PHYSICOCHEMICAL CHARACTERISTICS OF TILAPIA AND AFRICAN CATFISH FROM LAKE VICTORIA AND SELECTED FISH FARMS FROM THE COUNTIES OF KIRINYAGA AND MACHAKOS IN KENYA

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DECLARATION

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

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This thesis is dedicated to my lovely children Jazzlien Kapuki and Raymond Munyao

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis Of Variance
LSD	Least significant difference
AOAC	Association of Official Analytical Chemists
ATSDR	Agency for Toxic Substances and Disease Registry
DAP	Di-Ammonium Phosphate
DHA	Docosahexaenoic Acid
EPA	Eicosapentaenoic Acid
EPZA	Export processing Zone Authority
FAO	Food and Agriculture Organization
JKUAT	Jomo Kenyatta University of Agriculture and Technology
LVEMP	Lake Victoria Environmental Management Project
LVFO	Lake Victoria Fisheries Organization
OIE	Office International des Epizooties
PCM	Protein Calorie Malnutrition
PUFA	Polyunsaturated Fatty Acid
RDA	Recommended daily allowance

SAS	Statistical Analysis System
TBARS	Thiobarbituric acid reactive substances
USRDA	United States Recommended Daily Allowance
WHO	World Health Organization
MUFA	Monounsaturated fatty acid
GDP	Gross domestic product
KDHS	Kenya demographic and health survey
KNMS	Kenya national micronutrient survey

ABSTRACT

Fish is important for food security and optimal nutrition. To boost fish supply and subvert rural poverty and malnutrition, the Kenyan government is promoting fish farming. Previous studies have shown that wild and farmed fish vary in their nutritional composition. This study aimed at determining the difference in heavy metal levels, chemical, physical and sensory properties of wild and farmed fish particularly Nile Tilapia (*Oreochromis niloticus*) and African Catfish (*Claris gariepinus*) species. Randomized Block Design was used to sample both wild and farmed fish. Wild fish (sample size 128) were obtained from Kisumu through fish vendors from City market Nairobi, while farmed fish (sample size 288) were obtained from selected fish ponds in Sagana and Kamulu which are located in the counties of Kirinyaga and Machakos respectively. Proximate composition, mineral and heavy metal content of the fish were determined using (AOAC) official methods of analysis. Tissue fatty acid composition was determined by gas chromatography. Farmed fish contained significantly ($p<0.05$) higher moisture content than wild fish. The protein content of wild and farmed fish ranged from 21.9 – 22.1% and 16.0 – 19.2%, respectively. Fat content in wild fish ranged between 3.0 – 3.8% while farmed fish reported 1.9 – 4.8%. Ash content in wild ranged from 1.8 – 2.1% relative to 1.1 – 1.5% in farmed fish. Wild fish was found to contain significantly higher concentrations ($p<0.05$) of heavy metals relative to farmed fish. The concentration of minerals in wild fish ranged from 2.8 – 3.0 mg/100g of iron, 5.5 – 5.6 mg/100g zinc, and 39.9 – 43.8 mg/100g calcium compared to lower values of 1.9 – 2.4 mg/100g of iron, 28.2 – 37.0 mg/100g calcium and 4.3 – 5.0 mg/100g zinc in farmed fish. Palmitoleic acid ($C_{16:1}$) and oleic acid ($C_{18:1}$) were the predominant monounsaturated fatty acids (MUFA) in both farmed and wild fish with significantly higher values of 4.33– 6.7% and 20.5 – 22.4% for wild fish and 4.53-10.8%, 21.2-28.7% for farmed fish. The principal polyunsaturated fatty acids (PUFA) were linoleic acid ($C_{18:2}$), linolenic ($C_{18:3}$) (omega 3), linolenic ($C_{18:3}$) (omega 6), Eicosapentaenoic acid (EPA) ($C_{20:5}$) and Docosahexaenoic acid (DHA) ($C_{22:6}$). The content of EPA and DHA were in the range of 1.5-2.4% and 3.0-3.7% for wild fish relative to 0.6-1.6% and 1.5-2.8% for farmed fish. Wild fish also recorded higher levels of TBARS than farmed fish an indication that fatty acids in farmed fish are more stable after cooking than in wild fish. The wild fish had a firm texture range of 3.85-4.99 N compared to farmed fish with 1.63-3.65 N. In addition, wild fish were more preferred in terms of flavor, colour, texture and taste than farmed fish. In conclusion wild fish were nutritionally superior to farmed fish and this could be attributed to the type of feed they consume. Furthermore, wild fish has higher levels of heavy metals relative to farmed fish.

