPTION OF PROCEDURE: If you are willing to participate in this survey, you will be asked to provide information on your age, level of education, marital status, average monthly income, culture practice, feed and feeding, productivity, production constraints and socioeconomic benefits including food security. You don't need to provide your name.

ELIGIBILITY: To qualify for participation, you must be a small-scale (i.e. production level of 10 to below 50 metric tons per annum) pond fish farmer.

INCONVENIENCE: You will spend some time to complete the questionnaire. You are not compelled to answer the entire questionnaire or to complete the interview.

BENEFITS: The results of the survey will be used to produce cost-effective diets that will cut back the production cost of cultured fish and increase profit margin of small-scale fish farmers in the country.

CONFIDENTIALITY: Any information you will provide will be kept strictly confidential. Your consent form will be kept separate from the data. The data will not be available to any other than the researcher. The information may be used in presentations and/or research paper. However, your name will never be used in any case.

VOLUNTARY PARTICIPATION: participation in this survey is optional. You will not be penalized in any way if you opt out.

QUESTIONS: All your questions about the study are always welcome. For further information concerning your participation in this survey, you can contact the principal supervisor: Prof. Francis K. E. Nunoo on 0242 981 547 or the principal investigator, Francis A. Anani on 0242 139 634.

VOLUNTEER'S AGREEMENT: The above document describing the importance of the study on the commercial fish feeds used by small-scale pond fish farmers in Ghana and the feed ingredients they used in compounding on-farm fish feeds has been read and explained to me. I have been given the opportunity to ask any questions concerning my participation in the survey and answers have been given to my satisfaction. I agree to participate as a volunteer.

……. ……

DATE **SIGNATURE/MARK OF VOLUNTEER**

IF ANY VOLUNTEER CANNOT READ THE FORM, A WITNESS MUST SIGN HERE:

I was present when the importance of the survey was read to the volunteer. All questions were answered and the volunteer agreed to take part in the study.

……. ……

DATE **SIGNATURE OF WITNESS**

I certify that the nature and purpose of the potential benefits and the inconvenience associated with participating in this survey has been explained to the above individual.

……. …….....

DATE **SIGNATURE OF PERSON WHO OBTAINED CONSENT**

APPENDIX II

Fish Feeds and Feed Ingredients Survey

Department of Marine and Fisheries Sciences, UG, Legon

The purposes of this survey are to gather the following information:

1. Types of commercial fish feeds used by small-scale pond fish farmers in Ghana;
2. Fish feed ingredients used by small-scale pond fish farmers in compounding on-farm fish feeds in Ghana.

The results of the survey will be used to produce cost-effective diets that will cut back the production cost of cultured fish and increase profit margin of small-scale fish farmers in the country.

Please, take some time to complete this questionnaire.

Questionnaire Identification Code ( )

