

EVALUATION OF THE EFFECT OF THE PARTIAL REPLACEMENT OF *Caridina nilotica* (P. Roux, 1833) WITH SPIRULINA, *Arthrospira platensis*, (Gomont, 1892) ON WATER QUALITY PARAMETERS AND GROWTH PERFORMANCE OF CULTURED NILE TILAPIA, *Oreochromis niloticus* (Linnaeus, 1758).

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DECLARATION

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

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DEDICATION

I dedicate this work to my parents Moses Sumukwo and Rebecca Kipsetim, Sister Leah Sumukwo and husband Fredrick Kalabata. May the lord bless you all abundantly for your patience and your sacrifices throughout the experimental period.

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List of abbreviations

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CP	Crude Protein
DO	Dissolved Oxygen
EAC	East African Community
ESP	Economic Stimulus Program
FAO	Food and Agriculture Organization of the United Nations.
FBW	Final Body Weight
FCR	Feed Conversion Ratio
IBW	Initial Body Weight
ICIPE	International Centre of Insect Physiology and Ecology
K	Condition factor
ln	Natural logarithm
ppm	parts per million
S	Survival Rate
SGR	Specific Growth Rate
T	Treatment e.g. T ₀ , T ₁ , T ₂ , T ₃ and T ₄ .
t	time
TAN	Total Ammonium Nitrogen
WG	Weight Gain

Abstract

Tilapia is considered the best species for aquaculture production in Kenya and the world because it grows faster, has high tolerance to different environmental conditions and is easy to breed. However, tilapia culture faces the challenge of poor quality seeds, substandard and expensive feeds. Therefore, the present study was conducted in the University of Nairobi's Aquaculture laboratory, Department of Biological Sciences to determine the outcome of replacing shrimps (*Caridina nilotica*) (P. Roux, 1833) with Spirulina (*Arthrospira platensis*) (Gomont, 1892) (Spirulina) on the growth performance of *Oreochromis niloticus* (Linnaeus, 1758) fry and on the water quality parameters. The study used five diets T₀ - T₄. Four of these treatment (T₁ - T₄) contained *Arthrospira platensis* (Gomont, 1892) as the protein source at the following levels respectively, 10, 20, 50 and 100% while the fifth one (T₀) was the control diet with *Caridina nilotica* as the source of protein. The five treatment diets were tested in triplicate form in glass aquaria stocked with 300 fry with mean average weight of 1.6g. The Proximate Analysis of ingredients and formulated diets was examined using Association of Official Analytical Chemists (AOAC) methods. The effect of the different diets on growth parameters and water quality parameters were analysed using the analysis of variance (one-way ANOVA). Turkey's multiple range tests was used to compare statistical difference among treatment means. Differences between the treatment means were considered significant at $p < 0.05$. There was no significant difference ($p > 0.05$) in the water quality parameters among the treatments. The nutritional composition of formulated diets was 35% crude protein, 4 to 6% moisture, 6 to 8% fibre, 37 to 41% carbohydrate and 322 to 323Kcal per 100g energy.

Overall fish body weight increased significantly ($p < 0.05$) from 1.6g to 12g at the end of the experiment. Fish fed on T₂ (20% *Arthrospira platensis*) had the highest weight gain (12.3g, $p < 0.05$) while fish fed T₀ (control diet) had the lowest weight gain (9.1g). No significant difference ($p > 0.05$) in weight gain was observed among fish fed T₁ (10% *A. platensis*), T₃

(50% *A. platensis*) and T₄ (100% *A. platensis*). The specific growth rate was highest with T₂ (3.6%) and lowest with T₀ (3.3%). The mortality was 0% for all the different diets. The condition factor of the fish ranged from 1.2 to 1.8 ($p < 0.05$) while the Feed Conversion Ratio FCR was in the range of 1.03-1.11 ($p < 0.05$) with the highest being T₂ and the lowest in T₀. It can be concluded that, inclusion of *A. platensis* up to 20% in the diet of *O. niloticus* improves its growth performance and has no negative impact on the water quality and fish survival. However, the minimal advantage conferred by using *A. Platensis* may require a critical evaluation of its use against cost of aquaculture production.

CHAPTER ONE: INTRODUCTION

1.1 General introduction

Aquaculture is a field involving the rearing of fish under controlled conditions, it is an enterprise that is growing rapidly and improving world economies. Fish are cultivated as food and a source of income for the growing human population. Thus, restocking of streams, lakes, and rivers to curb the shortage needs special attention due to the decline in the wild capture and capturing of fish for sport fishing (FAO, 2016). Aquaculture aims at culturing fish and selling them to consumers as protein source in the diet (Sugunan, 2002). Fish is a source of good protein because it is easily digestible and prevents heart and neurological diseases (Tan *et al.*, 2007).

As the global population increases, the demand of a healthy diet also increases. This creates the need for aquaculture to meet this demand (Chamberlain, 1993). This is because, capture fisheries will not manage to meet this high demand for fish: most of the wild stock are already over exploited and the main areas of fishing have been fished at maximum capacity (FAO, 2016).

In Kenya, aquaculture production started from 1920s but the total annual production of aquaculture in Kenya by 2006 never exceeded 2,000 tonnes yr.⁻¹. From 2009, the government funded fish farmers through the Economic Stimulus Program, but before the program, there were approximately 7,500 fish farmers holding about 7,477 tonnes in production with in a cover area of almost 722.4 ha (Nyandat and Owiti, 2013). After the Economic Stimulus Program funded by the government in 2009, Kenya was ranked the fourth aquaculture producer in Africa. Its production increased from 4,218 tonnes in 2006 to 24,096 tonnes in 2014 (FAO, 2014). However, aquaculture dropped by 19.8% from 2015 to 14,052 tonnes in 2016. The performance of aquaculture in Kenya has remained to be low due to unavailability of

inexpensive fish feeds, poor feeds management, limited variety of fish species for culture and low quality fish seed (FAO, 2002). It has been claimed that, Kenya has the capacity to increase aquaculture production of above 11 million tonnes each year. Since Kenya has been included in EAC region that do regional exports, this is the best opportunity for Kenya to increase its production in the aquaculture sector (Nyandat and Owiti, 2013)

Fish oil and fish meal have widely been used in fish feed formulation. This is because, they contain nutritional components like protein, vitamins, essential fatty acids, amino acids and digestible energy that meets the major requirements of cultured fish (Tacon, 1993). However, since most aquaculture farmers uses *Rastrineobola argentea* (Pellegrin, 1904) as fish meal for feed formulation, human beings are also consuming it as food, this has increased competition for *Rastrineobola argentea* (Pellegrin, 1904). This competition has led to over-exploitation of this species putting it at risk of depletion. This thus creates the need for identifying an alternative protein source for feed formulation which will reduce the use of *Rastrineobola argentea* in formulating fish feed (Tacon, 1993).

Tilapia is the most common fish species being cultured in aquaculture and it is being produced in almost every country of the world (El-Sayed, 2006). The study focuses on using Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) which is a species of tilapia. With the continuous growing in tilapia production, there is need for finding suitable diets using the locally available ingredients that can be produced within each country,

Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) is a cichlid fish which is native to Africa and has successfully been cultured under varying conditions of the environment and is considered very crucial species in aquaculture (El-Sayed, 2006). It is considered as the most productive food species that is traded all over the world (Chakraborty and Benerjee, 2012). Nile tilapia has the ability to grow rapidly, survive in high stocking density, survive in water

with poor quality, exhibit rapid reproduction and high immunity making it one of the best species for aquaculture (Chamberlain, 1993).

Tilapia species is a strict omnivorous fish once they reach their maturity stage (Keenleyside, 1991). However, its production is stimulated by supplemental formulated feed which is very expensive. This is because, the composite fishmeal for fish feed formulation is used by both humans and the animal feed industry. This creates the need to look for an alternative cheaper but equally effective protein source to be used in fish feed formulation. The possible protein sources from plants includes sunflower, wheat bran, cassava leaf, rapeseed, alfalfa and barley (Abelghany, 2004; Belal, 1999; El Sayed, 1998 and Maina *et al.*, 2002).

Although most sources of plant proteins can be used in formulating feed for tilapia species, some plant proteins have poor quality protein while others are bi-products of already processed ingredients. When these plant proteins are used in fish feed formulation, it compromises the amino acid balance and the quality of protein leading to production of poor quality fish (De Silva and Anderson, 1995). Moreover, compounds which naturally occur and found in the feed stuffs can impact negatively the growth of fish (De Silva and Anderson, 1995). Examples of these compounds includes phytic acid, erucic acid, mucilage, tannins and protease inhibitors and they are found in canola, peas and flax (Grant, 1993). This therefore creates needs for alternative protein sources of higher quality that have not been tampered with or processed for other purposes.

The present study focuses on using *Arthrospira platensis* (Gomont, 1892), a single-celled microscopic blue green algae (filamentous cyanobacteria) whose high nutritional capacity makes it suitable for formulating fish feeds. It contains 60 - 70% protein but is also rich in minerals, vitamins, phycocyanin, carotenoids, essential amino acid and fatty acids. *Arthrospira platensis* does not contain cellulose in its cell walls but instead, it contains mucopolymer

murein which makes it easily digestible by the fish digestive enzymes. Its palatability has also been reported to minimise feed wastage, resulting in a better fish growth (Beresto, 2001).

Since studies have been conducted using spirulina in diet formulation, they reported significant growth enhancement of fish fed on these diets (Allam, 2016; Ayoola and Adeyeye, 2010). Besides that, research conducted in Japan indicates that, about \$2.5 million farmers in Japan use spirulina in feed formulation as it produces better growth rate and minimises wastage. The focus of the study therefore is to evaluate the effect of replacing *Caridina nilotica* with different concentrations of *Arthrospira platensis* on the water quality parameters and the growth performance of *Oreochromis niloticus*.

1.2 Rationale

The cost of feed is one of the challenges hindering the expansion of aquaculture industry in Kenya. This is because, fish meal (*Rastrineobola argentea*) has become very expensive. Human beings consume fish meal (*Rastrineobola argentea*) as a source of food while fish feed manufacturers are also using it for formulation of feed. This has increased the demand for *Rastrineobola argentea* leading to an increase in its costs, causing most farmers to look for cheaper substitutes. Therefore, in this study, the goal is to evaluate the effects of partial replacement of *Caridina nilotica* with *Arthrospira platensis* on the water quality parameters and the growth performance of *Oreochromis niloticus*. If *Arthrospira platensis* will enhance growth and not affect the water quality negatively, then farmers will be encouraged to culture *Arthrospira platensis* in their farms instead of purchasing them. As purchasing *Arthrospira platensis* is costly as compared to culturing it.

1.3 Objectives

1.3.1 General objective

To evaluate the effect of partially replacing *Caridina nilotica* with *Arthrospira platensis* on the growth performance of *Oreochromis niloticus*.

1.3.2 Specific objectives

- i. To determine the effects of the experimental diets on the growth performance of *Oreochromis niloticus*.
- ii. To determine the effects of the experimental diets on the water quality parameters during the two-month period.
- iii. To determine the survival or mortality of *Oreochromis niloticus* during the experimental period.
- iv. To carry out a partial economic analysis of the experimental diets.

1.4 Research questions

This research seeks to answer the following questions:

- i. How do the experimental diets affect the growth performance of *Oreochromis niloticus*?
- ii. What effect does the experimental diets have on the water quality parameters?
- iii. What is the survival of *Oreochromis niloticus* fed on the experimental diets?
- iv. What is the incidence cost and the profit index of the experimental diet after conducting a partial economic analysis?

1.5 Research hypothesis

There is an improvement in the growth performance of *O. niloticus* fed on the experimental diets containing different concentrations of *Arthrospira platensis*.

The experimental diets did not have a negative effect on the water quality parameters.

CHAPTER TWO: LITERATURE REVIEW

2.1 The global state of aquaculture

Aquaculture and fisheries products are very important globally. This is because they provide the much needed source of protein, employment, foreign exchange and income. Almost 950 million people found worldwide rely on fisheries and aquaculture, either indirectly or directly, for their livelihoods (SPARE, 2003). Globally, consumption of fishery products as protein source has been increasing over the years constituting to about 20% of the total protein consumed (FAO, 2006). The population of the world is over 6 billion currently, and it is also predicted to be over 8 billion by 2030, and seafood consumption by that time is forecasted to be ranging from 150-160 million tonnes (FAO, 2005).

The global aquaculture sector for finfish and shellfish production grew at an average rate of 16% between the years 1984-1990 (Tacon, 1993). From 1990, aquaculture industry has been growing at an annual rate of 5% (Chamberlain, 1993). According to report by Chamberlain (1993), aquaculture industry is expected to grow at percentage rate of 6.5 yearly to match the growing market demand for the aquatic products by 2025. In 2000, aquaculture increased from 25.6% to 46.8% in 2016. However, although it still experiences sporadic growth, it does not enjoy the high annual growth rate it used to experience in 1980s and 1990s (FAO, 2018). In 2004, Production of aquaculture was 45.5% of the total fish production which amounted to US\$63.3 billion. In 2005, total fish production was 157.53 million tonnes with 40% being from aquaculture (FAO, 2007). Between 1990 and 2004, aquaculture grew yearly at a percentage rate of 9.4. This growth of aquaculture has helped in eliminating poverty and enhancing food security in various parts of the world (FAO, 2007).

In 2005, reports from major countries carrying out fishing like south Korea, Russia, Iceland, china and others indicates that, the total fishery production in the world reached about 142

million tonnes, thus representing over 1 million tonnes increase which was a record of high production (FAO, 2006). Moreover, over harvesting of the marine environment has led to the classification of ocean fish resources as fully exploited, depleted or even overexploited (National Research Council, 1999).

Besides that, world fish stocks have been declining over the years due to the high capacity of fishing fleets which uses new technologies (Pauly *et al.*, 2002). This has contributed to depletion of fish stocks from the wild. Most fishing fleets continue to exhaust fish stocks from the wild, as they continuously harvest fish at the lower trophic level (Schiermeier, 2002). Analysis of data on fishing by Myers and Worm (2003) points out that, with the continuous reduction of dominant fish populations, harvest on alternative predatory fish increased. Therefore, this calls upon a critical analysis to look for other areas like aquaculture where fish could be cultured and produced in large amounts to cater for the high market demand for fish. Aquaculture production has been improving globally due to an improvement in the quality of seeds and quantities of feeds for feeding the cultured. This has therefore contributed to an increase in the yields obtained from aquaculture (SPARE, 2003). Increase in production in aquaculture sector will be very beneficial in the coming years as it will increase the food supply, employment rate, food value, biodiversity protection through reducing harvests, restocking and improving fish habitat (Frankin and Hershner, 2003).

In 2016, global production from aquaculture increased at roughly 47% of the gross production from fisheries and aquaculture with the total sales of about USD 362 billion. The total global production in 2016 was 110.2 million tonnes with a sale of 243.5 billion. Moreover, the total production comprised of 80.0 million tonnes (USD 231.6 billion) of food fish and 37 900 tonnes for the non-consumables (USD 214.6 million) (FAO, 2018). In 2016, production was contributed 37 countries who were producing more fish from aquaculture than capturing from the wild. These countries are found in every region except in Oceania and if combined, they

contribute less than half but over 30% of the overall production of fish nationally in another 22 countries (FAO, 2018).

Moreover, in order to satisfy the world wide food demand for the overgrowing population projected to be 9.6 billion by the year 2050, production from agriculture, aquaculture and fisheries has to be increased by 60% (FAO, 2014). In order to meet this increase in demand for food and protein, the contribution from sustainable aquaculture production will be required.

Globally, the leading country in aquaculture production by 2018 is china with the production of 63.7 million tonnes every year. The top most countries in aquaculture production are shown in table 1 below with the highest being china and the lowest producer being **Malaysia with a production of 0.52 million** tonnes annually.

Table 1: Top 14 aquaculture producers in the world in 2018 (FAO, 2019).

Rank	Country	Annual aquaculture harvest (Million tonnes)
1	China	63.7
2	Indonesia	16.6
3	India	5.7
4	Vietnam	3.60
5	Bangladesh	2.20
6	Philippines	2.20
7	South korea	1.90
8	Egypt	1.40
9	Norway	1.30
10	Japan	1.10
10	Japan	1
11	Myanmar	0.96
12	Thailand	0.93
13	Brazil	0.56
14	Malaysia	0.52

Even though aquaculture is considered to be very important globally, it may contribute to reduction in habitat, water contamination due to disposal of waste, exotic species introduction, pathogens and exploitation of fish meal for feed formulation (Naylor *et al.*, 2000). Therefore, to ensure fish stocks have recovered from overfishing, aquaculture has to increase its production and this will meet the existing demand and reduce pressure exerted on capture fisheries (Watson and Pauly, 2001).

2.2 The state of aquaculture in Africa

The modern African aquaculture has shown significance progress since its introduction. However, its growth has followed a very rough path. Initially, the high interest of Africans to practice fish farming diminished gradually in the 1960s because, their expectations had not been met leading to abandonment of many aquaculture enterprises (CIFA/OP24, 2000).

Other than ancient Egyptians, tilapia was cultured successfully in 1946 at Lubumbashi, RD Congo (Heenen ponds and Kipopo station) for the first time with two species of tilapia from Moëro lake (*Tilapia rendalli* and *Oreochromis macrochir*) (Vincke, 1995). In the late 1950s, Africa had approximately 300 000 ponds. Trout fish was then introduced between 1859 and 1896 in South Africa and initial the production of aquaculture in Africa was determined by fish that found their way naturally into the rice fields via the water supply (Randriamiaran *et al.*, 1995).

In 1960s, African aquaculture started decelerating due to scarcity of resources but improved in 1980s because of aquaculture development projects which aimed at increasing fish supply (Vincke, 1995). From then, aquaculture started improving due to several attempts from various collaborators and FAO who reviewed aquaculture in Africa and identified the major constraints hindering it (Coche, *et al.*, 1994).

Therefore, comparing aquaculture production 50 years ago to 2016 (2000 to 2016), there has been a tremendous improvement (FAO, 2016). Most African countries recognize aquaculture as a crucial production system and are practicing it. Other countries like Malawi, Zambia and Madagascar have developed aquaculture programs for promoting aquaculture. Other countries like Zimbabwe and South Africa have established commercial systems for aquaculture and are leaders in practicing mariculture.