CHAPTER ONE

INTRODUCTION

1.1 Background

Kenya has a long history of fishing which runs for more than five centuries. Until 30 years ago, nearly all fish caught in Kenyan waters was consumed locally (Nguka *et al.*, 2017). Kenya began exporting fish in the early 1980s, when fish processing factories were established around Lake Victoria. This allowed the fisheries sub-sector to gradually evolve from a domestic consumption oriented industry to an export oriented industry with value added processing being applied (EPZA, 2005; van Hoof and Steins, 2017).

Fishing in Kenya is mostly carried out by artisan fishermen operating small fishing boats (Samoilys *et al.*, 2017). Artisanal fishing activities are undertaken by 12,077 fishermen, operating about 2,687 boats (Wekesa, & Ndegwa, 2011). The most common fishing methods used are gillnets, traditional traps, seine nets, long line hooks, and others (Wekesa and Ndegwa, 2011). The Kenyan fishery sector contributes approximately 0.54% to the country's gross domestic product (GDP). *Omena* production is valued at 200 million dollars while its trade supports more than 2 million livelihoods (Kariuki, 2011). Capture fisheries contributes approximately 140,000 metric tonnes of fish products annually (Annual Fisheries Statistical Bulletin, 2013; KMFRI, 2017). Out of this, Kenya exports only about 7000 metric tonnes of fish annually (Annual Fisheries Statistical Bulletin, 2013) which means that the bulk of fish landings are sold domestically. In 2012, the value of fish exports was about USD 62.9 million, or about 5 times greater than the USD 12.3 million in fish imports. In 2013, the total fishery and aquaculture production amounted to 186 700 tonnes, with 83% coming from inland capture fisheries of which Lake Victoria contributed about 90 %. As a result, about 129,300 people derived their livelihood from fishing and fish farming activities (including 48 300 in inland waters, 13 100 in coastal waters fishing and around 67 900 in fish farming) (FAO, 2016).

There is a declining trend in fish stocks from natural sources as a result of over fishing and pollution of water bodies with organic and inorganic contaminants (Kundu, *et al.*, 2017). As a result, there is a campaign to promote aquaculture in Kenya. Aquaculture systems found in Kenya include semi-intensive culture of Nile Tilapia and African Catfish, practiced by small-scale fish farmers in static ponds and intensive culture of trout in raceways and tanks in high latitude regions, which have been mostly adapted in western and central parts of Kenya (Olio *et al.*, 2018). Aquaculture has the potential of enhancing fish supplies and will therefore have a greater impact on poverty alleviation and malnutrition eradication.

Aquaculture contributes an estimated 2% of the total fish produced and is practiced mainly under smallholder mixed farming systems, where farmers grow crops and keep livestock in addition to fish farming (EPZA, 2005; Mbugua 2008). Currently, aquaculture only produces about 24,000 metric tonnes of fish annually compared to an annual average of 178,000 metric tonnes from natural fisheries (Aloo *et al.*, 2017). However aquaculture in Kenya is faced with challenges e.g. cost of fish feeds, availability of fingerlings.