Date……

I. LOCATION

1. Region: ……

2. District: ……

3. Name of Village/Locality: ……

II. BIO-DATA

4. Gender:……

5. Age:……

6. Educational level:……...

III. LIVELIHOOD/HOUSEHOLD

7. Are you married? Yes ☐ No ☐

8. How many spouses do you have? ……

9. How many children do you have? ……...

10. Do you have any other occupation(s) aside from fish farming? Yes ☐ No ☐

11. If Yes, state it/them……..

12. Does your household have the following? (*Tick appropriate boxes*)

i. Electricity ☐ ii. Fixed phone (line) ☐ iii. Television ☐

iv. Fridge ☐ v. Radio ☐ vi. Computer ☐

vii. Internet connection (of any sort) ☐ viii. Mobile phone ☐

13. What is your average monthly income?.....

IV. CULTURE PRACTICE

14. Which of these culture practices do you engage in? (*Tick the appropriate box*)

i. Extensive ☐ ii. Intensive ☐ iii. Semi-intensive ☐

15. Do you use fertilizer in your ponds? Yes ☐ No ☐

16. If Yes, why?.....

17. If Yes, what type? ……...

18. If No, why?.....

19. Do you feed your fish every day? Yes ☐ No ☐

20. If No, which days you don't feed them and why? ….....

21. How many times do you feed your fish in a day? ……..

22. What quantity of feed do you give the fish per day?.....

23. How do you determine this?.....

V. PRODUCTIVITY

24. What type(s) of fish do you culture? …….

25. Why do you culture this/those type(s) of fish? ……..

26. How many ponds do you have?.....

27. What are the sizes of your smallest and largest ponds and the number and type of fish you put in each

Type of pond	Size	Types of fish	No. of fish
Smallest			
Largest			

28. Where do you obtain your fingerlings from? ……..

29. If you produce your own fingerlings, where do you obtain your brood stocks (parent fish) from?.....

30. Is/Are your source(s) of fingerling supply reliable? Yes ☐ No ☐

31. If No, why?.....

32. What average size (g) of fingerlings do you stock?.....

33. At what size (g) do you harvest the stocked fish?.....

34. Why do you harvest the fish at that size? ……

35. How long does it take for the stocked fish to reach the size at harvest? ……

36. What is your average annual production level in metric tons?.....

VI. PRODUCTION CONSTRAINTS

37. What are the challenges (difficulties) you are facing as a pond fish farmers?

i. …….. ii. ……

iii……. Iii……

38. Do you think you have sufficient knowledge in fish farming? Yes ☐ No ☐

39. If Yes, how did you acquire the knowledge? (*Tick the appropriate box*)

Apprenticeship ☐ Expert training ☐

On the job experience ☐ Formal education/training ☐

VII. FISH FEEDS

40. Do you use commercial or on-farm produced fish feeds or both? ……

If you only produce your own feeds, skip to 48

41. If you use commercial feed(s) then provide the following:

	Brand name	Price (GH¢)/CP (%)	Wt. (kg) per bag
i.			
ii.			
iii.			
iv.			
v.			

42. Why do you use this/these brand(s) of feed(s)?.....

43. State the crude protein (CP) levels of the commercial feeds you use and the categories of fish you feed these with:

	CP of Feed Used	Category of Fish Fed (i.e. fry, fingerlings, Juveniles, table-sized, brood stocks)
i.		
ii.		
iii.		
iv.		

44. Which of these factors do you consider when buying commercial fish feeds?

(*Tick appropriate boxes*) i. Ingredients used ☐

ii. Cost ☐ iii. Expiry date ☐

iv. Others (specify)…….…….. ……

45. Why do you use commercial feeds instead of producing your own fish feeds?

(*Tick appropriate boxes*) i. You do not know how ☐

ii. Lack of machinery/equipment ☐ iii. Non-availability of necessary ingredients ☐

iv. Others (specify)…….…….. ……

46. Do you wish to produce your own fish feeds in the future? Yes ☐ No ☐

47. If No, why? …….

Skip to 66

48. Why do you produce your own feed?.....

49. Have you had any training in fish feed formulation and production? Yes ☐ No ☐

50. If Yes, where did you have the training? (*Tick the appropriate box*)

Apprenticeship ☐ Expert training ☐

On the job experience ☐ Formal education/training ☐

51. Which ingredients do you use to produce your feed?

i…….. ii ……

iii…… iv……

v…… . vi.....

52. Where do you obtain your ingredients from and how much does a bag of each go for?

	Ingredient	**Source**	**Price per bag (GH¢)**	**Net Weight (kg)**
i.				
ii.				
iii.				
iv.				
v.				
vi.				

53. Do you have any knowledge on anti-nutritional factors (ANFs) in feed ingredients?

Yes ☐ No ☐

54. Do you use any additives/attractants in your feeds? Yes ☐ No ☐

55. If Yes, why?.....

56. If Yes, name them:

i…….. ii……

iii……. iv……...

57. What are the crude protein (CP) levels of feeds you produce and the corresponding categories of fish you feed each type with?

	CP of Feed Used	Category of Fish Fed (i.e. fry, fingerlings, Juveniles, table-sized, brood stock)
i.		
ii.		
iii.		
iv.		
v.		

58. What are the factor(s) that influence your choice of ingredients used in feed production?

(*Tick as many boxes as appropriate*)

i. Affordability ☐ ii. Availability ☐ iii. Cost ☐

iv. Nutrient composition ☐ v. Seasonality ☐

vi. Others (Specify)……

59. Do you Process your ingredient(s) in any way before usage? Yes ☐ No ☐

60. If Yes, by what means? (*Tick as many boxes as appropriate*)

i. Boiling ☐ ii. Roasting ☐ iii. Steaming ☐ iv. Milling ☐

v. Others? (Specify) ……

61. Do you run any chemical analysis on the ingredients used? Yes ☐ No ☐

62. Name the equipment/tools you use in producing the feed(s)

	Equipment/Tool	What it's used for
i.		
ii.		
iii.		
iv.		
v.		