In 2005, statistics indicated that contribution of African Aquaculture globally never exceeded 1%. However, large scale investments of aquaculture are being practiced in in Ghana, Egypt, Zimbabwe and Nigeria where they produce large amount of fish from aquaculture (FAO, 2005). In spite of an increase total number of fish being supplied, the consumption of fish is not in pace with the increase in population with consumption of fish in Africa declining from 4.6 million tonnes total in the 1980's and reaching 6.4 million tonnes total in 2007 (Brummett, 2007). Moreover, since fish contributes to above 30% of the protein being consumed from animals in fifteen African countries, there is need to increase the production of fish to ensure it meets the demand for the ever increasing population (FAO, 2005).

Africa has an opportunity to increase aquaculture production because, an increase in population increases competition for resources. This calls upon aquaculture to provide food security. Aquaculture in Africa should be a contributor to increase economic and nutrition well-being. By doing this, it will help in creating employment, alleviating poverty, increasing income and improving the economy (FAO, 2012)

2.3 The state of aquaculture in Kenya

Kenya is blessed with several inland water resources like Lake Turkana, Baringo, Victoria, Naivasha, Kanyaboli, Chala, among other. It is also comprised of rivers like the Athi, Tana, Kerio, Nyando, Migori, Gucha, Nzoia, Mara and Yala. In addition, it has artificial water bodies like dams and approximately 600km of coastal shoreline plus an Exclusive Economic Zone of

200 nautical miles that can be enhanced and be used for both capture fisheries and aquaculture. Despite the fact that most parts of Kenya can be used for aquaculture, only 0.014% of the available 1.4 million ha has been utilized for commercial fish farming with about 95% being practiced in small scale (Otieno, 2011). However, fish farming has mostly been practiced in Nyanza, Western provinces, Central, Rift Valley and the Coastal provinces for commercial purposes (Nyonje et al., 2011).

Aquaculture in Kenya is categorized into mariculture and freshwater aquaculture. The mariculture sector has not been fully exploited whereas the fresh water aquaculture has recorded a significant improvement over the years. When aquaculture began in Kenya in the 1920s, the first species to be cultured was tilapia followed by African catfish and common carp. In 1960s, the Government of Kenya constructed some ponds to popularize fish farming in the rural. This resulted in the expansion of tilapia culture in Western and Nyanza provinces of Kenya. However, the number of these ponds decreased in 1970s due to poor quality fingerlings, few extension officers and inadequate trainings for extension workers. Until 1990s, the Kenyan aquaculture was similar to the pattern seen in most of the countries in Africa, characterized with low production levels, small ponds and subsistence-level management (Ngugi *et al.*, 2007).

However, Kenya was able to renovate various fish culturing facilities including establishing research programs for determining the suitable pond culture practices. Kenya also developed training programs for aquaculture extension officers which has renewed the interest of practicing aquaculture in Kenya. In 2006, fisheries production contributed 0.5% of the total GDP in Kenya while it registered a 4.1% sub-sector growth in 2005 (Mwangi, 2008). When the Economic Stimulus Program funded by the government began in 2009, the program boosted aquaculture production from 4,218 tonnes in 2006 to 24,096 tonnes in 2014. This was a representation of 15% of the total national production of fish.

The Economic Stimulus Program (ESP) introduced fish farming in 140 political constituencies. The main objective of ESP was to encourage people to practice commercial fish farming so as to boost the growth of aquaculture. The aim of the program was to boost fish production from 4,000 to 20,000 tonnes within the first two years and above 27,000 tonnes by 2030 (Charo-Karisa and Gichuri, 2010). Each of these constituencies was given funds enough for purchasing 1000 fingerlings, 15kg of fertilizes and for constructing 200 ponds. The second phase of the exercise was conducted in 2011/2012 where 20 additional constituencies were included. This added an extra 300 ponds for the extra constituencies and 100 ponds for the first 140 constituencies with 1000 fingerlings for each pond and 15 kg of fertilizer in each pond (Nyonje et al., 2011).

The ponds constructed during the ESP program triggered a short term demand of approximately 14,000 tonnes fingerlings of both catfish and tilapia including over 14,000 tonnes of fish feeds that were formulated by either public or private sector provided it was delivered in a timely manner (Musa et al., 2012). The ESP program triggered some farmers to construct their own ponds which further boosted aquaculture to above 100,000 tonnes valued at 100 million (Musa et al., 2012; Charo-Karisa and Gichuri, 2010). Moreover, the program made other people to abandon subsistence farming and to start practising commercial aquaculture and they now own bigger ponds and produce higher fish yields (Otieno, 2011).

Until date, the government of Kenya has positioned various facilities of aquaculture in different counties. These facilities act as training centres, centres for research, fish feed sources and fingerlings production centres. These facilities include fish farming training centres in Kisii, trout farm in Kiganjo (central Kenya), trout farm in Ndagaru (central Kenya), National Aquaculture Research Development & Training Center (NARDTC) in Sagana (central Kenya), fish farm in Chwele (Western Kenya), LBDA in Kisumu (Nyanza Kenya) and fish farm in Wakhungu (at Bumala in Busia County, Western province) among others. Despite all these

efforts, majority of these centres don't have basic equipments and personnel to help in spurring significant aquaculture development in these localities (Charo-Karisa and Gichuri, 2010).

However, Kenya has a great opportunity to increase aquaculture production. With the decline in wild catches, Kenya has a promising future of increasing its fish production and fill the gap in national fish supply. Kenya also has fish species that grows fast (African catfish and Nile tilapia) together with fresh water resources that can be utilized for pond, tank-based and cage aquaculture systems. They can use this opportunity as the fisheries sector produces raw materials required for formulating local feeds (Otieno, 2011).

Besides that, most Kenyans are used to consuming fish, and for this, it has been categorised among the regions in East African Communities for regional exports. Kenya also possess well developed fish feed industry and laboratories for quality assurance. It can use these facilities to improve the aquaculture industry by supplying fish locally, regionally and internationally (Nyandat and Owiti, 2013).

Kenya also has other opportunities in mariculture that it can take advantage of it. For instance, the permanent established in the Kenyan coast of *Artemia* population is a great opportunity for aquaculture production (Kapinga, 2012; Ogello *et al.*, 2013; Mremi, 2011). *Artemia*, feed with high nutrition suitable for feeding larval fish (Sorgeloos *et al.*, 1995). Aquaculture can use *Artemia* to increase the production of food and enhance mariculture activities.

In addition, culture of shellfish like oysters, mussels and abalone has not yet been done in Kenya. This is a good opportunity for farmers to start culturing it and increase aquaculture production (Dhont and Sorgeloos, 2002). Farmers can also culture shrimps. In countries like Ecuador, China and Southeast Asia, shrimps culture contribute about 80 to 85% of the country total sales. Kenya can emulate these countries' success as farming *Artemia* and shrimps could be gold mine (Dhont and Sorgeloos, 2002).

Table 2: Production of capture fisheries and aquaculture in Kenya for over 50 years (FAO, 2018)

	Marine		Freshwater		Aquaculture	
		Ksh'000	tonnes	Ksh'000	tonnes	Ksh'000
2017	-	-	12,356	-	12,360	-
2016	-	-	14,953	-	14,957	-
2015	-	--	18,656	-	18,658	-
2014	9	-	24,094	-	24,098	-
2013	8.9	-	23,501	-	23,501	-
2012	8.6	-	21,488	-	21,488	-
2011	-	-	22,135	-	22,135	-
2010	8.5	-	12,154	-	12,154	-
2009	-	-	4,895	-	4,895	-
2008	-	-	4,452	-	4,452	-
2007	-	-	4,240	-	4,240	-
2006	-	-	1,012	-	1,012	-
2005	-	-	1,047	-	1,047	-
2004	-	-	1,035	-	1,035	-
2003	-	-	1,012	-	1,012	-
2002	-	-	798	-	798	-
2001	-	-	1,009	-	1,009	-
2000	5.2	-	512	--	512	-
1997	6,099	378,073	154,937	4,242,193	199	10,495
1996	6,296	348,200	173,218	6,208,268	579	6,314
1995	5,995	348,869	186,711	4,752,075	1,302	103,365
1994	4,904	249,154	196,842	3,641,491	1,385	77,045
1993	4,336	156,756	177,741	3,552,106	1,145	56,819
1992	7,194	197,446	154,928	3,197,231	1,136	48,911
1991	7,450	146,407	190,170	1,622,030	1,178	44,087
1990	-	-	-	-	1,236	-

	Marine		Freshwater		Aquaculture	
		Ksh'000	tonnes	Ksh'000	tonnes	Ksh'000
1989	7,610	118,756	137,871	663,865	972	36,458
1988	7,099	106,603	121,033	505,751	561	35,849
1987	7,747	101,197	122,340	3,407,761	210	34,028
1986	6,604	68,909	112,214	260,495	980	30,662
1983	6,339	56,111	90,483	150,697	201	15,880
1982	7,116	50,851	73,577	145,117	195	23,819
1981	5,967	36,780	50,964	103,499	160	23,747
1980	4,905	23,117	42,286	777,225	596	1,464
1979	2,858	12,493	45,930	72,756	568	1,395
1978	4,177	15,911	41,203	52,273	557	1,368
1977	4,046	13,574	36,078	39,097	547	1,296
1976	3,889	10,823	36,872	44,005	-	-
1975	4,220	10,758	22,810	26,964	-	-
1974	3,116	74,225	25,165	26,099	-	-
1973	3,546	7,307	24,898	23,350	-	-
1972	7,411	9,261	22,084	19,952	-	-
1971	6,562	10,234	21,129	18,877	-	-
1970	7,617	9,216	25,730	20,263	121	288
1969	6,396	6,924	25,151	20,137	121	288
1968	5,715	6,115	22,234	17,721	121	288
1967	5,850	6,305	21,391	21,260	102	240

2.3.1 Challenges of aquaculture sector in Kenya

After several years of aquaculture in Kenya, it still faces basic challenges. According to Ngugi and Manyala (2004), the Kenyan aquaculture industry experiences the challenge of inadequate knowledge of investing in aquaculture. Most of the people don't understand the benefits incurred when they invest in aquaculture. They invest into sectors like dairy farming and agriculture but ignore aquaculture yet its profitability is high as most people have not invested in it.

According to Kaliba *et al.*, (2007), lack of certified quality feed is another challenge facing aquaculture in Kenya. This challenge has become a longstanding hurdle to aquaculture growth and development. This has prompted most farmers to abandon fish farming due to the losses they incur after using these feeds. The farmers have preferred moving to dairy farming or to other agricultural practices than investing in aquaculture yet they continue incurring losses.

Other hindrance to aquaculture in Kenya include, inadequate aquaculture research, few extension officers, lack of aquaculture funding, poor aquaculture policy and failure of private sectors to invest in aquaculture. The introduction of efficient systems, development of sustainable production mechanism, increasing pond productivity and production of pond inputs are other challenges that Kenyan aquaculture has to address (Gitonga, Mbugua and Nyandat, 2004).

Osure (2011) also reported that, the major challenge facing the Kenyan aquaculture includes uncoordinated fish farming promotion (by NGOs, government and research institutes). He also reported that Kenya lacks well trained extension officers. Due to poor training most of them give varying and confusing information to farmers making it difficult for farmers to determine the best information to use. Aquaculture has also not been prioritized by policy makers. The policy makers have disregarded the role aquaculture can play in improving the economy and have thus not set strict policy framework governing aquaculture.

Besides that, Mwangi (2008) explained that, the lack of strict policy framework governing aquaculture has discouraged most people from investing in aquaculture. This has also reduced effectiveness of management and research in the aquaculture sector making majority of people to lose interest in aquaculture.

In Kenya, outreach programs on aquaculture are very inadequate. This decreases the efficiency of disseminating information nationally and creating awareness of the importance of investing in aquaculture. It also does not provide room for technology transfer to the farmers practising aquaculture. This contributes to the backwardness of aquaculture. This is because, even those farmers who have good lands that are very suitable for aquaculture have no idea on the potential of aquaculture (Osure, 2011).

According to Munialo (2011), poor record keeping is another hindrance to aquaculture growth. Farmers do not keep records of their production and also uses inefficient data collection tool which prevents them from adequately disseminating information on fish farming. There is also poor entrepreneurship skills by the farmers in that, they may be getting good returns but since they lack the entrepreneurial skills their production does not grow.

2.3.2 Current status of fish feed industry in Kenya

In both semi-intensive and intensive aquaculture systems, the cost of feed amounts to roughly 40 to 60% of the total cost of production (De Silva and Hassan, 2007). To ensure aquaculture becomes more profitable, farmers must be provided with affordable and quality seeds. In aquaculture, most fish species are reared in earthen ponds and consume locally formulated diets produced using low cost ingredients (Ali *et al.*, 2010). Before compounded diets became available farmers used ingredients found locally like corn meal, rice bran, wheat bran and cassava meal. In traditional aquaculture systems, farmers reared fish in ponds that have been fertilized without supplementing feed or supplementing it (Liti *et al.*, 2006).

The main challenge affecting aquaculture in Kenya lack of cheap and quality feeds (Munguti *et al.*, 2012). When the ESP program was introduced in Kenya in 2009, the feed sector started experiencing a shortage of 1400 per year. From then, demand for fish feed has increased to approximately 50,000 tonnes per year (Charo-Karisa and Gichuri, 2010). This increase in the fish feed demand paved way for unscrupulous dealers who started selling poor quality feeds to farmers. This act prompted the government to establish national standards for all formulated fish feed to ensure its quality is not compromised. Each industry or farm formulating fish feed had to abide by these standards set by the government (Charo-Karisa and Gichuri, 2010).

In feed formulation, single ingredient like brans don't possess sufficient micro and macronutrients while the high fibre content in brans reduces fish palatability and digestibility leading to yield reductions (Liti *et al.*, 2006). However, research done in Sagana fish farm proved that the performance of the different brans differs a lot with maize bran which performs better in fish growth than using rice or wheat bran (Liti *et al.*, 2006).

In Kenya, commercial fish feeds contain 24 to 28% of crude protein required by fish (Liti *et al.*, 2006) but it is usually costly for most farmers to purchase it. Majority of farmers have opted for feeds mixed locally like a combination of fish meal (24%), Rice bran (76%) and freshwater shrimps. While others use maize bran in place of rice bran and Omena *Rastrineobola argentea* as the fish meal instead of shrimps (Ngugi, Bowman and Omolo, 2007).

Research conducted by Liti *et al.* (2006) indicated that, feeds are often a common challenge facing aquaculture. In Kenya, the low fish feed quality in the market prompted the ESP nutrition team and aquaculture stakeholders to formulate a process of vetting for the manufacturers fish feed. To date, there are 15 fish farms producing approved fish feeds and further research is also being conducted to identify more firms producing certified fish feeds in Kenya.

Besides that, quality of feed given to fish and the feeding management that is adopted can be very crucial as it can seriously affect the feed conversion ratio, survival and the fish growth. It is crucial to ensure fish are fed with standard and quality feeds. Fish should not be over fed as this wastes feed while contaminating water which may stress fish (Tacon & De Silva, 1997). Other study also reported that, if meals are equally divided and fed to fish, diet will be wasted because during low temperatures of the day, the feeding rate of fish declines. This wastage of seeds in turn increases cost of feed leading to losses. Farmers should ensure they contribute in reducing costs by avoiding feed wastage (Ali et al., 2010).

2.4 Tilapia culture requirements

According to Pompa and Masser (1999), *Oreochromis niloticus* commonly called tilapia fish, is the third to be cultured worldwide. Tilapia originated from river Nile and are the descendants of Cichlid family. Their appearance is similar to s snapper or perch but is distinguished by the lateral line found at its back which is the main characteristic of the cichlid family. Based on Maar *et al.*, (1966), some description on a sunk-relief which is located in the Egyptian tombs showed that people used to fish tilapia from ponds which is an indication that by 2500BC, tilapia was already being cultured in Egypt. Moreover, while referring to the biblical passage, it indicates that species of tilapia as the fish fed to the multitudes (in Jesus miracles) and is thus called the “fish of Saint Peter” (Suresh, 2003).

Tilapia belongs to the family of Cichlidae family of the tropical freshwater fish with bilaterally compressed bodies exhibiting parental care. Tilapia fish are indigenous to Africa though they naturally occur in Middle East (Wohlfarth and Hulata, 1981). “Tilapia” is a name commonly for the hybrid species found in the genera *Sarotherodon*, *Tilapia* and *Oreochromis* which contains majority of cultured species as well as to pure species.

Nile tilapia, scientifically named *Oreochromis niloticus*, is favored mostly in aquaculture because of its performance when subjected to typical culture conditions. Tilapia is famous

among the consumers because of its sweet flavor and few small bones. The success of farming Nile tilapia is because they can be easily cultured as they can tolerate crowding and poor water quality, they have high resistance to diseases and can breed easily in captivity (Suresh, 2003).

Nile tilapia is considered quality food due to its neutral taste, firm texture and white flesh which makes it to be accepted by different individuals with different preferences and tastes. These qualities have made the fish to be called the “aquatic chicken” (Chervinski, 1980). This explains the reason why almost 95% of fish farmers culture tilapia in the world (Kaliba *et al.*, 2006)

2.4.1 Water quality

According to USGS (2006), water quality refers to the measure of water suitability for a particular purpose based on selected chemical, biological and physical characteristics. Boyd (1998) further defines water quality as the biological, physical and chemical factors influencing the beneficial utilization of water. Boyd (1998) further explains that, putting aquaculture into consideration, any water characteristic affecting reproduction, survival, management and growth of fish or any aquatic organism in whichever way is a variable of water quality.

According to Aquasol, Inc. (2003), a provider of technical assistant services in aquaculture, the important environmental parameters for tilapia culture are salinity, temperature, PH, concentration of nitrite and ammonia. Aquasol, Inc. (2003) expounds that, when fish are growing rapidly, the water quality parameters has to be within the optimum levels for tilapia production to be cost effective.

2.4.1.1 Temperature

Water temperature is important for any culture system producing tilapia. Since tilapia is a warm water fish, the optimum temperature range for tilapia lies between 27 to 28⁰c (Phillipart and Ruwet, 1980). Craig and Helfrich, (2002) explained that, during higher temperatures, most

tilapia die. A more serious problem occurs when the temperatures falls below optimal range. Popma and Masser (1999) further explained that, temperature ranges of 50 to 52⁰c is lethal to tilapia species and can cause mortality.

According to Phillippart and Ruwet, (1980), the upper, lower or lethal limits of temperature are necessary for fish and it varies with species. On the contrary, Phillippart and Ruwet (1980) reported that species of *O. niloticus* can tolerate extensive temperatures and can survive in low temperature of 8°C and as high as 42°C.