63. How do you store the feed you produce? ……

64. Do the fish eat the feed you produce easily?.....

65. Do your fish perform well on the feed you give them?

Yes ☐ No ☐

66. Are you available to be contacted for further information to advance the purposes of this study? Yes ☐ No ☐

67. If Yes, kindly provide the following:

i. Name:……

ii. Phone Number:……...

iii. E-mail:……

68. COMMENTS:……..

……

……

……

……

……

THANK YOU FOR YOUR TIME AND COOPERATION

Francis A. Anani

Researcher

APPENDIX III

Mean living weight (±SD) for each treatment during growth trials

Week	Diet A (g)	Diet B (g)	Coppens (g)	Raanan (g)	Diet E (g)
Initial	23.0 ± 2.0	23.2 ± 1.9	22.7 ± 1.9	22.6 ± 2.3	22.5 ± 2.2
Second	33.1 ± 3.8	33.0 ± 4.4	32.7 ± 3.9	32.3 ± 3.2	31.9 ± 4.0
Fourth	48.1 ± 6.0	48.9 ± 7.0	46.1 ± 7.0	46.6 ± 5.2	46.4 ± 6.2
Sixth	56.7 ± 7.6	59.0 ± 9.1	54.6 ± 8.9	55.7 ± 6.4	55.8 ± 8.0
Eighth	64.5 ± 9.1	66.3 ± 11.6	68.5 ± 13.8	67.1 ± 9.9	63.7 ± 11.1
Tenth	77.7 ± 11.6	80.1 ± 14.8	87.1 ± 17.1	87.6 ± 14.0	78.8 ± 13.9
Twelfth	94.1 ± 14.6	95.9 ± 17.0	107.9 ± 18.8	114.0 ± 19.2	97.8 ± 17.0
Fourteenth	106.8 ± 15.3	106.3 ± 18.7	120.0 ± 20.0	138.1 ± 25.3	110.1 ± 19.2
Sixteenth	115.7 ± 16.7	114.8 ± 20.17	128.9 ± 20.9	157.7 ± 29.8	121.3 ± 21.7
Eighteenth	129.1 ± 19.2	125.2 ± 21.8	139.8 ± 24.0	176.1 ± 36.3	133.8 ± 27.1
Twentieth	140.3 ± 23.4	131.0 ± 24.4	148.3 ± 25.4	187.6 ± 42.1	140.7 ± 28.5

APPENDIX IV

Detailed Water Quality Parameter range for the various dietary treatments and open pond waters during growth trials

	Diet A	Diet B	Coppens	Raanan	Diet E	Open Pond
Temperature (^{o}C)	27.58-29.83	27.66-29.78	27.71-29.76	27.72-29.76	27.69-29.82	27.76-29.82
Dissolved Oxygen (mgL^{-1})	1.15-3.30	1.29-3.08	1.38-3.10	1.48-2.90	1.55-3.03	1.56-2.95
Salinity (ppt)	0.03-0.04	0.03-0.04	0.03-0.04	0.03-0.04	0.03-0.04	0.03-0.04
Ph	5.79-7.62	6.03-6.95	6.00-6.88	6.00-6.58	6.03-6.66	6.12-6.58
Phosphate (mgL^{-1})	0.10-0.67	0.12-2.55	0.09-0.58	0.10-0.58	0.11-1.09	0.10-0.40
Nitrate (mgL^{-1})	0.40-6.10	0.40-3.20	0.40-5.60	0.40-6.60	0.60-3.70	0.50-1.80
Nitrite (mgL^{-1})	0.001- 0.086	0.001-0.040	0.002-0.111	0.001-0.113	0.002-0.012	0.003-0.007
Ammonia (mgL^{-1})	0.07-0.50	0.11-0.51	0.10-0.52	0.10-0.50	0.08-0.49	0.16-0.49
Alkalinity (mgL^{-1})	55.0-68.5	53.0-69.0	54.5-73.0	54.5-67.5	52.0-66.0	57.0-68.0
Total Suspended solids (ppt)	21-70	22-75	22-61	22-60	18-70	20-85
Total Hardness (mgL^{-1})	2.42-3.81	2.48-4.33	2.95-4.98	2.61-4.74	2.05-4.84	2.49-4.60