Temperature tolerance by *tilapias* relies on species and size of fish. Small fish can survive in high and low temperatures as compared to adults (Phillippart and Ruwet, 1980). Although tilapias can endure intense temperatures, their growth and reproduction is affected. When the temperatures fall below 20°C, they reduce the rate at which they feed and below 16°C their normal growth stops completely as it renders them inactive. In addition to that, temperatures below 22°C stops reproduction (Chervinski, 1980).

Species of tilapia don't thrive well in lower temperatures but can survive at high temperatures. The optimum temperature for tilapia is usually 28-32⁰C (FAO, 2015). Therefore, growth of tilapia species reduces with a reduction in water temperature and thus, their inability to tolerate low levels of temperatures hinders the culture of tilapia in the temperate zones (Tiechert *et al.*, 1997).

According to Campbell, (1987), tilapia species cannot easily adapt sharp temperature fluctuations. Campbell (1987) further notes that, a fall of water temperature from sixty-four to forty-six degrees and then the temperature remains constant for some hours, 25% mortality rate will occur. Popma and Masser (1999) also noted that, low temperature slows the feeding of fish and contributes to fatal fish diseases. According to Popma and Masser (1999), the optimal reproduction temperatures for tilapia is approximately eighty degrees and when it falls below sixty degrees, reproduction will not take place.

2.4.1.2 Dissolved oxygen

The concentration of dissolved oxygen are very important aspects of water quality in any kind of culture system and can largely affect fish growth (Rice, 2002). Dissolved oxygen concentration in water has to be high to ensure the respiratory needs of fish in any culture system are met. Though most researcher accept that tilapia can survive in low levels of DO, they cannot clearly indicate the lowest limit which is acceptable.

According to Popma and Masser (1999), the levels of DO should be above 1 mgL⁻¹. In contrast to that, Pescod (1992) believes that, the levels of DO should not be less than 5 mgL⁻¹ for fish survival. Funge and Phillips (2001) reported that, the levels of DO should not come below 3mg/l while Rice (2002) stated that, tilapia can perform better in DO levels above 4 mg/l.

Moyle and Joseph (1988) reported a reduced growth rate and feed conversion ratio in juvenile largemouth bass (*Micropterus almonides*) with dissolved oxygen level below 5mg/l at a temperature of 26⁰C. Presumably, the reduction of oxygen below this level hinders activities like reproduction and growth.

However, Mallya (2007) indicated that, when dissolved oxygen levels falls below the minimum range required by fish, it stresses the fish and eventually causes mortality. Besides that, Mallya (2007) further expounded that, the low levels of dissolved oxygen inhibit reproduction, fertilization and survival rate of larvae. Maintenance of dissolved oxygen close to saturation or at super saturation will boost the growth of fish, reduce its FCR and also increases fish production.

As dissolved oxygen levels decreases in water, the feeding activities and fish respiration rates also decreases. This results in a reduction of fish growth rate increasing the likelihood of the fish being attacked by diseases. Nevertheless, low levels of dissolved oxygen make the fish unable to assimilate the food it consumes (Mallya, 2007)

O. niloticus can endure low levels of the dissolved oxygen up to 1 parts per million which is usually considered to be lower than those of other species of fish requiring 7 - 8 parts per million of the oxygen (Chervinski, 1980). When the levels of oxygen fall below this level, tilapia uses the atmospheric oxygen enabling them to survive (Chervinski, 1980). *O. niloticus* have developed a method that they use it to receive oxygen by swallowing air at the interface between water and air, allowing water which is oxygenated pass over their gills (Winfrey and Stickney, 1981). Low levels of oxygen also decrease the growth of tilapia and even reduces their feeding (Jobling, 1994).

According to Popma and Masser (1999), low dissolved oxygen levels which have been prolonged causes depression of metabolism, disease resistance and growth and Rice (2002) also agrees and views this situation to be very stressful to the fish and increases to chances of fish diseases. At night, respiratory demand is often very high for the phytoplankton's. This leads to oxygen depletion resulting to mortalities. Therefore, DO depletion are caused by so many factors that should be well managed to reduce fish mortality.

2.4.1.3 Ammonia

According to Riche and Garling (2003), ammonia creates concern in any culture system. For this, the farm should ensure that, ammonia levels in the water is closely monitored. Ammonia in water is as a result of waste product discharged by the fish. It also comes from bacteria that decomposes organic matter like excessive feed supplemented to the fish. In high pH and temperature, the toxic unionized ammonia will exist. For this reason, since tilapia thrives in warm waters, it is crucial to monitor the levels of ammonia in water to avoid water toxicity and fish mortality.

Besides that, Riche and Garling (2003) concurred with Rice (2002) that, concentration of unionized ammonia higher than 2 mg/l can lead to death in tilapia. Levels of 0.2mg/l for a prolonged time leads to death and a concentration of about 0.08 mg/l reduces the feeding of

fish. Feeding of fish increases the production of ammonia in the feed and the levels often peaks with 4 to 6 hours after the fish is fed. The quickest way to reduce ammonia levels in water as explained by Riche and Garling (2003) is to stop or reduce feeding fish for the ammonia levels to attain its normal level.

2.4.1.4 Salinity and pH

The species of tilapia can tolerate brackish water compared to other fish being cultured in freshwater (Popma and Masser, 1999). Tilapia can survive in saline water up to 15 ppt. During tilapia reproduction, water with low salinity is the most favourable, 5 ppt as the optimum level and 10 ppt as the acceptable level (Rice, 2002). Though tilapia can survive in high salinities, Rice (2000) maintains that, tilapia salinity levels should be monitored as higher salinities can cause oxygen depletion and tilapia can tolerate specific range of salinity and a slight change stresses the fish.

Most of tilapia species are regarded as euryhaline as they can withstand wide ranges of salinity levels (Phillipart and Ruwet, 1980). Since tilapia are observed to survive in low salt concentrations, they have osmotic properties and can also regulate ion to curb salt concentrations in their bodies (Jobling, 1994). Although, high levels of salinity reduce the levels of dissolved oxygen because the solubility of oxygen in the water reduces.

The favourable pH for the tilapiine species is close to neutral. At this pH, the fish is able to uphold the most favourable growth and grow well (Phillipart and Ruwet 1980; Chervinski, 1980). According to Tiechert *et al.*, (1997), tilapia fish can remain alive in pH ranges of 5 to 10 though it performs best in pH range 6 to 9.

Consensus among various experts indicate that, the optimum pH range for culturing tilapia lies between 6-9 (Popma and Masser, 1999; Funge and Phillips, 2001; Rice 2002). Nonetheless, Campbell (1987) fails to agree that the pH range desirable for growth and reproduction of tilapia is 3.5 to 5.2. Campbell (1987) has ascertained the lower pH range of tilapia to be

between 3.0 and 3.3. In his study, pH levels were held between 3 and 3.3 for a period of seven days and he recorded 50% mortality rates.

According to Rice (2002), extreme levels of pH on either end are lethal for any kind of fish even the hardiest fish. Therefore, Rice (2002) advises for the consideration of pH when choosing a location for tilapia culture.

2.4.2 Nutrition

Nutrition is a very critical component globally for the aquaculture industry. It represents above 50% of the farm operating costs (Twibell and Brown, 1998).

2.4.2.1 Protein

Fish species don't have a specific requirement of crude protein but need essential amino acid combination. Thus, the dietary protein profile is crucial in tilapia diet formulation. Dietary protein is continuously used in fish feed as it helps in reproduction, growth and maintenance functions (Winfrey and Stickney, 1981; Al Hafedh, 1999; Twibell and Brown, 1998). Some other warm water fishes need 10 essential amino acids to be provided in the diet. These essential amino acids can be supplied in the diet through feeding fish with a balance of animal and plant protein and if it is necessary, synthetic amino acids can be added in diet formulation (Twibell and Brown, 1998).

Proteins represent approximately 50% of the overall cost of feed in the culture system. This indicates that, for tilapia to be successfully cultured, proper quality and quantity of dietary protein should be selected (FAO, 2004). Various factors influence the requirement of dietary protein in tilapia feed: during larval stage, protein requirement is 35 to 50%, and the requirement decreases with an increase in fish size (Siddiqui *et al.*, 1988; El-Sayed and Teshima, 1992). For the juveniles of tilapia, 30 to 40% protein is required in the diet with 20 to 30% protein content for the adult tilapia. In addition, the brood stock of tilapia needs 35 to

45% protein content in the diet for optimum reproduction (Abdel-Tawwab et al., 2010; El-Sayed *et al.*, 2003; Gunasekera *et al.*, 1996a, b; Siddiqui *et al.*, 1998;).

According to Bowen (1987), fish require higher protein than other organisms (National Research Council, 1993). Overall retention of protein in fish ranges from 20 - 50% and is the same requirements for the poultry and the pigs (Bowen, 1987). This higher protein requirement for fish has been attributed by their lower energy requirements (Smith, 1989). In *O. niloticus*, the optimum requirement for protein depends on age, water temperature and the size of fish.

Higher energy required by fish requires them to have higher protein content in their body for heat increment and body maintenance (National Research Council, 1993). The protein content that can be digested into energy for tilapia to grow well is between 81 to 117 mg kcal⁻¹ (National Research Council, 1999). Excessive fish energy reduces feed intake and low energy also results in the fish utilising protein for body maintenance rather than growth (National Research Council, 1999).

In addition, Hafedh (1999) reported that, the fry for tilapia which is 0.5 grams, grows and matures faster when given 40% levels of protein in the diet. As tilapia grows, their protein intake decreases which in turn increases the fecundity rate of the female tilapia fishes thus indicating that, protein levels differs with age and size of fish (Hafedh, 1999).

2.4.2.2 Fats

Proteins are usually expensive and thus instead fats help in reserving protein and to decrease the expenses incurred in producing tilapia feeds. Chou and Shiau (1996) indicated that reducing fat content in feeds resulted in the reduction of growth. Lim et al., (2011), also explained that, improving tilapia diet can be best achieved by using quality protein or fat in the diet of fish. Furthermore, Lim et al., (2011), also noted that when lipid is added into the diets, it results in an increase in the fat content in fish.

Based on Lim et al., (2011), the dietary fat content required in tilapia is in the range of 5% to 12%. Han *et al.*, (2010) also recorded a better growth of fish with increases dietary fat from 55 to 85g per kg in fish feed.

2.4 2.3 Carbohydrates

Carbohydrates is very crucial in fish diet as it is a cheaper source of energy in the diet compared to the proteins. Inclusion of carbohydrate in the diet also improves the pelleted feeds quality. Tilapia can utilize carbohydrates levels of 30 to 40% in their diet which is higher than carbohydrate contents in the diets of other cultured fish (Anderson *et al.*, 1984).

Bergot (1979) reported that carbohydrate incorporation in fish body varies with species, quantities of carbohydrates and environmental conditions. Further studies by Anderson *et al.*, (1984) recorded an improvement in the growth of *O. niloticus* that were given diets containing dextrin or starch than those fed with diets without carbohydrate indicating that carbohydrate is essential in fish diet.

2.4.2.4 Fibre

Fiber content in tilapia diet is often considered to be indigestible. This is because, tilapia species do not have the required enzymes for the digestion of fiber (though study discovered there are often microbes' cellulose activities that was found in *O. mossambica*) (Saha et al., 2006). In this case the levels of crude fiber in tilapia diets has to be less than 5% for tilapia to attains its maximum growth.

2.4.2.5 Vitamins and minerals

Minerals and vitamins are very crucial for normal metabolism of fish. Minerals and vitamins are usually supplemented in fish diet in form of premixes although most of them are often naturally met in pond cultures. The general requirements of vitamins in tilapia diet are 4 mg/kg in juveniles to adults (Lim *et al.*, 2000). Abdelghany (1996) also reported that, tilapia fish of

between 0.56 to 4.5 g require 50 mg/kg in the diet and Soliman et al. (1994) advised on the use of vitamin levels of 420 mg/kg in fish diet of size 1.0 to 18.0 g.

The mineral requirement for tilapia varies depending on the kind of mineral: calcium, phosphorus, potassium, magnesium. Calcium content required in tilapia is 7g/kg for tilapia of sizes 2.3 to 61.3 g (Robinson *et al.*, 1987). For phosphorus, tilapia of between 6 to 32 g requires phosphorus content of 9 to 10g/kg. Tilapia of sizes between 0.7 to 3.5 g will require potassium content of 2 to 3g/kg (Shiau and Huang, 2001) while the magnesium content required for tilapia between 20 to 54g is 0.59 g/kg (Reigh, Robinson and Brown, 1991).

As the size of tilapia increases, the levels of minerals required in the diet becomes lower. Smaller fish on the other hand needs high mineral content as they consume a lot of energy as growth is at its maximum (Eid and Ghonim, 1994).

2.4.3 Feeding

The quantity of food to be fed on tilapia fish is determined by the percentage their weight and the average size of the fish. According to Robinson (n.d.), 15 to 20% of the weight of fish should be daily provided for fish of size 0.5g or even less. He further adds that, 1.5% should be fed on fish of 400g.

Riche and Garling (2003) claimed that, small tilapia fish should be fed with 10 to 30% of the fish body weight and fish more than 100g should be given 1.5 to 3% of their total body weight. The quantity of feed to be fed on different sizes of fish is summarized in table 3 below from 0.1g to more than 100g body weight of fish.

Table 3: Table for feeding *Oreochromis niloticus* (Riche & Garling, 2003).

Fish weight (grams)	Daily feeding rates (% Biomass)
0-1	30-10

1-5	10-6
5-20	6-4
20-100	4-3
>100	3-1.5

The intervals of feeding are also very important. According to Riche and Garling (2003), it is important to feed fish at an interval of 4 to 5 hours in between feeding. The feeding intervals will change because of varying digestion habits of the younger fish and their sizes. Riche and Garling (2003) explains that, when fry are fed eight to ten times per day, they will grow best. Fingerling on the other hand will perform better when fed for almost four times a day.

According to Riche and Garling (2003), tilapia species can eat more than their stomach requirement. The extra food eaten by tilapia will directly go to the intestines though energy is wasted in digesting this excess food. That is why feeding protocol is put farther apart to ensure food is fully digested before the next feeding. It is hard to figure out if fish has eaten to its maximum capacity or not. This makes it difficult to decide when to stop feeding them. That is why fish end up being overfed to ensure they consume the adequate content of nutrition (Riche and Garling, 2003).

These feeding durations and feeding rates of tilapia are dependent on the environment. According to Robinson (n.d.), several factors influence the feeding habits of fish: fish density, water quality, feeding behavior of fish, water temperature and the barometric pressure. These environmental factors should be put into considerations before feeding tilapia to avoid feed wastage.

Tilapia species feed on a wide array of food sources with each kind having different benefits on the fish. This makes it difficult in determining the best food content for tilapia. For this

reason, Riche and Garling (2003) reported tilapia fingerling to perform best on diet containing 32 to 36% of protein while fish of 40g and more consuming diet containing 28 to 32% .

2.4.4 Aquaculture and feed technologies

The common technique used in feeding fish his fertilization of the culture media with inorganic and organic fertilizers. This stimulates zooplanktons and phytoplankton growth. In other systems like polyculture where several species of fish are cultured together, fingerlings and fry of herbivore species are eaten by the carnivores. When there is excessive increase in fish stock, food become inadequate and fertilizing the ponds to enhances growth of zooplanktons and phytoplankton which are food for fish (Sogbesan, 2006).

According to Helfrich and Smith (2001), liming is another technique used ensuring food is available for fish. It is poured in the culture system and it enhances the growth of zooplanktons and phytoplankton's. Just like fertilization, it makes the pond water to turn green indicating abundance of planktons and an increase in fish food. Besides the natural feeds, the fish are also fed with supplemental feeds where they are spread in the water containing fish. In other cases, the feed is put in a bag which is then tied on a specific spot and is introduced to the fish at a specific time (Madu, Sogbesan and Ibiyo, 2003).

In other cases, fry of fish is usually fed with paste from boiled chicken egg. This has proven to be very nutritious as it contains very high protein content enhancing fry growth and development. One of the technologies used in feed formulation is feed processing. Processing is the collective or individual mechanical treatments subjected to single or multiple components in manufacturing an aquatic feed (Abowei and Ekubo, 2011). Tilapia feeds are often processed into pellets of different sizes depending on the size of fish (Goddard, 1996).

There majorly two kinds of tilapia feeds. The dry feeds and the wet feeds. The feeds are also produced in other forms like crumbles, marsh and pellets. The pellets are created after

compacting the feed ingredients that have been mixed into different ratios. These mixed feed are then compacted and forced through die openings through a mechanical process. On the other hand, mash is a combinations of ingredients in form of meal while crumble are pellets that have been reduced into granular form (Azim *et al.*, 2005).

To manufacture these feeds, the equipment used ranges from those used in reducing particle size like grinders (roller and hammer mills) mixers to the pelletizers. All of them perform different ranging from reducing particle size, pelletizing, extrusion, compacting and crumbling (Goddard, 1996).

2.4.5 Breeding protocols/procedures

The breeding of tilapia is usually done in earthen ponds, hapas or concrete tanks. Tilapia brood stock of between 40 to 250 in the hapas, tanks or earthen ponds at a sex ratio 1: 3 which is one male and three females. The fish are then fed twice everyday with supplemental feeds at 3 to 5% of body weight. After 2 to 4 weeks of stocking the brood stock, the fry is then collected on a daily basis on the water surface by dipnetting. After four weeks, harvesting of the breeders is done and they are separated based on their sex for conditioning them in holding units which can be net enclosures (Guerrero 1987).

The breeders are conditioned for a period of two weeks while being fed with a formulated diet twice daily (Guerrero 1987). The collected fry are then taken to the hatcheries where feeding is introduced too them using live feeds like artemia and they are later given formulated diets.

2.5 Use of non-conventional feed ingredients in feed formulation.

Utilization of several non-conventional feeds has been observed to improving fish growth and meat quality. Focus is on the use of insects, worms, garden snails and tadpoles among others as alternative protein source for cultured fish (Devendra, 1988). The assumption so far is that

alternative fish feeds can supply adequate essential nutrients requirements for fish growth and health (Devendra, 1988).

Non-conventional fish feeds are those ingredients that have not yet been used in the production of fish feed due to limited research on their protein content and insufficient information on their benefits as ingredients in fish feeds. Limited findings indicate that non-conventional fish feeds possesses high nutrient quality that can favourably be compared with the conventional types. The expectation is that they are likely to be cheaper due to the fact that they are from plants or animals not regularly used as food by humans (Roberts, 1989).

The plant protein source of fish diets thus includes; leaf meal, leaf protein, aquatic macrophytes, mucuna bean, bread beans, winged beans, yam beans and any other legume that can produce pods containing seeds (Nandeeshha *et al.*, 1998).

Spirulina is another plant protein that has been used in aquaculture for feed formulation. Spirulina has been used for supplementing the feeds for fish larvae and was very effective (Lu and Takeuchi, 2004). It has also been used in producing diets for the juveniles of common carp and the adults (Nandeeshha *et al.*, 1998, 2001; Palmegiano *et al.*, 2005, 2008). Henson (1990) reported that, fish that were fed with Spirulina showed an improvement in the quality of their flesh flavour, its colour and its consistency. He further reported that sea bream, Yellow tail, ornamental koi carp and the Mackerel were able to exhibit an enhanced coloration after being fed with Spirulina supplements. Cohen and Vonshak (1991) and Mahajan and Kamat (1995) also proposed that Spirulina could can be used as a supplement or being added to food to prevent diseases and keep an individual healthy.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

The present study was conducted at the University of Nairobi aquaculture lab using 300 fry of *Oreochromis niloticus* from January to April 2017

3.2 Collection and stocking of the fry

Oreochromis niloticus fry of initial mean weight of 1.693 ± 1.424 g used in this experiment were obtained from Kiama fish farm in Sagana, Kenya. They were then packed in double plastic bags (18 by 32 inches) which was then filled with $\frac{3}{4}$ of oxygen gas and $\frac{1}{4}$ proportion of water. The plastic bags were then twisted and sealed tightly with rubber bands to make them air tight. The plastic bags were put in cornered containers to avoid corner collapse which may lead to suffocation. The fry were then transported to the University of Nairobi aquariums where they were acclimatized for a period of two weeks before the experiment began. After the acclimatization period, the fry were sampled randomly and their weight taken using the electronic scale (Scout Pro Balance, Ohaus) (in order to be able to establish the individual weight at the start of the experiment) and results recorded. The individual length of each fry was also measured using a 50cm ruler and results recorded.

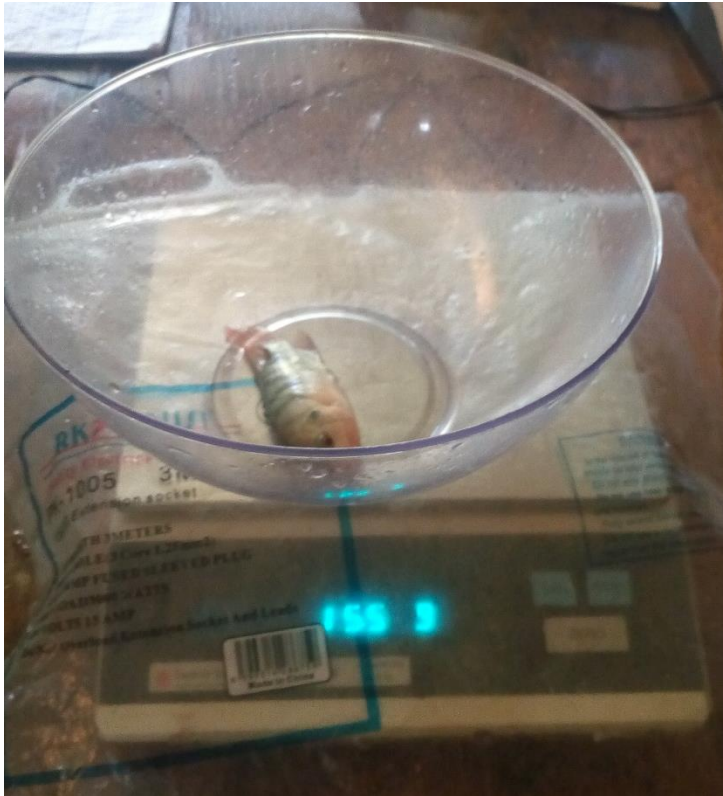


Plate 1: Measuring of weight of the fry using an electronic weighing scale

3.3 Collection of feed ingredients

In preparation of feed for feeding the experimental fish, ingredients for feed preparation were purchased from the local market in Kenya. These ingredients included wheat bran, flour and shrimps (*C. nilotica*). Wheat bran and *C. nilotica* were purchased from an agrovet shop in Sagana which is about 80km away from Nairobi town while wheat flour used as a binder was sourced from Tuskys supermarket in Nairobi. *A. platensis* was also purchased from Dunga Spirulina farm in Kisumu (approximately 400km from Nairobi) in dried form. These ingredients were grounded separately into very fine powder using a Model BL335 dry mill kitchen blender (Kenwood, Tokyo, Japan). The feed ingredients are as shown in plate 2 below.



Plate 2: Fish feed ingredients: Caridina nilotica, Arthrospira platensis and wheat bran.

3.4 Proximate analysis of feeds and feed ingredients

Proximate analysis of ingredients and the formulated diets was done at the Department of Food Science and Technology, the University of Nairobi. Wheat bran, *C. nilotica* and *A. platensis* were analysed for crude fiber, moisture content, carbohydrate, total ash, crude fat, and crude protein by the use of standard methods of the laboratory (AOAC, 1990).

3.4.1 Moisture content

5g of the sample was dried using an oven (Gallenkamp Hotbox Oven with the fan size of 1, model EOEH610MSS manufactured by Gallenkamp (Sanyo/Weiss) in china) controlled thermostatically at temperatures of 110°C for about 12hours. The samples were finally removed after being dried and then put to cool in a desiccator before being weighed. The loss in the initial weight of the sample and the final weight was used as the gravimetric measurement of

water available in the feed ingredients. This was then calculated by expressing the diets as the percentage of initial sample weight as shown:

$$\text{Moisture \%} = \{(\text{Initial weight} - \text{final weight}) / \text{Initial weight}\} \times 100$$

3.4.2 Crude protein

Micro kjeldahl method was used in determining crude protein content (N x 6.25) (Jones, 1991). 2g of the sample was digested in 25ml of concentrated sulphuric acid using a Digester 2040 (FOSS, Denmark) with selenium tablet as the catalyst then Kjeltac 2300 auto-analyser was used in distilling the sample (FOSS, Denmark) to help in determining the content of nitrogen which had been converted to crude protein by the use of conversion factor of 6.25.

$$\text{Nitrogen \%} = \{[0.7 (V_1 - V_0)]/M\} \text{ (AOAC, 1990)}$$

Where:

V_1 – mean volume of 0.1 HCl required for the sample in ml.

V_0 - mean volume of 0.1 HCl required for the blank in ml.

M- Weight of portion taken from sample in grams.

3.4.3 Carbohydrates

The carbohydrate content in the diet was determined through the addition of moisture content, ash, fat, fibre and protein and then subtracting the value obtained from hundred.

$$\text{Carbohydrate} = 100 - (\text{protein content} + \text{moisture content} + \text{crude fat} + \text{total ash} + \text{fibre})$$

3.4.4 Ash

It was determined by incineration of 2g of the sample which were then put in a pre-weighed crucible then to a Stuart Scientific muffle furnace with temperatures of 550°C and left overnight. The difference in the final and initial weight of the crucible which is empty and that

of the crucible containing the sample became the ash content. This was then expressed as the % of the original sample.

$$\text{Ash content \%} = \{(\text{weight of ash}) / (\text{weight of the crucible})\} \times 100 \text{ (AOAC, 1990)}$$

3.4.5 Crude fibre determination

The standard method of AOAC, (1990) was used. 2g of the defatted sample was boiled in 1.25% of H₂SO₄ and in 1.25% of NaOH. Then, the residue obtained was washed before being placed in crucibles for ashing using a muffle furnace at temperatures of 550⁰C. Crude fibre which was in the defatted fibre was expressed as the percentage of original sample that had not been defatted.

$$C_{\text{fibre}} = \{(b-c)/a\} \times 100 \text{ (AOAC, 2005)}$$

Where:

c- crude fiber determination

a- Mass of sample in grams.

b- Is the of mass in grams after ashing had been done

c- Loss of mass in grams after the ashing and during the blank test.

3.4.6 Crude fat determination

Dry fat extraction method was used. A dry sample was extracted from the sample using an organic solvent. Fat was determined using the Ether extraction method using Soxhlet apparatus. After that, 1 g of a sample which is moisture free is then placed in a thimble. This content is then put in a receiving beaker in the extraction tube which had petroleum ether then their weight was taken and the content was thoroughly cleaned. The receiving beaker was then fitted with extraction apparatus to begin the extraction while the water and heater was switched on. The sample was siphoned 4-6 times and the ether left to evaporate and beaker was disconnected

just before doing last siphoning. A clean dish made of glass was the used in emptying the extract in it. The glass had ether washing and this helped in evaporating the ether using a water bath. Then the extract was dried using an oven at temperatures of 105⁰c for about 2 hours then it was cooled in a desiccator. The crude fibre percentage was calculated with the following formula:

$$\% \text{ crude fat} = \text{weight of ether extract} / \text{weight of the sample}$$

3.5 Experimental diet preparation

Five experimental diets were prepared with shrimps (*C. nilotica*) and *A. platensis* to make diets using wheat bran, wheat flour and multivitamin and and they were formulated to have 35% of crude protein. T₀ which is the control diet contained (0%) of *A. platensis*, while diet T₁, T₂, T₃ and T₄ contained 10, 20, 50 and 100% *A. platensis* as indicated in table 4 below. The feed ingredients obtained and already grounded into a fine powder were individually weighed and then mixed thoroughly into different ratios for the preparation of the five diets. The formulated diet was then dried after which they were put inside airtight containers for feeding the fish.

Table 4: Formulated diets composition used in the present study (grams).

Ingredients	10% <i>A.platensis</i>	20% <i>A.platensis</i>	50% <i>A.platensis</i>	100% <i>A.platensis</i>	Control diet
<i>C. nilotica</i>	412.1	378.5	253	-	462.4
Wheat bran	541.3	541.3	541.3	541.3	524.6
<i>A. platensis</i>	33.6	67.2	192.7	445.7	-
Wheat flour	3	3	3	3	3
Vitamin premix	10	10	10	10	10

3.6 Experimental design

Fifteen aquaria with sizes 60cm * 40cm * 20cm were used in this study. Twenty-five fry were randomly sampled and each batch put into the aquariums. The five dietary treatments with which fish meal was replaced with different concentrations of *A. platensis* were assigned randomly to the aquariums in triplicates. The aquaria were connected to a temperature controlled system (heaters) (JAD microprocessor digital heater, DR 9200 manufactured in Amazon, UK) and air pumps (Resun, AC 9908 manufactured by Jeneca independent international, China) for aeration. All aquaria were placed on laboratory benches for ease of accessibility and observation. Clean water was supplied from a reservoir tank into each aquarium using inlet pipes and the dirty water was drained by siphoning it with a pipe. The set up of the experimental design is shown in plate 3 below.



Plate 3: The laboratory set up where the experiment was carried out.

3.7 Feeding protocol

The fry were fed daily at 10% body weight at 10.00am and at 4.00 pm for a period of two months. The aquaria were cleaned daily prior to the feeding period by siphoning the faecal matter and wasted feed from the bottom of the tank using siphoning pipe. Warm ($26\pm 2^{\circ}\text{C}$) dechlorinated water was replaced in the tank using water from a reservoir tank to replace the

siphoned water removed during cleaning. Measurement of weight and length was also done weekly for the two-month period.

3.8 Water quality monitoring

Water temperature and the levels of dissolve oxygen were daily measured in the morning, mid-morning and evening using HANNA DOD meter model HI9142 manufactured by HANNA instruments in Singapore. The pH level was also measured twice daily using pHep pH meter, model H198107 manufactured by HANNA instruments in Woonsocket, Rhode Island. TAN was determined by titration at the food nutrition lab in the University of Nairobi, Kabete campus from water samples collected and transported there from Chiromo campus in small plastic containers in a cooler box.

3.9 Growth measurements/parameters

At the start of the experiment, the weight of fish was taken and after that, the weight was taken on a weekly basis. Fish weight gain was obtained by subtracting fish wet weight during the start and from when weight was taken again.

After the experiment, the fry from the aquariums were removed, counted and weight measured. Their growth performance was evaluated according to SADO *et al.* (2008) as follows:

3.9.1 The specific growth (SGR)

Specific growth rate (SGR) was expressed as the percentage increase in the fish weight per day over the time interval of the experimental period. The SGR was determined according to Ricker (1979) calculated as:

$$\text{SGR (\%)} = [(\ln W_f - \ln W_i) \times 100] / t$$

Whereby;

W_i- initial mean weight of the fish

W_f- final mean weight of the fish

t- Time in days from the time of stocking to the time of the harvest.

3.9.2 Fulton's Condition factor (K)

The Fulton condition factor (K) of the fish was determined according to Bagenal and Tesch (1978) as follows:

$$K = (BW/SL^3) \times 100$$

Where:

BW is the mean weight of fish body in grams.

SL is the mean standard length of fish in cm.

3.9.3 Percentage survival of fish

The survival of fish after the experiment was determined by:

The fish Survival (%) = $100 \times (\text{total number of fish after the experiment} / \text{total number of fish at the start of the experiment})$

3.9.4 Weight gain

Weight gain (WG) was obtained by subtracting final fish body weight from the initial fish body weight over a specified period. It was computed as shown below:

$$WG\% = \{(\text{the final fish weight} - \text{initial fish weight}) / \text{initial fish weight}\} \times 100$$

3.9.5 Feed conversion ratio (FCR)

The FCR was obtained according to Anderson and De silva, (1995).

FeedConversionRatio = Feed taken by the fish during the experiment (g) / Weight that fish gained during the experiment (g)

3.10 Partial economic analysis

Cost effectiveness of experimental diets for the two-month period was assessed using a non-complex method of economic analysis. The market price of the ingredients used in feed formulation was used in calculating the feed cost. These included:

$I.C = \text{feed cost}/\text{produced fish weight}$

I.C therefore is cost of feed incurred to be able to produce one kilogram of fish and the lower the I.C value, the more profitable it will be to use the selected feed (Nwanna, 2003).

Profit index (PI)

$P. I = \text{produced fish weight}/\text{value}/\text{feed cost}$

3.11 Statistical Analysis

Length, weight and water quality results were subjected to one-way ANOVA to test for significant differences between the experimental group ($P < 0.05$) and the control group. Whenever the variation were found to be significant ($P \leq 0.05$), means were then compared using the Tukey's test. The statistical analysis were performed using GENSTAT version 15 manufactured in VSN International, Hemel Hempstead, UK and the results obtained from the analysis were presented as the mean \pm SE (standard error).

CHAPTER: FOUR RESULTS

4.1 Physico-chemical water parameters of the different treatments diets

The physicochemical water parameters of the fish culture environment in the aquaria were observed over the two months' period of the experiment (Table 5). The temperature was in the range of 27.88⁰C to 28.02⁰C in all the tanks and did not differ significantly among the five dietary treatments ($F_{4,8} = 0.44$, $p > 0.05$). Dissolved oxygen (DO) concentration was in the range of 7.22Mg L⁻¹ to 7.41Mg L⁻¹ and didn't show any significant difference ($F_{4,8} = 0.7$, $p > 0.05$) in all the treatments while pH ranged from 7.473 to 7.561 and did not also differ ($F_{4,8} = 0.64$, $p > 0.05$) amongst the treatments.

Total ammonium nitrate (TAN) significantly varied among the treatments within the two months of the study ($F_{4,8} = 2.11$, $p > 0.05$). T₀ (control diet) had the highest TAN value of 0.81ppm while the lowest was in T₄ (100% *A. platensis*) with 0.37ppm.

Table 5: Water quality parameters in the present study.

	T ₁	T ₂	T ₃	T ₄	T ₀
TEM (°C)	28.02±0.045 ^a	27.91±0.147 ^a	27.91±0.083 ^a	28.01±0.037 ^a	27.88±0.098 ^a
DO Mg L⁻¹	7.41±0.023 ^a	7.46±0.070 ^a	7.22±0.181 ^a	7.30±0.094 ^a	7.33±0.074 ^a
pH	7.55±0.007 ^a	7.561±0.003 ^a	7.533±0.015 ^a	7.473±0.051 ^a	7.482±0.073 ^a
TAN (ppm)	0.78±0.127 ^a	0.59±0.342 ^b	0.49±0.092 ^c	0.37±0.039 ^d	0.81±0.172 ^a

Mean (±SE) values in the same row having similar superscript letters do not show any significant variation ($P > 0.05$).

4.2 Proximate analysis of feed ingredients and the formulated diets.

Proximate analysis of feed ingredients and formulated diets is indicated in table 6. The moisture content varied significantly among the three ingredients ($P_{2,4} = 3.9$, $p < 0.05$). Wheat bran had the highest moisture content (10.4 ± 0.058) and *A. platensis* recorded the lowest

moisture content (7.4 ± 0.006). The moisture content of formulated diets was highest in T₀ (control diet) (5.757 ± 0.064) and lowest in T₁ (with 10% *A. platensis*) (4.053 ± 0.132). However, T₁ (10% *A. platensis*), T₂ (20% *A. platensis*) and T₄ (100% *A. platensis*) did not record any significant difference ($p > 0.05$).

Fat content varied significantly among the three ingredients with the test statistic of ($P_{2,4} = <.001, p < 0.05$). The fat content was higher in *C. nilotica* (4.467 ± 0.033) and lower in wheat bran (3.2 ± 0.058). The fat content of the formulated diets was highest in T₀ (control diet) (6.797 ± 0.083) and lowest in T₃ (50% *A. platensis*) (5.213 ± 0.060). However, the fat content did not significantly differ among T₁ (10% *A. platensis*), T₂ (20% *A. platensis*) and T₄ (100% *A. platensis*) ($p > 0.05$).

The crude protein content varied significantly among the three ingredients with a test statistic of ($P_{2,4} = 4.09, p < 0.05$). The crude protein was significantly higher in *A. platensis* (66.02 ± 0.006) then in *C. nilotica* (53.63 ± 0.088) followed by wheat bran (11.73 ± 0.067). Moreover, no significant difference was recorded among the five formulated diets ($F_{4,8} = 0.25, p > 0.05$). The crude protein content was constant (35%) for all the treatments.

Significant variation was also observed in ash content among the three ingredients ($P_{2,4} = 0.16, p < 0.05$). The highest ash content was recorded in *C. nilotica* (15.2 ± 0.058) and the lowest in wheat bran (2.967 ± 0.067). In formulated diets, the highest ash content was recorded in T₃ (50% *A. platensis*) and the lowest in T₂ (20% *A. platensis*). No significant difference was observed in ash content between T₁ (10% *A. platensis*) (7.643 ± 0.159), T₂ (20% *A. platensis*) (7.577 ± 0.057), T₄ (100% *A. platensis*) (7.873 ± 0.023) and T₀ (7.827 ± 0.085) ($p > 0.05$).

The three ingredients also showed significant variation in fibre content ($P_{2,4} = 3.81, p < 0.05$). The fibre content was higher in wheat bran (9.767 ± 0.033) and lower in *A. platensis* (0.66 ± 0.006). Fibre content in the formulated diets was significantly higher in T₁ (10% *A. platensis*)

(9.317 ± 0.051) and lower in T₃ (50% *A. platensis*) (5.317 ± 0.055) ($p < 0.05$). There was no significant difference observed in fibre content among T₂ (20% *A. platensis*) (8.533 ± 0.057), T₄ (100% *A. platensis*) (8.343 ± 0.088) and T₀ (control) (8.31 ± 0.173) but they differed significantly with T₁ (10% *A. platensis*) and T₃ (50% *A. platensis*).

Moreover, the carbohydrate content varied significantly among the three ingredients ($F_{2,4} < 0.001$, $p < 0.05$). The highest content of carbohydrate was recorded in wheat bran (61.94 ± 0.005) and the lowest in *A. platensis* (14.63 ± 0.04). In the formulated diets, T₃ (50% *A. platensis*) recorded the highest carbohydrate content of 41% while T₀ (control) had the lowest 33% (Table 6).

The value of energy in the three ingredients was in the range of 323.48 – 358.40 Kcal/100g indicating significant variation ($p < 0.05$). The energy content was higher in *A. platensis* (358.4 ± 0.552) and lower in wheat bran (323.40 ± 0.552). The energy content in the formulated diets did not show any significant difference ($P > 0.05$) and it ranged from 322 to 323 Kcal/100g with the highest being recorded in T₂ (20% *A. platensis*) (323.75Kcal/100g) and the lowest in the T₀ (control) (322.99 Kcal/100g).

Table 6: Nutrient composition of feed ingredients

Diets	Moisture%	Fat (%)	Protein (%)	Ash (%)	Fibre %	CHO Mg/L	Energy Kcal/100g
T₁ (10%<i>A. platensis</i>)	4.053±0.132 ^d	6.747±0.061 ^c	35.19±0.096 ^a	7.643±0.159 ^b	9.317±0.151 ^a	37.05±0.63 ^c	323.68±1.202 ^a
T₂ (20% <i>A. platensis</i>)	4.773±0.047 ^c	6.457±0.027 ^d	35.13±0.046 ^a	7.577±0.057 ^b	8.533±0.057 ^b	37.53±0.39 ^a	323.75±1.014 ^a
T₃ (50% <i>A. platensis</i>)	5.21±0.058 ^b	5.213±0.060 ^e	35.16±0.026 ^a	8.09±0.012 ^a	5.317±0.055 ^d	36.01±0.069 ^d	323.50±1.66 ^{ab}
T₄ (100% <i>A. platensis</i>)	4.673±0.081 ^c	6.797±0.083 ^b	35.12±0.055 ^a	7.873±0.023 ^{ab}	8.343±0.088 ^c	37.20±0.056 ^b	323.45±1.025 ^b
T₀ (control)	5.757±0.064 ^a	7.65±0.069 ^a	35.12±0.052 ^a	7.827±0.085 ^{ab}	8.31±0.173 ^c	33.35±0.026 ^c	322.99±1.546 ^b
Wheat bran	10.4±0.058 ^a	3.2±0.058 ^c	11.73±0.067 ^c	2.967±0.033 ^c	9.767±0.033 ^a	61.94±0.005 ^a	323.48±0.617 ^c
<i>A. platensis</i>	8.27±0.088 ^b	4.467±0.033 ^a	53.63±0.088 ^b	15.2±0.058 ^a	0.8±0.058 ^b	17.63±0.073 ^b	325.24±0.601 ^b
<i>C. nilotica</i>	7.43±0.006 ^c	3.977±0.009 ^b	66.02±0.006 ^a	7.287±0.003 ^b	0.66±0.006 ^c	14.63±0.047 ^c	358.40±0.552 ^a

Mean (± SE) values in the same row having the same superscript(s) do not significantly vary (P > 0.05).

4.3 Growth performance of *Oreochromis niloticus* fed on the experimental diets.

The initial weight of the *O. niloticus* fry ranged from 1.5 to 1.7 g (table 7). The mean body weight of fish increased progressively during the two months' experimental period and was significantly higher ($p < 0.05$) at the end of the experiment (Mean= 12g) than at the beginning (Mean= 2g). Moreover, at the end of the experiment, fish fed on diet with 20% *A. platensis* (T₂) had a significantly higher ($p < 0.05$) weight gain (Mean = 761.34) compared to control diet (T₀) (Mean = 608.5%) (Table 7). However, the weight gain of the fish fed on diet with 50% *A. platensis* (T₃) (700.79%) did not significantly vary ($p > 0.05$) from those fed on diet with 10% *A. platensis* (T₁) (633.79) and with diet containing 100% *A. platensis* (T₄) (706.49) (Table 7).

Table 7: Growth performance of *Oreochromis niloticus* in the present study.

Growth performance	T₁	T₂	T₃	T₄	T₀
Initial mean weight	1.693±0.072 ^a	1.609±0.068 ^{ab}	1.524±0.057 ^b	1.54±0.082 ^b	1.502±0.064 ^b
Final mean weight	12.42±0.376 ^b	13.86±0.309 ^a	12.2±0.333 ^b	12.43±0.366 ^b	10.64±0.233 ^c
Weight gain	10.727±0.143 ^b	12.251±0.132 ^a	10.676±0.134 ^b	10.89±0.524 ^b	9.138±0.098 ^c
% weight gain	633.79±15.22 ^c	761.34±10.29 ^a	700.79±12.71 ^b	706.49±9.29 ^b	608.52±6.32 ^d
SGR (g day ⁻¹)	3.321±0.048 ^{bc}	3.589±0.055 ^{ab}	3.467±0.066 ^b	3.481±0.053 ^b	3.265±0.034 ^c
Condition factor (K)	1.27±0.043 ^b	1.23±0.034 ^b	1.35±0.00.061 ^a	1.18±0.037 ^c	1.37±0.026 ^a
FCR	1.05±0.023 ^{bc}	1.11±0.014 ^a	1.07±0.012 ^b	1.08±0.053 ^b	1.03±0.036 ^c
Survival (%)	100	100	100	100	100

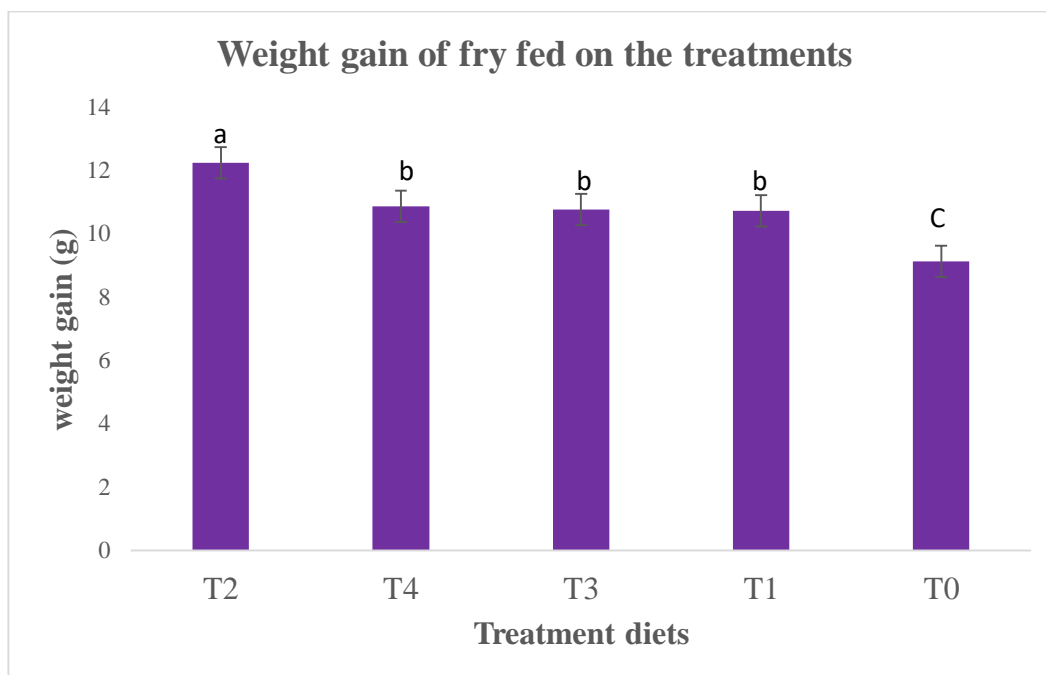


Figure 1: Weight gain of *Oreochromis niloticus* fed on the treatment diets.

Bar graphs accompanied by similar letters do not significantly vary ($p \leq 0.05$); standard error of the mean is represented by error bars.

Figure 1 above shows the weight gain of the fry fed on the five treatment diets with the highest being in T₂ and lowest in T₀.

The highest specific growth rate was observed in fry fed on diet containing 20% *A. platensis* (T₂) (3.589%/day) while lowest specific growth rate was recorded in the control diet (T₀) (3.265%/day). However, no significance difference was recorded in SGR was recorded in the diet containing T₂ (3.589%/day), T₃ (3.467%/day) and T₄ (3.481%/day)

The survival of the fry fed with the five treatments remained constant throughout the experimental period (100% survival) and there was no any observed mortality during the experiment. No significant difference in the survival rates was observed among the experimental fish during the two months ($p > 0.05$).

Significant differences on condition factor was recorded among the five treatment diets $F_{4,28} = 27.65$, $p > 0.05$. The condition factor of the fry ranged from 1.18 to 1.37 with highest condition factor being observed in diet with 50% *A. platensis* (T₃) and control diet (T₀) compared to T₁ (diet with 10% *A. platensis*), T₂ (diet with 20% *A. platensis*) and T₄ (diet with 100% *A.*

platensis) ($p < 0.05$). The highest condition factor was recorded in the T₀ (1.37) with lowest condition factor being observed in T₄ (1.18).

The FCR was in the range of 1.03 to 1.11. The FCR was significantly higher in T₂ (diet with 50% *A. platensis*) (1.11) and lower in T₀ (control) (1.03) ($p < 0.05$). There was no significance variation in FCR between T₃ (diet with 50% *A. platensis*) and T₄ (diet with 100% *A. platensis*) and between T₁ (diet with 10% *A. platensis*) and T₀ (control diet).

4.4 Partial economic analysis

As illustrated in table 8 among the treatments, diet with 100% *A. platensis* recorded the highest incidence cost (I.C) (14.858) followed by diet with 50% *A. platensis* (6.230), then diet with 20% *A. platensis* (2.353), diet containing 10% *A. platensis* (1.561) and finally control diet (58.62). Moreover, fish fed with the control diet had the highest profit index compared to the fish fed on the other diets.

Table 8: Partial economic analysis of formulated diets

Diet	Feed				
	Cost Kg ⁻¹ (Ksh)	input(g)	Weight gain	IC	PI
10% <i>A.platensis</i>	251.32	1000	10.73	1.561	0.640
20% <i>A.platensis</i>	432.13	1000	12.25	2.353	0.425
50% <i>A.platensis</i>	996.4	1000	10.68	6.230	0.161
100% <i>A.platensis</i>	2037	1000	10.88	14.858	0.008
Control	58.62	1000	9.14	0.428	2.339

CHAPTER: FIVE DISCUSSION

5.1 Discussion

Temperature is paramount for optimum growth of fish because it directly influences feeding, growth and maturation of fish (Amoah, 2012). According to Ngugi, Bowman and Omolo, (2007), temperature range of 20⁰C to 35⁰C is ideal for tilapia culture. Kauser and Salim (2006) also reported that, a temperature of 25⁰C to 27⁰c is ideal for the survival and growth of the tilapia. The study recorded a temperature that was in the range of 27.9⁰C to 28.0⁰C. This were within the optimum limit of tilapia fish as recorded by Amoah (2012). The results from present study were also the same as those observed in laboratory experimental set ups for *O. niloticus* elsewhere (Hauser, 1977; Makori *et al.* 2017).

Saoud, Mohanna and Ghanawi, (2008) observed that, low water temperature restricts growth of fish because of low feed intake and low metabolic rate. Thus, since the present study didn't record any low temperatures, the fish were able to feed well and metabolise which contributed to their positive growth. Robinson and Li (2012) further explained that low temperatures below 20⁰C generally reduces the feeding activity of fish and the fish stops eating at temperatures of 10⁰C. temperatures in the range of 27.9⁰C to 28.0⁰C reported in present study were similar to those recorded in laboratory experimental set ups for *O. niloticus* elsewhere (Hauser, 1977; Makori *et al.* 2017). In this study, since the water mean temperature was within the optimum range (standard range 19⁰C -30⁰C) for all treatments, the feeding activity of the fish was not reduced but they were expected to be feeding actively thereby contributing to their growth.

Dissolved oxygen (DO) is the most paramount water quality parameter for all fish and aquatic life (Ajiboye *et al.* 2015; Sallenave, 2012). A concentration of dissolved oxygen concentrations below 3 mgL⁻¹ stresses the fish increasing their susceptibility to diseases and may result to death (Sallenave, 2012). On the lower limits of dissolved oxygen, Ross (2008) reported that, a concentration of DO of 3mg/L is minimum for the growth of tilapia. The concentration of

dissolved oxygen (DO) recorded in this study was in the range of 7.22 to 8.1 mgL⁻¹ throughout the experimental period and was above the lower limit required for tilapia culture. This observation was consistent to results obtained by Green (2010), Bhatnagar *et al.* (2004), Bhatnagar and Singh (2010), Musa *et al.* (2012), Riche and Garling (2003) who recorded DO levels of between 7 to 8 mgL⁻¹ in tilapia culture. The present study also recorded dissolved oxygen more than 3mg/13 mgL⁻¹, this was above the minimum limits reported by Ross (2008) which may have contributed to the high fish survival recorded in the present study. In contrast to the observation in the present study, Kramer (1987) reported that, dissolved oxygen > 6 mgL⁻¹ can cause excessive water saturation, which may lead to the “gas bubble disease”. However, the present study recorded DO >7 but did not encounter any cases of the gas bubble disease and the survival rates of the fish were very high. Therefore, DO for the present study indicated that, a range of 7-8 mgL⁻¹ levels of dissolved oxygen are excellent for the survival and the growth of *O. niloticus* fry.

According to Abbas *et al.* (2008), BFAR (1992), Boyd (1979), Crane (2006), Mazik *et al.* (1991), Santhosh and Singh (2007), a pH range of 6 mgL⁻¹ to 9 mgL⁻¹ is optimum for tilapia growth. Sallenave (2012) further agreed that, the pH value outside the range of 6 to 9 mgL⁻¹, results to reduced growth and increased mortalities as the average pH of fish blood is 7.4 and thus further deviation from 7.4 stresses the fish reducing its feeding which may contribute to mortalities. Bryan *et al.* (2011) also reported that, majority of fish species grow well at pH levels close to 7.0 and pH below 6.0 can lead to stunted growth and reduce the survival rate of fish. The pH concentration observed during the experiment was in a range of 7.5 to 7.7 in all the tanks. This range proved to be favourable for culture of *O. niloticus* fry as they were within the optimum range reported by other studies. The pH range of the present study also concurred with the results from Phillippart and Ruwet (1980) and Chervinski (1980) who reported that the species of tilapia is able to grow well and remain healthy at pH close to neutral. Therefore,

based on the results obtained in the present study, the pH was within the required range of tilapia species which thus enabled the fish to feed well, grow and survive well while remaining healthy. Moreover, according to Wurts (2000), high levels of pH increases the TAN levels in water. This causes water toxicity and mortality to fish. However, since the pH level was low and remained constant during the time of the study, the TAN levels also were within the acceptable limits required for tilapia culture.

Ammonia is a very crucial parameter for good production in aquaculture. Ammonia exists in two forms in water. The un-ionized toxic ammonia (NH_3) and the non-toxic ammonia. Ammonia presence in water is normal because of fish metabolism. The higher the temperature and pH, the concentration of toxic ammonia increases (Boyd, 1998). According to Chapman (1992), the levels of Total Ammonia and Nitrite (TAN) of 0.3 to 0.8 ppm are acceptable for tilapia culture. This concurred with the present study results with TAN levels of between 0.38 to 0.81ppm. Besides that, the TAN level recorded in the present study was less than the lethal levels of 2.4ppm recorded by Daud, Hasbolla and law (1988) for red tilapia hybrid cross. It also concurred with results from Leclerg and Hopkins (1985) who obtained TAN levels of less than 0.81ppm in the culture of tilapia. Moreover, Boyd (1998) reported that, TAN concentration higher than 3-4 ppm is toxic to water with pH 8 to 9 ppm which was not so in this study. Thus, since TAN did not exceed the lethal levels reported to be toxic for tilapia fish, the fry were able to survive and grow as water was within the range favourable for their survival.

According to Boyd (1998), levels of dissolved oxygen in water decreases as the temperature in water increases. However, in the present study, water temperature remained constant throughout the experimental period and did not affect the DO levels. Therefore, dissolved oxygen, temperature, pH and TAN remained constant throughout the experimental period.

There were no fluctuations in temperature nor the DO which in turn caused the pH and TAN to remain constant.

The present study observed that, wheat bran had the highest content of moisture while Spirulina had the lowest. The recommended content for moisture on fish feeds is less than 12% to prevent feed from moulding and to maintain palatability (Robinson and Li, 2012). High moisture content increases deterioration of feeds and reduces its self-life (Adefemi, 2011). Proximate analysis of the experimental diets in the present study indicated a low moisture content for all the experimental diets (7-8%). This implies that, the storage span or shelf-life of the diets will be high, hence they can be stored for a long period. The shelf life could thus be improved probably by drying the feed in an oven before storing them to reduce the content of moisture in them and increase its storage span.

Fats are highly digestible and plays crucial role as they provide energy source which improves fish growth together with its development (Robinson and Li, 2005). Diet without fats decreases the growth of fish as it decreases fish weight (Obeng, Atuna and Aihoon, 2015). The optimum requirement of fat in the diet of tilapia ranges from 5-20% (Han *et al.*, 2010; Lim, Oksoy, and Klesius, 2011). In the present study, fat content varied among the feed ingredients and was higher in shrimps and lower in wheat bran and the recorded fat content for the formulated diets ranged from 5-7% which was within required range for tilapia diets.

According to Jauncy and Ross (1982); Lovell (1989), protein is the main factor that promotes growth in feeds and is very important in fish diet and its sufficient supply is needed to enhance growth of fish. The crude protein of present study was highest in Spirulina while wheat bran had the lowest. The proportion of protein in wheat bran and shrimps was estimated to be 12% and 54% which concurred with results from Obeng, Atuna and Aihoon, (2015). The findings were also similar to research by Wurts (2000) who observed that protein content in shrimps is between 50 to 60 and 9 to 15% for wheat bran. The high protein content in shrimps may have

probably contributed to significant growth of the fry in the present study. In all the formulated diets, crude protein was 35% and was in the range recommended for tilapia fry (El-sayed and Teshima, 1992). These results agreed with Jauncey and Ross (1982) who recorded that, protein range of 35-56% is ideal for growth *O. niloticus* fry. Balarin (1982) also combined different studies and concluded that tilapia fry <1g require diet containing 35-50% crude protein for it grow well which compares well with results from the present study as the protein content in feeds was 35%. Based on these studies, for aquaculture to continue growing in Kenya, farmers should learn to use protein quantities which are sufficient for fish growth and avoid using excess protein in the diets of fish as this will be wasteful and will increase the cost of producing feeds. This is because, reducing the cost of feeds is the key factor for a successful aquaculture development in Kenya.

Ash content is a good measure of the total mineral elements like calcium and phosphorous in feeds (Obeng, Atuna and Aihoon, 2015). The ash content significantly varied among the three ingredients and ranged from 7-8% in the formulated diets. In the present study, Spirulina and shrimp contained high amount of minerals due to its high ash content. This high ash content in ingredients could have positively influenced the growth of tilapia because of the presence of mineral that promotes growth. The ash content of 7-8% also recorded in formulated diets indicated that the feed contained enough minerals elements like phosphorus and calcium for enhancing fish growth (Obeng, Atuna and Aihoon, 2015). This was in agreement with results from Kiriratnikom and Kiriratnikom (2012) and Cornélio *et al.* (2014) who reported that high ash content of >7% in feed has been reported to produce better growth performance.

Fibre is very important in fish feed as it gives it the physical bulkiness (Obeng, Atuna and Aihoon, 2015). The presence of fibre in feed helps in binding and moderating the passage of food in the alimentary canal (Ayuba and Iorkohol, 2013). However, high levels of fibre content exceeding 9-12 % in fish feed are not advisable as it “lowers digestibility of nutrients” and

slows the growth (Adewolu *et al.*, 2010; Agbabiaka *et al.*, 2013). Fibre content observed in the present study was high and significantly varied among the feed ingredients. Wheat bran was abundant in crude fibre content while Spirulina had the lowest content. On the other hand, crude fibre of formulated diets ranged from 5 to 9% which was within the recommended quantities. This low crude fibre content in the ingredient and diets could have helped in improving the fry growth possibly due to increased digestibility.

Carbohydrates are essential nutrients in fish diets since they act as energy source for fish growth and reproduction (Obeng, Atuna and Aihoon, 2015). Soluble carbohydrates contained in fish feed helps in giving “stability and integrity of pellets and reducing their density” (Gatlin, 2010). The low proportion of carbohydrates in the feed ingredients could be positively correlated to the good growth rate observed in tilapia fry. Fish requires small amount of carbohydrate and the carbohydrate requirement for optimum growth in tilapia is 22 to 46% (Wang *et al.*, 2005). Carbohydrate content in the present study was in the range of 37 to 41% and was within the range needed for growth of *O. niloticus*. The high content of carbohydrate provided the fish with energy source enabling them to grow well.

The value of energy in feed ingredients was in the range of 323 to 358 Kcal/100g, and was highest in Spirulina and lowest in wheat bran. This energy content of the feed ingredients made them suitable to be used in tilapia feed formulation. Moreover, the experimental diets energy content was 323Kcal/100g in the current study, and was within the optimum energy range required by fish as reported by Robinson and Li (2005). This energy content may have contributed to the survival and growth of the fry for the two-month period.

Growth performance of *O. niloticus* in the present study indicated that, fish weight increased significantly during the two months' experimental period. Weight gain and percentage weight gain was highest in T₂ (20% *A. platensis*) followed by T₄ (50% *A. platensis*), T₁ (10% *A.*

platensis), T₃ (50% *A. platensis*) and finally T₀ (control diet). These concurred with results from Belay and Ota (1996) who recorded a weight gain increase for rainbow trout which was fed with diet containing *A. platensis*. Improved growth rate in diet replaced with 20% spirulina in the present study indicated that, spirulina can replace fish meal at 20% and improve survival and fish growth.

Similar findings were reported by Nandeeshha *et al.*, (2001) who observed that Spirulina can completely or partially substitute fishmeal in fish diet. El- Sayed (1994) further indicated that, Spirulina can be an excellent replacer for fish meal in Sea bream diet. In contrast to that, Olvera-Novoa *et al.* (1998) reported a reduction in *Oreochromis mossambicus* growth fed with diets containing Spirulina while other studies proposed that, replacing Spirulina up to 100% in Siberian sturgeon (*Acipenser baeri*) and (*Cyprinus carpio*) diets did not affect growth (Palmegiano *et al.*, 2005). However, according to the results from current study, adding *A. platensis* in *O. niloticus* diet up to 100% improved growth performance although it performed best at a replacement level of 20%.

In the present study, the SGR was ranging between 3.27 to 3.59 % /day⁻¹ and it was higher in fish fed with T₂ (20% *A. platensis*) and lowest in T₀ (control diet). The good performance observed on growth of the fry fed on the feeds containing 20% of *A. platensis* indicated that the diet contained well balanced nutrients as well being highly digestible and well utilized by the fish. These results concurred with the research carried out by Nandeeshha *et al.*, (2001) who explained that, *A. platensis* improved the SGR of *Labeo rohita* and *Catla catla* (Indian carps). Similarly, observations from other studies indicated positive effect of using Spirulina as it improved the growth of other fish species which included nibbler *Girella punctata* gray with 3.1%/day (Nakazoe *et al.*, 1986), red sea bream *Pagrus major* with 1.78%/day) (Mustafa, Umino, and Nakagawa, 1994). Striped jack (*Pseudocaranx dentex*) with 1.08%/day (Watanabe *et al.*, 1990), Nile tilapia with 2.6%/day (Lu and Takeuchi, 2004). Siberian sturgeon *Acipenser*

baeri with 3.3%/day (Palmegiano *et al.*, 2005) and hybrid tilapia with 1.78%/day (Ungsethaphand *et al.*, 2010). It also agreed with report by Duncan and Klesius (1996) who reported that, Spirulina is a good protein source in animal feeds because of its high minerals and vitamins contents which helps in enhancing the animals growth rate.

The present study recorded 100% survival for all the experimental fish. This high survival was similar to the results recorded by Dernekbası *et al.*, (1993), Kiriratnikom, Zaaú and Suwanpugdee, (2005), Burr *et al.*, (2012) and James (2010) on fish given diet containing Spirulina. Similar results of higher survival rates were also reported in the estuary grouper, *Epinephelus salmoides* with a survival rate of 99.1% (Teng and Chua, 1979), 90% in *Pisodonophis boro* (Narejo, Haque, and Rahmatullah, 2002) and 99% survival rate in *Penaeus monodon* (Ali, Shafiquzzoha and Ahmed, 1999). Nakono *et al.* (1990) further reported that, due to lack of cellulose in Spirulina cellular structure, it makes it easily digestible thus enhancing fish health and survival.

The condition factor helps in showing the degree of fish health. The condition factor was in the range of 1.18-1.37 in present study. These results are in agreement with report from Ayode (2011) who reported that condition factor higher than 1 suggests the fish is in good health which is an indication that the fish has isometric growth suitable in an aquaculture farm. It also concurred with the results from Ighwela *et al.* (2011) portraying that the fish were healthy. The condition factors of the fry were also close to results recorded by Abo-state *et al.*, (2009) and Olurin and Aderibigbe (2006) who observed that condition factor ranging from 1.08 and 1.14 is a sign that the fish is in a healthy state.

FCR is the measure how efficient an animal can convert a mass of feed to biomass. In the present study, the fry FCR was in the range of 1.03 to 1.11 and was significantly higher in T₂ (20% *A. platensis*) than on other diets. According to De Silva and Hasan (2007), the FCR for fish, that are fed with a well formulated diets ranges from 0.46 and 1.15 which concurred with

the current results. The same results were observed by Takeuchi, Yoshikazi and Satoh (2002) and Ibrahim, Mohamed and Ibrahim (2013) who observed that feeding fish with diets containing *A. platensis* improved the FCR and the growth rate of striped jack (*Pseudocaranx dentex*). In addition, Takeuchi, Yoshikazi and Satoh (2002) further explained that, fish with lower FCR (less than 1.2) indicates less feed will be used in producing a kilogram of fish but high FCR (more than 1.2) will need more feed to produce a kilogram of fish. The low FCR thus indicates a high quality feed. Therefore, the results in the present study proposed that, inclusion of 20% of *A. platensis* in *O. niloticus* diet enhanced its growth and utilization of nutrients which was reflected in the improvement in their FCR, SGR and weight gain.

It is therefore clear that, fish growth corresponded with the parameters of water quality in the present study. This is because, since the parameters of water quality remained constant during the whole experiment and remained within the recommended level required for the growth tilapia, the water quality parameters influenced the growth of the fry respectively and also increased the fry survival. Good water quality parameters are therefore capable of producing healthier and larger fish compared to fish cultured in poor water quality (Boyd, 1998).

Moreover, constant specific growth rate recorded in the present study indicated a good growth of the fry contributed by the good water quality. This concurred with results from different studies where, Abdel-Hakim et al. (2009) recorded a specific growth rate of 3.308 and 3.153%/day in the culture of tilapia under the following water quality average values: DO- 7.5mg/L, pH of 7.6, temperature of 27.5 and TAN of 0.40mg/L.

According to USDA (1996), changes occurring in the parameters of water quality can adversely affect fish growth and its survival. In the current study, DO was in the range of 7.2 to 7.4mg/L, pH range of 7 and temperature of 27 to 28⁰C tended to favour the growth of the fry in the aquariums. Since the parameters of water quality in the present study were within the optimum levels required for tilapia culture, the growth and survival of fish was enhanced. This indicates

that, it is important for precautionary measures to be taken to ensure water quality parameters remain within the optimum levels for the culture of tilapia.

Besides that, Economic analysis conducted in the present study indicated that, the control diet had the lowest incident costs with the highest profit index followed by the diet containing 10%, 20%, 50% and 100% *A. platensis*. Higher incident costs and lower profit index in diet containing 10, 20, 50 and 100% *A. platensis* indicated that it is not profitable to formulate diet of *O. niloticus* while replacing shrimps with *A. platensis* but it is profitable to raise *Oreochromis niloticus* while feeding them with shrimps as the protein source. This is because, the higher incidence cost, the higher the cost of feed and this was reflected in the cost per kilogram of the diets containing *A. platensis* than using control diet. It was also noticed from the study that the lower the IC in the use of a particular diet, the higher the return or the higher the profit index value. The present study thus indicated that, although the fry performed well with inclusion of Spirulina in the diet, it is very costly to purchase it and use it in diet formulation of *O. niloticus*. On the other hand, according to the study, the control diet proved to be very profitable as feed for *O. niloticus* fry though its growth performance was low compared to diets containing Spirulina. Therefore, the study concluded that, replacing *Caridina nilotica* with *Arthrospira platensis* in the diet of *O. niloticus* would be very costly since Spirulina will be very expensive to purchase for local farmers practising aquaculture although Spirulina is correlated with improved growth and survival rates of *O. niloticus*.

CHAPTER SIX: CONCLUSIONS AND RECCOMENDATIONS

6.1 Conclusion

From the present study, the parameters of water quality were within the recommended range for tilapia fry and did not negatively influence the growth of *O. niloticus* fry. The highest weight gain and growth rate observed in *O. niloticus* fed on diet containing concentration of 20% *A. platensis* respectively correlated to the good nutritional contents found in Spirulina contributing to this improvement in the growth of *O. niloticus*. Moreover, including Spirulina in diet of tilapia is associated with an improvement in the survival of the fish. However, despite the benefits associated with including Spirulina in diet of tilapia, the study concluded that, replacing *A. platensis* in *O. niloticus* feeds increases costs and also leads to a reduction in profitability of culturing *O. niloticus* as compared to using the control diet.

6.2 Recommendations

Based on the present study, the following recommendations are made:

1. Further culturing of *O. niloticus* should be carried out in the natural environment in order to determine the period the fish will take to become table size for selling with these formulated diets.
2. Since *Arthrospira platensis* responded positively in growth of *O. niloticus* and improved its survival yet it is expensive to purchase, farmers should be taught on ways to culture it for mass production and to use it in formulating fish feed for tilapia.
3. Further studies should be conducted to identify other benefits of using Spirulina in diet of *O. niloticus* apart from protein replacement. These benefits may perhaps be associated with survival rates, disease resistance and other benefits obtained from the micronutrients contained in Spirulina.

References

- Abbas, S., Ahmed, I., Hafeez-Ur-Rehman, M., & Mateen, A. (2008). Replacement of fish meal by canola meal in diets for major carps in fertilized ponds. *Pakistan Veterinary Journal*, 28(3).
- Abdelghany, A. E., (1996). Growth response of Nile tilapia, *Oreochromis niloticus*, to dietary L-ascorbic acid, Lascorbyl- 2-sulfate, and L-ascorbyl-2-polyphosphate. *J. World Aquacult. Soc.* 27: 449–455.
- Abdel-Hakim, N. F. Abo-State, HA., Al-Azab, AA. and El-Kholy, KF., (2009). Effect of feeding regimes on growth performance of juvenile hybrid tilapia (*Oreochromis niloticus*× *Oreochromis aureus*)–*World. J. Agric. Sci*, 5, 49-54.
- Abdel-Tawwab M, Ahmad M.H, Khattab Y.A.E, Shalaby A.M.E. 2010, Effect of dietary protein level, initial body weight, and their interaction on the growth, feed utilization, and physiological alterations of Nile tilapia, *Oreochromis niloticus* (L.). *Aquaculture* 298:267-274.
- Abelghany, A.E., (2004). Replacement of herring fish meal by soybean flour in practical diets for red tilapia, *Oreochromis niloticus* x *O. mossambicus*, grown in concrete tanks. *J. App. Aqua.* 14, 69-87.
- Abo-State HA, Tahoun AM, Hammouda YA. 1996, Effects of Replacement of Soybean meal by DDGS combined with Commercial Phytase on Nile tilapia (*Oreochromis niloticus*) Fingerlings Growth Performance and Feed Utilization;4:26 – 28.
- Abowei, JFN. and Ekubo AT., (2011). A review of conventional and unconventional feeds in fish nutrition. *Br J Pharmacol Toxicol* ; 2(4):179-191.
- Adefemi, O. S., (2011). Chemical composition of *Tilapia mosambis* fish from major dams in Ekiti-State Nigeria. *African Journal of Food Science*, 5(10): 550-554.

- Adewolu, M. A., Ikenweibe, N. B. and Mulero S. M., (2010). Evaluation of an animal protein mixture as a replacement for fishmeal in practical diets for fingerlings of *Clarias gariepinus* (Burchell, 1822). *Israeli Journal of Aquaculture*, 62: 237-244.
- Agbabiaka, L. A., Okorie, K. C. and Ezeafulukwe, C. F., (2013). Plantain peels as dietary supplement in practical diets for African catfish (*Clarias gariepinus* Burchell 1822) fingerlings. *Agriculture and Biology Journal of North America*, 4(2): 155-159.
- Ajiboye, A. O., Awogbade, A. A. and Babalola, O. A., (2015). Effects of water exchange on water quality parameters, nutrient utilization and growth of African catfish (*Clarias gariepinus*). *International Journal of Livestock Production*, 6(5), 57-60.
- Al Hafedh, Y. S., (1999). Effects of dietary protein on growth and body composition of Nile tilapia, *Oreochromis niloticus* L. *Aquaculture Research*. 30: 385–393.
- Alam, S. M. D., Karim, M. H., Chakraborty, A., Amin, R. and Hasan, S., (2016). Nutritional Characterization of the Long-whiskered Catfish *Sperata aor*: A Commercially Important Freshwater Fish of Bangladesh. *International Journal of Food Science and Nutrition Engineering*, 6(1): 1-8.
- Ali, M. S., Shafiquzzoha, A. F. M. and Ahmed, S. U., (1999). Effect submerged aquatic vegetation on growth and survival of *Penaeus monodon* (Fab). *Bangladesh J. Fish Res.*, 3:145-149.
- Ali, M., Hayward, R. S., Bajer, P. G. and Whitley G. W., (2010). Maintenance/submaximum feeding schedules for reducing solid wastes and improving feed conversion in aquaculture. *Journal of the World Aquaculture Society*, v. 41, n. 3, p. 319-331.
- Amoah, Y. T., (2012). *Effect of dietary protein levels on growth and protein utilization in juvenile arctic char (Salvinus alpinu)*. United Nations University Fisheries Training 55 Programme, Iceland [final project], pp:73 – 76.

- Anderson, J., Jackson, A.J., Matty, A.J. and Capper, B.S., (1984). Effects of dietary carbohydrate and fibre on the tilapia *Oreochromis niloticus* (Linn.). *Aquaculture*, 37(4), pp.303-314.
- AOAC 1990, Official Methods of Analysis of the Association of Official Analytical Chemists. Helrich, K., (Ed.) 15 edn, Arlington, VA, USA.
- AOAC international. (2005). AOAC International Guidelines for Laboratories Performing Microbiological and Chemical Analyses of Food and Pharmaceuticals: An Aid to Interpretation of ISO/IEC 17025: 2004. AOAC international.
- Ayode, A.A., (2011). Length -Weight Relationship and Diet of African Carp *Labeo ogunensis* (Boulenger, 1910) in Asejire Lake Southwestern Nigeria. *J. Fisheries and Aquatic Sci.*, pp: 1816-4927.
- Ayoola, P. B. and Adeyeye, A., (2010). Phytochemical and nutrient evaluation of *Carica papaya* (pawpaw) leaves. *Ijrras*, 5(3), 325-328.
- Ayuba, V. O. and Iorkohol, E. K., (2013). Proximate composition of some commercial fish feeds sold in Nigeria. *Journal of Fisheries and Aquatic Science*, 8(1): 248-252.
- Azim, M.E., Verdegem, M.C.J., van Dam, A.A. and Beveridge, M.C.M. (eds.), (2005). *Periphyton: Ecology, Exploitation and Management*. CABI Publishing, Wallingford, UK, p 320.
- Bagenal, T.B. and Tesch, A.T., 1978. Conditions and growth patterns in fresh water habitats. pp 75 – 89.
- Balarin, J.A., (1982). The intensive culture of tilapia in tanks, raceways and cages. *Recent advances in aquaculture*, pp.265-356.

- BFAR, (1992). Basic biology of Tilapia. Bureau of Fisheries and Aquatic Resources. <https://www.bfar.da.gov.ph/bfar/download/nfftc/BasicBiologyofTilapia.pdf>. Quezon city. Phillipines.
- Belal, I.E.H., (1999). Replacing dietary corn with barley seeds in Nile tilapia, *Oreochromis niloticus* (L.), feed. *Aqua. Res.* 30, 265-269.
- Beresto, V., (2001). Our experience in spirulina feeding to minks in the reproduction period. *Scientifur*, 25(1/2), pp.11-15.
- Bergot, F., (1979). Carbohydrate in rainbow trout diets: effects of the level and source of carbohydrate and the number of meals on growth and body composition. *Aquaculture*, 18(2), 157-167.
- Bhatnagar, A. and Singh, G., (2010). Culture fisheries in village ponds: a multi-location study in Haryana, India. *Agric Biol J N* ;1(5):961–8.
- Bhatnagar, A., Jana, SN., Garg SK., Patra BC., Singh G. and Barman UK., (2004). Water quality management in aquaculture. In: Development of sustainable aquaculture technology in fresh and saline waters, CCS Haryana agricultural, Hisar (India); p. 203–10.
- Bowen, S.H., (1987). Dietary protein requirements of fishes—a reassessment. *Canadian Journal of Fisheries and Aquatic Sciences*, 44(11), pp.1995-2001.
- Boyd C. E., (2001). Water quality standards: total ammonia nitrogen. *The Advocate*, 4(4), 84-85.
- Boyd, C.E., (1979). *Water quality in warmwater fish ponds* (No. 639.3 B6923w Ej. 1 009523). AUBURN UNIVERSITY. p 359.
- Boyd CE. Water quality for pond aquaculture. *Res Develop.* 1998; 43:1–11.

- Brummett R. E., (2007). Freshwater fish seed supply: Africa regional synthesis, pp. 41- 58. In: M. G. Bondad-Reantaso (ed.). Assessment of freshwater fish seed resources for sustainable aquaculture. FAO Fisheries Technical Paper. No. 501. Rome, FAO. 2007, 628p. Bull. Inst. Fran.Afri.Noï.Tome XIX, Se´rie A 1, 295–323.
- Bryan R., Soderberg, W., Blanchet, H. and Sharpe, WE., (2011). Management of Fish Ponds in Pennsylvania. pp 7-12.
- Burr, G.S., Wolters, W.R., Barrows, F.T., and Hardy, R.W., (2012). Replacing fishmeal with blends of alternative proteins on growth performance of rainbow trout (*Oncorhynchus mykiss*), and early or late stage juvenile Atlantic salmon (*Salmo salar*). Aquaculture, 334-337: 110-116.
- Campbell, D., (1987). A review of the biology and culture of tilapia guineensis. Food and Agriculture Organization of the United Nations. p40.
- Chakraborty, S. B. and Banerjee, S., (2012). Comparative growth performance of mixed-sex and monosex Nile tilapia at various stocking densities during cage culture. Recent Research in Science and Technology, 4, 46-50
- Chamberlain, G. W., (1993). Aquaculture trends and feed projections. *World Aquacult. Soc.*, 24, 19- 29
- Chapman, F.A., (1992). Culture of Hybrid Tilapia: A Reference Profile. Fisheries and Aquatic Sciences Department, University of Florida, Circular 1051
- Charo-Karisa, H. and Gichuri M., (2010). Overview of the Fish Farming Enterprise Productivity Program. In: *End of Year Report Fish Farming Enterprise Productivity Program Phase I. Aquaculture Development Working Group Ministry of Fisheries Development, Nairobi, KE.* pp 1 -6.

- Chervinski, J., (1980). Environmental physiology of tilapias. In R.S.V. Pullin, R.H. Lowe McConnell (Eds.). The Biology and Culture of Tilapias. ICLARM Conference Proceedings 7, International centre for Living Aquatic Resources Management, Manila, Philippines, pp 119-128.
- Chou, B. S., & Shiau, S. Y. (1996). Optimal dietary lipid level for growth of juvenile hybrid tilapia, *Oreochromis niloticus* x *Oreochromis aureus*. *Aquaculture*, 143(2), 185-195.
- CIFA/OP24., (2000). Africa regional aquaculture review, FAO Regional Office for Africa, Accra, Ghana 2000, 50 pp. 29 November - 05 December 1999, Rome 2000, 34 pp.
- Coche, A.G. ed., (1994). *Aquaculture development and research in Sub-Saharan Africa: national reviews* (No. 23). Food & Agriculture Org, Rome, Italy.
- Cohen, Z. and Vonshak, A., (1991). Fatty acid composition of Spirulina and Spirulina-like cyanobacteria in relation to their chemotaxonomy. *Phytochemistry*, 30: 205–206.
- Corn'elio, F. H. G., Cunha, D. A., Silveira, J., Alexandre, D., Silva, C. and Fracalossi, D. M., (2014). Dietary protein requirement of juvenile Cachara Catfish, *Pseudoplatystoma reticulatum*. *Journal of the World Aquaculture Society*, 45(1): 45-54.
- Craig, S. and Helfrich, L.A., (2002). Understanding Fish Nutrition, Feeds and Feeding, Cooperative Extension Service, publication 420-256. Virginia State University, USA, pp. 26-27.
- Craig, S., Helfrich, L. A., Kuhn, D. and Schwarz, M. H. (2017). Understanding fish nutrition, feeds, and feeding. Virginia. pp 1 – 6.
- Crane, B., (2006). Results of Water quality Measurements in Messer Pond. London. Pp 1 – 9.
- Daud, S.K., Hasbollah, D. and Law, A.T., (1988). Effect of unionized ammonia on red *Oreochromis mossambicus*/*O. niloticus* hybrid) fry. p 411- 413.

- De Silva S.S. and T.A. Anderson, (1995). Fish Nutrition in Aquaculture. Chapman & Hall Aquaculture Series, London, 319 pp.
- Dernekbası, S., Una, H., Karayucel, I. and Aral, O., (1993). Effect of dietary supplementation of different rates of spirulina (*Spirulina platensis*) on growth and feed conversion in guppy (*Poecilia reticulata* Peters, 1860). J. Anim. Vet. Adv., 9: 1395-1399.
- De-Silva, SS. and Hasan MR., (2007). Feeds and fertilizers the key to long term sustainability of Asian aquaculture. In Hasan MR, Hecht T, De-Silva SS & Tacon AGJ, eds. Study and analysis of feeds and fertilizers for sustainable aquaculture development, FAO Fisheries Technical Paper; 497:19–47.
- Devendra, C., (1988). General approaches to animal nutrition research and their relevance to fish production in the Asian region. *Finfish Nutrition Research in Asia* (Ed. SS DeSilva). Heinemann Asia Singapore, Singapore, pp.7-24.
- Dhont, J. and Sorgeloos P., (2002.) Applications of *Artemia*. In: Artemia Basic and Applied Biology. Abatzopoulos TJ, Beardmore JA, Clegg JS and Sorgeloos P, eds. Kluwer Academic Publishers, Dordrecht, NL, pp. 251-257.
- Duncan, PL. and Klesius, PH., (1996). Effects of feeding *Spirulina* on specific and non-specific immune responses of channel catfish. J Aquat Animal Health 8:308-313.
- Eid, A.E. and Ghonim, S.I., (1994). Dietary zinc requirement of fingerling *Oreochromis niloticus*. *Aquaculture*, 119(2-3), pp.259-264.
- El Chao, C.A., (2003). Tilapia Farming. [Http://www.fishfarming.com](http://www.fishfarming.com). *Aquasol Inc.* Florida, USA.
- El-Sayed, A.F.M. and Teshima, S.I., (1992). Protein and energy requirements of Nile tilapia, *Oreochromis niloticus*, fry. *Aquaculture*, 103(1), pp.55-63.

- El-Sayed, A.F.M., (2006). Tilapia culture. Wallingford, Oxfordshire, UK. p 292.
- El-Sayed, A.F.M., Mansour, C.R. and Ezzat, A.A., (2003). Effects of dietary protein level on spawning performance of Nile tilapia (*Oreochromis niloticus*) broodstock reared at different water salinities. *Aquaculture*, 220(1-4), pp.619-632.
- El-Sayed, A-F.M., (1994). Evaluation of soybean meal, *Spirulina* meal and chicken offal meal as protein sources for silver seabream (*Rhabdosargus sarba*) fingerlings. *Aquaculture*, 127: 169-176.
- El-Sayed, A.M., (1998). Total replacement of fish meal with animal protein sources in Nile tilapia, *Oreochromis niloticus* (L.), feeds. *Aqua. Res.* 29, 275-280.
- Food and Agriculture Organization of the United Nations (FAO), (2002). The State of World Fisheries and Aquaculture 2000. FAO, Rome, Italy. 159pp.
- Food and Agriculture Organization of the United Nations, (FAO), (2004). Fishstat Plus. Aquaculture production 1950-2002. 13pp.
- Food and Agricultural Organization of the United Nations (FAO), (2005). The state of world fisheries and aquaculture 2003. Rome, Italy. 47pp.
- Food and Agriculture Organization of the United Nations (FAO), (2006). The state of world fisheries and aquaculture 2004. FAO, Rome, Italy. 200pp.
- Food and Agricultural Organization of the United Nations (FAO), (2007). State of world aquaculture 2007. FAO Fisheries and Aquaculture 2006, Rome, Italy. 52pp.
- Food and Agriculture Organization of the United Nations (FAO), (2012). The State of World Fisheries and Aquaculture 2010. Rome, FAO. 230 pp.
- Food and Agricultural Organization of the United Nations (FAO), (2014). The State of World Fisheries and Aquaculture 2014. FAO Fisheries Department, FAO, Rome, Italy.

- Food and Agriculture Organization of the United Nations (FAO), (2015). The state of world fisheries and aquaculture 2013. FAO, Rome, Italy. 40pp.
- Food and Agriculture Organization of the United Nations (FAO), (2016). WFP (2015). The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress. *Food and Agriculture Organization Publications, Rome.*
- Food and Agriculture Organization of the United Nations (FAO), (2017). The state of world fisheries and aquaculture 2015. FAO, Rome, Italy. 6pp.
- Frankin, A. and Hershner. C., (2003). Sustainable aquaculture: Developing the promise of aquaculture, *Aquaculture international*, 11:517-530
- Funge-Smith, S. and Phillips, M., (2001). Aquaculture Systems and Species. *Aquaculture in the Third Millennium*. FAO Corporate Document Repository. FAO, Rome, Italy.
- Gatlin, D. M. III., (2010). Nutrition and fish health. In: Halver, J. E., Hardy, R. W. (Eds). *Fish Nutrition*. Academic Press, San Diego, CA, USA, pp 671 - 702.
- Gitonga NK, Mbugua H and Nyandat B., (2004). New approach to fish farming extension in Kenya. In: *Samaki News: A magazine of the Department of Fisheries of Kenya*. Vol. 3. No. 1. Motif Creative Arts Ltd., Nairobi, KE, pp. 8-12.
- Goddard, S., (1996). *Feed Management in Intensive Aquaculture*. Chapman and Hall. New York, USA. pp 3 – 5.
- Grant, J.W.A., (1993). Whether or not to defend? The influence of different feeds on fish . *Mar. Behav. Physiol.* 23, 137–153.
- Green, B.W., (2010). Effect of channel catfish stocking rate on yield and water quality in an intensive, mixed suspended-growth production system. *North American journal of aquaculture*, 72(2), pp.97-106.

- Guerrero, R.D., (1987). Tilapia farming in the Philippines. Technology and Livelihood Resource Center. Published by National Book Store. Philippines. 301 pp.
- Gunasekera, R.M., Shim, K.F. and Lam, T.J., (1996a). Influence of protein content of broodstock diets on larval quality and performance in Nile tilapia, *Oreochromis niloticus* (L.). *Aquaculture*, 146(3-4), pp.245-259.
- Gunasekera, R.M., Shim, K.F. and Lam, T.J., (1996b). Effect of dietary protein level on spawning performance and amino acid composition of eggs of Nile tilapia, *Oreochromis niloticus*. *Aquaculture*, 146(1-2), pp.121-134.
- Hafedh, Y.S.A. (1999). Effects of dietary protein on growth and body composition of Nile tilapia, *Oreochromis niloticus* L. *Aquaculture Research* 30:385- 393.
- Han, C.Y., Wen, X.B., Zheng, Q.M. and Li, H.B., 2010. Effects of dietary lipid levels on lipid deposition and activities of lipid metabolic enzymes in hybrid tilapia (*Oreochromis niloticus* × *O. aureus*). *Journal of animal physiology and animal nutrition*, 95(5), pp.609-615.
- Hauser, W.J., (1977) Temperature requirement of tilapia. *Calif. Fish Game* 63 (4), 228–233.
- Helfrich L, Smith S. (2001). *Fish Kills: Their Causes and Prevention*. Virginia. pp 3 – 10.
- Henson, R.H., (1990). Spirulina algae improves Japanese fish feeds. *Aquaculture Magazine*, 6(6), pp.38-43.
- Ibrahem, M., Mohamed, M.F. and Ibrahim, M.A., (2013). The role of *Spirulina platensis* (*Arthrospira platensis*) in growth and immunity of Nile tilapia (*Oreochromis niloticus*) and its resistance to bacterial infection. *Journal of Agricultural Science*, 5: 109-117.
- Ighwela, A., Ahmed, B. and Abol-Munafi, B., (2011). Condition factor as an indicator of growth and feeding intensity of Nile Tilapia fingerlings (*Oreochromis niloticus*) fed on

- different levels of Maltose. *American-Eurasian Journal of Agriculture and Environmental Sciences*; 11:559- 563.
- James, R., (2010). Effect of dietary supplementation of *Spirulina* on growth and phosphatase activity in copper-exposed carp (*Labeo rohita*). *The Isr. J. Aquac. Bamidgeh*, 62: 19-27.
- Jauncey, K. and Ross B., (1982). A guide to tilapia feed and feeding. University of Stirling, Scotland, UK. p 220.
- Jobling, M., (1994). *Fish Bioenergetics*. Chapman & Hall, London, UK, 309 pp.
- Jones, E. W. (1991). Tackling the protease problem in *Saccharomyces cerevisiae*. In *Methods in enzymology* (Vol. 194, pp. 428-453). Academic Press. Amsterdam, Netherlands.
- Kaliba, A.R., Osewe, K.O., Senkondo, E.M., Mnembuka, B.V. and Quagraine, K.K., (2006). Economic Analysis of Nile Tilapia (*Oreochromis niloticus*) Production in Tanzania. *Journal of the World Aquaculture Society* 37 (4):464-473.
- Kaliba, AR., Ngugi, CC., Mackambo, J. and Quagraine, KK., (2007). Economic profitability of Nile tilapia (*Oreochromis niloticus* L.) production in Kenya. *Aquac Res* 38, 1129-1136.
- Kapinga, I., (2012). Characterization of *Artemia* from solar salt works in Kenya. M.sc. Thesis, Ghent University, Ghent, BE. pp 56-63.
- Kausar, R. and Salim, M., (2006). Effect of water temperature on the growth performance and feed conversion ratio of *Labeo rohita*. *Pakistan Veterinary Journal*, 26(3), pp.105-108.
- Keenleyside, M.H.A., (1991). *Cichlid Fishes: Behaviour, Ecology and Evolution*. Chapman and Hall, New York, 378 pp.

- Kiriratnikom, S. and Kiriratnikom, A., (2012). Growth, feed utilization, survival and body composition of fingerlings of slender walking catfish, *Clarias nieuhofii*, fed diets containing different protein levels. *Songklanakarinn Journal of Science and Technology*, 34(1): 37-43.
- Kiriratnikom, S., Zaaui, R. and Suwanpugdee, A., (2005). Effects of various levels of *Spirulina* on growth performance and pigmentation in goldfish (*Carassius auratus*) *Songklanakarinn J. Sci. Technol.*, 27(Suppl. 1): 133-139.
- Leclercq, D.I. and Hopkins, K., (1985). Preliminary test of an aerated tank system for tilapia culture. *Aqua Eng*: 4: 229-304.
- Lim, C., Barros, M. M., Klesius, P. H. and Shoemaker, C. A., (2000). Thiamin requirement of Nile tilapia, *Oreochromis niloticus*. p 201 *In: Book of Abstracts. Aquaculture America 2000*, New Orleans, Louisiana. Baton Rouge, Louisiana: World Aquaculture Society.
- Lim, C., Oksoy, M. and Klesius P., (2011). Lipid and fatty acid requirements of tilapia. *North American Journal of Aquaculture*. 73(2): 188-193.
- Liti DM, Mugo, RM., Munguti JM. and Waidbacher, H., (2006) Growth and economic performance of Nile tilapia (*Oreochromis niloticus* L.) fed on three brans (maize, wheat and rice) in fertilized ponds. *Aquaculture Nutrition*; 12:239-245
- Lovell, T., (1989). *Nutrition and Feeding of Fish*. An AVI Book, Van Nostrand Reinhold, New York, p 260.
- Lu, J. and Takeuchi, T., (2004). Spawning and egg quality of tilapia *Oreochromis niloticus* fed solely on raw *Spirulina* throughout three generations. *Aquaculture*, 234: 625-640.
- Maar, A., Mortimer, M.A.E. and Van der Lingen, I., 1966. *Fish culture in central East Africa* (Vol. 20). Food & Agriculture Org. Rome, Italy.

- Madu CT, Sogbesan, OA. and Ibiyo LMO., (2003). Some nonconventional fish feed resources in Nigeria. In: Eyo AA, editor. Proceeding of the Joint Fisheries Society of Nigeria held at National Institute for Freshwater Fisheries Research, New Bussa;, p. 73-82.
- Mahajan, G. and Kamat, M. (1995). Linolenic acid production from *Spirulina platensis*. *Appl. Microbiol. Biotechnol.*, 43:466-469.
- Maina, J.G., Beames, R.M., Higgs, D., Mbugua, P.N., Iwama, G. and Kisia, S.M., (2002). Digestibility and feeding value of some feed ingredients fed to tilapia *Oreochromis niloticus* (L.). *Aquaculture Research*, 33(11), pp.853-862.
- Makori, A. J., Abuom, P. O., Kapiyo, R., Anyona, D. N., & Dida, G. O. (2017). Effects of water physico-chemical parameters on tilapia (*Oreochromis niloticus*) growth in earthen ponds in Teso North Sub-County, Busia County. *Fisheries and Aquatic Sciences*, 20(1), 30.
- Mallya, Y.J., (2007). The effects of dissolved oxygen on fish growth in aquaculture. *The United Nations University Fisheries Training Programme, Final Project*. Reykjavik, Iceland. 70 p.
- Mazik, P.M., Hinman, M.L., Winkelmann, D.A., Klaine, S.J., Simco, B.A. and Parker, N.C., (1991). Influence of nitrite and chloride concentrations on survival and hematological profiles of striped bass. *Transactions of the American Fisheries Society*, 120(2), pp.247-254.
- Moyle, Peter B. and Joseph J., (1988). *Fishes: An Introduction to Ichthyology*. 2nd edition. Food and Agriculture Organization of the United Nations 2005a. Rome, Italy. pp 10 – 13.
- Mremi PA., (2011). Pond production of *Artemia* in a solar salt work in Kenya. M.sc. Thesis, Ghent University, Ghent, BE. pp 63 – 70.

- Munguti, J. M., Charo-Karisa, H1., Opiyo, M. A., Ogello, E. O., Marijani, E., Nzayisenga, L. and Liti, D., (2012). Nutritive value and availability of commonly used feed ingredients for farmed Nile tilapia (*Oreochromis niloticus* L.) and African catfish (*Clarias gariepinus*, burchell) in Kenya, Rwanda and Tanzania. *African Journal of Food, Agriculture, Nutrition and Development*, 12(3): 6135-6155
- Munialo, M., (2011). Fish Pond Management, Fisheries workshop presentation, Kisumu, Kenya. 56pp.
- Musa, S., Aura, MC., Owiti, G., Nyonje, B., Orina, P. and Charo-Karisa, H., (2012). Fish farming enterprise productivity program (FFEPP) as an impetus to *Oreochromis niloticus* (L.) farming in Western Kenya: lessons to learn. *Afr J Agric Res*, 7, 1324-1330.
- Mustafa, MG., Umino, T. and Nakagawa, H., (1994). The effect of *Spirulina* feeding on muscle protein deposition in red sea bream, *Pagrus major*. *J Appl Ichthyol* 10, 141-145.
- Mwangi, HM., (2008). Aquaculture in Kenya, Status Challenges and Opportunities, Directorate of Aquaculture, Nairobi, Kenya. 27p.
- Myers, R. A. and Worm. B., (2003). Rapid worldwide depletion of predatory fish communities *Nature* 423:280-282.
- Nakazoe, J., Kimura, S., Yokoyama, M. and Iida, H., (1986). Effect of supplementation of alga to the diets on the growth and body composition of nibbler, *Girella punctata* Grey. *Bull Tokai Reg Fish Res Lab* 120, 43-51.
- Nakono, T., Yamaguchi, T., Sato, M. and Iwama, GK., (1990). Biological Effects of Carotenoids in Fish. International Seminar Effective Utilization of Marine Food Resource, Songkhla, Thailand, 2003, 1-15.

- Nandeesh, M.C., Gangadhar, B., Varghese, T.J. and Keshavanath, P., (1998). Effect of feeding *Spirulina platensis* on the growth, proximate composition and organoleptic quality of common carp, *Cyprinus carpio* L. *Aquaculture Research*, 29(5), pp.305-312.
- Nandeesh, M.C., Gangadhara, B., Manissery, J.K. and Venkataraman, L.V., (2001). Growth performance of two Indian major carps, catla (*Catla catla*) and rohu (*Labeo rohita*) fed diets containing different levels of *Spirulina platensis*. *Bioresource Technology*, 80: 117-120.
- Narejo, N. T., Haque, M.M. and Rahmatullah, S.M., (2002). Growth performance of snake eel, *Pisodonophis boro* (Hamilton) reared experimentally with different food items. *Bangladesh J. Train, Dev.*, 15: 221-225.
- National Aquaculture Sector Overview. Kenya. National Aquaculture Sector Overview Fact Sheets. Text by Nyandat, B. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 1 February 2005. [Cited 30 May 2019].
- National Research Council, (1993). *Nutrient Requirements of Fish*. National Academy Press, Washington, DC, 114 pp.
- National Research Council, (1999). *Committee on Ecosystem Management for Sustainable Marine Fisheries*, National Research Council, National Research Council. Commission on Geosciences, Resources, Division on Earth, Life Studies, Resources Commission and Ocean Studies Board, *Sustaining marine fisheries*. Haworth Press. 120 pp.
- Naylor, R., R. J., Goldburg, J. H., Primavera, N., Kautsk, M. C. M., Beveridge, C., Clay, C., Folke, J., Luchenco, H., Mooney. and Troell, M., (2000). Effect of aquaculture on world fish supplies. *Nature*.405, 1017-1024.

- Ngugi, CC, Bowman, JR., Omolo, BO., (2007). A New Guide to Fish Farming in Kenya. Aquaculture Collaborative Research Support Program, Nairobi, Kenya. pp 43 -60.
- Ngugi, CC. and Manyala JO., (2004). Aquaculture extension services in Kenya. In: Aquaculture Extension Services in Sub-Saharan Africa. Fisheries Department Circular No. 1002. Food and Agriculture Organization of the United Nations, ed. FAO Fisheries Department, Rome, IT, pp. 35-42.
- Ngugi, CC., Bowman, JR. and Omolo, BO., (2007). A New Guide to Fish Farming in Kenya. Aquaculture Collaborative Research Support Program, Naitobi, KE.
- Nwanna, L. C., (2003). Nutritional value and digestibility of fermented shrimp head waste meal by African catfish *Clarias gariepinus*. *Pakistan Journal of nutrition*, 2(6), 339-345.
- Nyandat, B. and Owiti, G.O., (2013). Aquaculture needs assessment mission report. Report/Rapport: SF-FAO/2013/24. FAO-SmartFish Programme of the Indian Ocean Commission, Ebene, Mauritius, pp. 1-83.
- Nyonje, BM., Charo-Karisa, H., Macharia, SK. and Mbugua, M., (2011). Aquaculture Development in Kenya: Status, Potential and Challenges. In Samaki News: Aquaculture Development in Kenya towards Food Security, Poverty Alleviation and Wealth Creation. Vol. 7. No. 1. pp. 8-11.
- Obeng, A.K., Atuna, R.A. and Aihoon, S., (2015). Proximate composition of housefly (*Musca domestica*) maggots cultured on different substrates as potential feed for Tilapia (*Oreochromis niloticus*). *International Journal of Multidisciplinary Research and Development*, 2(5): 172-175.
- Ogello EO, Mlingi FT, Nyonje BM, Charo-Karisa H and Munguti JM. 2013. Can integrated livestock-fish culture be a solution to East Africa's food insecurity? A review. *Afr J Food Agric Nutr Dev* 13, 8058-8076.

- Olurin, K. B., & Aderibigbe, O. A. (2006). Length-weight relationship and condition factor of pond reared juvenile *Oreochromis niloticus*. *World journal of Zoology*, 1(2), 82.
- Olvera-Novoa, M.A., Domínguez-Cen, L.J., Olivera-Castillo, L. and Martínez-Palacios, C.A., (1998). Effect of the use of the microalga *Spirulina maxima* as fish meal replacement in diets for tilapia, *Oreochromis mossambicus* (Peters), fry. *Aquaculture research*, 29(10), pp.709-715.
- Osure, G., (2011). Introduction to Aquaculture. performance and amino acid composition of eggs of Nile tilapia, *Oreochromis niloticus* (L.). *Aquaculture* 146:121-134.
- Otieno, MJ., (2011). Fishery Value Chain Analysis: Background Report – Kenya. FAO, Rome, IT, pp. 2-10.
- Palmegiano, G.B., Agradi, E., Forneris, G., Gai, F., Gasco, L., Rigamonti, E., Sicuro, B. and Zoccarato, I., (2005). *Spirulina* as a nutrient source in diets for growing sturgeon (*Acipenser baeri*). *Aquaculture Research*, 36(2), pp.188-195.
- Palmegiano, G.B., Gai, F., Dapra, F., Gasco, L., Pazzaglia, M. and Peiretti, P.G., (2008). Effects of *Spirulina* and plant oil on the growth and lipid traits of white sturgeon (*Acipenser transmontanus*) fingerlings. *Aquaculture Research* 39,587^595.
- Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R. and Zeller, D., (2002). Towards sustainability in world fisheries. *Nature*, 418(6898), p.689.
- Pescod, M.B., (1992). Wastewater treatment and use in agriculture - FAO irrigation and drainage paper 47. *Food and Agriculture Organization of the United Nation*. Rome, Italy.

- Philappart, J-CL., Ruwet, J-CL., (1980). Ecology and distribution of tilapias. *In* R.S.V. Pullin, R.H. Lowe-McConnell (Eds.), the Biology and Culture of Tilapias. ICLARM Conference Proceedings 7, International Centre for Living Aquatic Resources Management, Manila, Philippines, pp. 15-59.
- Popma, T. & Masser, M., (1999). Tilapia: Life History and Biology. *Southern Regional Aquaculture Center*. 240 pp.
- Randriamiarana, H., Rabelahatra, A., Janssen, J., Symoens, J.J. and Micha, J.C., (1995). Rice/fish farming in Madagascar: the present situation and future prospects and constraints. 70 pp.
- Reigh, R. C., Robinson, E. H. and Brown. P. B., (1991). Effects of dietary magnesium on growth and tissue magnesium content of blue tilapia (*Oreochromis aureus*). *J. World Aquacult. Soc.* 22:192–200.
- Rice, Michael A., (2002). Aquaculture. *In* Hazeltine, Barrett & Bull, Christopher (Eds.) *Field Guide of Appropriate Technology*. Academic Press. Thailand.
- Riche, M. and Garling, D., (2003). Feeding Tilapia in Intensive Recirculating Systems. *Northern Central Regional Aquaculture Center*. pp 20-36.
- Ricker, W.E., (1979). Growth rates and models. *Fish physiology*, pp.673-743.
- Roberts, R.J., (1989). *Nutritional Pathology of Teleosts*. *In*: Roberts R.J., (Ed). *Fish Pathology*, BalliereTindall, London, pp: 337-362
- Robinson, Bob. n.d. Feeding techniques, Conditions on Two Different Tilapia Farms.
- Robinson, E. H. and Li, M. H., (2005). A summary of catfish nutrition research conducted under a cooperative agreement between MAFES and Delta Western Research Center. Mississippi Agricultural and Forestry Experiment Station Technical Bulletin 1144.

- Robinson, E. H. and Li, M. H., (2012). Composition and formulation of channel catfish feeds. Mississippi Agricultural and Forestry Experiment Station Bulletin No. 1200.
- Robinson, E.H., LaBomascus, D., Brown, P.B. and Linton, T.L., (1987). Dietary calcium and phosphorus requirements of *Oreochromis aureus* reared in calcium-free water. *Aquaculture*, 64(4), pp.267-276.
- Ross, L. G., Martinez Palacios, C. A., and Morales, E. J. (2008). Developing native fish species for aquaculture: the interacting demands of biodiversity, sustainable aquaculture and livelihoods. *Aquaculture Research*, 39(7), 675-683.
- Sado, R. Y., Almeida Bicudo, A. J. D. and Cyrino, J. E. P. (2008). Feeding dietary mannan oligosaccharides to juvenile Nile tilapia, *Oreochromis niloticus*, has no effect on hematological parameters and showed decreased feed consumption. *Journal of the World Aquaculture Society*, 39(6), 821-826.
- Saha, S., R. N. Roy, S. K., Sen, A. K., Ray., (2006). Characterization of cellulase-producing bacteria from the digestive tract of tilapia, *Oreochromis mossambica* (Peters) and grass carp, *Ctenopharyngodon idella* (Valenciennes). *Aquaculture Research*. 37: 380–388.
- Sallenave, R., (2012). Understanding Water Quality Parameters to Better Manage Your Pond. Guide W-104, pp: 9.
- Santhosh, B. and Singh, NP., (2007). Guidelines for water quality management for fish culture in Tripura, ICAR Research Complex for NEH Region, Tripura Center, Publication no.29.
- Saoud, I.P., Mohanna, C. and Ghanawi, J., (2008). Effects of temperature on survival and growth of juvenile spinefoot rabbitfish (*Siganus rivulatus*). *Aquaculture Research*, 39(5), pp.491-497.

- Schiermeier, Q., (2002). Fisheries science: how many more fish in the sea? *International journal of science*. 419, 662–665
- Shiau, S. Y. and Huang, S.Y., (2001). Dietary folic acid requirement for maximum growth of juvenile tilapia *Oreochromis niloticus* × *O. aureus*. *Fish. Sci.* 67: 655–659.
- Siddiqui, A.Q., Howlader, M.S. and Adam, A.A., 1988. Effects of dietary protein levels on growth, feed conversion and protein utilization in fry and young Nile tilapia, *Oreochromis niloticus*. *Aquaculture*, 70(1-2), pp.63-73
- Smith, R.R., (1989). Nutritional energetics. In J.E Halver (Ed.), *Fish Nutrition*. Academic Press, San Diego, California, pp 2-28.
- Sogbesan, O.A., (2006) Effects of different organic substrates on growth and survival of long winged termite (*Macrotermes subhyabrius*) under laboratory conditions. *Afr J Gen Agric*; 2(2):37-44.
- Sorgeloos P, Dehasque M, Dhert, P. and Lavens P., (1995). Review of some aspects of marine fish larviculture. *ICES Mar Sci Symp* 201, 138- 142.
- SPARE Recommendations to BIFAD, (2003). USAID Agriculture Sub-Sector Review on Fisheries/Aquaculture Integrated Pest Management Sustainable Agriculture, Draft 11.
- Sugunan, V.V., (2002). Enhancement: an effective tool for increasing inland fish production. *Fishing chimes*, 21(10&11), pp.21-22.
- Suresh, V., (2003). Tilapias. In: Lucas, J.S. and Southgate, P.C., (Eds.) *Aquaculture: farming of aquatic animals and plants*, United Kingdom: Blackwell publishing. pp 40 – 59.
- Tacon, A. J. and De Silva, S. S., (1997). Feed preparation and feed management strategies within semi-intensive fish farming systems in the tropics. *Aquaculture*, v. 151, n. 1-4, p. 379-404.

- Tacon, A.G., 1993. Feed ingredients for warmwater fish, fish meal and other processed feedstuffs. *FAO Fisheries Circular (FAO). no. 856*. Rome, Italy.
- Takeuchi, T., Lu, J.U.N., Yoshizaki, G. and Satoh, S., (2002). Effect on the growth and body composition of juvenile tilapia *Oreochromis niloticus*. *Fisheries Science*, 68(1), pp.34-40.
- Tan Q, Xie S, Zhu X, Lei W, Yang Y (2006). Effect of dietary carbohydrate sources on growth performance and utilization for gibel carp (*Carassius auratus gibelio*) and Chinese longsnout catfish (*Leiocassis longirostris* Gu'nther). *Aquacult Nutr* 12:61–70.
- Teichert-Coddington, D. R., Popma, T. J., and Lovshin, L. L., (1997). *Attributes of tropical pond-cultured fish* (pp. 183-198). CRC Press: Boca Raton, FL, USA.
- Teng, S.K. and Chua, T.E., (1979). Use of artificial hides to increase the stocking density and production of estuary grouper, *Epinephelus salmoides* Maxwell, reared in floating net cages. *Aquaculture*, 16(3), pp.219-232.
- Twibell, R. G. and Brown, P. B., (1998). Optimal dietary protein concentration for hybrid tilapia (*Oreochromis niloticus* × *Oreochromis aureus*) fed all-plant diets. *J. World Aquacult. Soc.* 29: 9–16.
- Ungsethaphand, T., Peerapornpisal, Y., Whangchai, N. and Sardud, U., (2010). Effect of feeding *Spirulina platensis* on growth and carcass composition of hybrid red tilapia (*Oreochromis mossambicus* × *O. niloticus*). *Maejo international journal of science and technology*, 4(2), pp.331-336.
- USGS, (2006). NWISWeb Home Page. Available from: <http://nwis.waterdata.usgs.gov>.

- Vincke, M.M.J., (1995). The present state of development in continental aquaculture in Africa. In J-J Symoens & J.-C. Micha, eds. *The Management of integrated freshwater agro-piscicultural ecosystems in tropical areas*. Netherlands, pp. 27-62.
- Wang, Y., Liu, Y.J., Tian, L.X., Du, Z.Y., Wang, J.T., Wang, S. and Xiao, W.P., (2005). Effects of dietary carbohydrate level on growth and body composition of juvenile tilapia, *Oreochromis niloticus* × *O. aureus*. *Aquaculture research*, 36(14), pp.1408-1413.
- Watanabe, T., Liao, W.L., Takeuchi, T. and Yamamoto, H., (1990). Effect of dietary *Spirulina* supplementation on growth performance and flesh lipids of cultured striped jack. *J Tokyo Univ Fish* 77, 231-239.
- Watson, R. and Pauly, D., (2001). Systematic distortions in world fisheries catch trends. *Nature*, 414(6863), p.534.
- Winfree, R. A. and Stickney, R. R., (1981). Effects of dietary protein and energy on growth, feed conversion efficiency and body composition of *Tilapia aurea*. *J. Nutr.* 111: 1001–1012.
- Wohlfarth, G.W. and Hulata, G.I., (1981). *Applied Genetics of Tilapias*. ICLARM Studies and Reviews 6. Manila, Phillipines. pp 60 – 70.
- Wurts, W. A. (2000). Sustainable aquaculture in the twenty-first century. *Reviews in Fisheries Science*, 8(2), 141-150.