Many species of fish are consumed in virtually all regions around the world. Fish is highly nutritious, tasty, easily digested, and constitutes a very important source of proteins, minerals, vitamins, and polyunsaturated fatty acids (PUFAs) (Kumar, 2018). Fish’s protein, which accounts for approximately 16% of animal protein consumed worldwide, has a good balance of essential amino acids (Aguiar *et al.*, 2011). The PUFAs are beneficial in reducing the risk of coronary diseases and certain type of arrhythmias (Storelli, 2008). Nevertheless, fish differ in their nutritional value depending on the species, whether they are wild or farmed, and the environment in which they grow (González *et al.*, 2006). There are also variations in sensory characteristics (Fuentes *et al.*, 2010).

Several studies have occasionally reported that the nutritional and physical quality of farmed fish is lower than that of wild fish (El-Zaeem *et al.*, 2012; Adeniyi *et al.*, 2012). However, limited studies have been undertaken to compare the nutritional value and safety of wild and farmed fish in Kenya.

1.2 Problem Statement

The Kenyan population is rapidly growing (47.5millon), paralleled by widespread malnutrition of all types, which includes Protein-Energy Malnutrition (KDHS2014), Micronutrient deficiency (KNMS2011) and increasing health related problems due to obesity. The eating habits of Kenyans are culturally inhibitive and restricted to certain non nutritious foods. Availability of highly nutritious foods like fish is limited and this had led to intensive production of farmed fish (Aloo *et al.*, 2017). Although fish farming may increase supply, previous studies though limited have shown there are some differences in nutritional value and acceptability of wild and farmed fish (Bronnmann and Asche, 2017; Polymeros *et al.*, 2015). Even fewer studies have been undertaken to compare the differences in nutritional and safety profiles of wild and farmed fish in Kenya. This indicates that there is a large gap in knowledge and understanding on what drives the demand for wild fish as compared to farmed fish and what needs to be done to improve the quality of farmed fish. Consequently, this study aims at comparing the nutritional and safety profiles of wild and farmed fish in Kenya to allow development of targeted interventions that can be used by fish farmers and fish traders in Kenya to increase commercialization of farmed fish.

1.3 Justification

Due to stagnating wild fisheries and a growing demand for fish, aquaculture is expected to fill the gap in supplies of fish as food for humans. Aquaculture has grown rapidly in Kenya over the last one decade and plays an increasingly important role in national fish supply. The aquaculture system recorded a growth from 4,218 metric tons (MT) in 2006 to peak at 24,096 MT in 2014, as a result of the rapid growth. Kenya is ranked the fourth major producer of fish in Africa (KMFRI, 2017). Therefore aquaculture has a greater impact on poverty alleviation and malnutrition eradication. It is in this respect that the government of Kenya has put a lot of efforts to improve production of farmed fish and strengthen blue economy to boost production and consumption of fish and other marine foods. This commitment is demonstrated by Kenya hosting the first global Blue economy conference in 2018. Equally important is the prioritization of ocean and blue economy by President Uhuru Kenyatta (blue economy conference; GOK, 2020) that ocean and freshwater economy is a smart investment that will deliver social, economic, health and environment benefits to Kenyans. This is considered as an enabler of the Vision 2030 economic blue print.

To boost the position of Kenya as key source of fresh and farmed fish while promoting local consumption, it is important to consider what fish types are the most accepted in Kenya and in the region. Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) are the most widely farmed and consumed freshwater fish species in Kenya due to their large acceptability. These fish are commonly sold in the markets. They are native to Africa and form important cultural fish because they reproduce very easily and do not have feeding problems. Increased production of these fish will lead to improvement of the local and export economy. The production of fish grew from 4218 metric tonnes in 2006 to 24096 metric tonnes in 2014, representing a 15 % of total fish production Nyandat and Owiti, 2013). The potential is far much higher than the current production levels meaning that Kenya needs to increase its effort in harnessing the fish economy potential.

More importantly, fish nutritional properties have rendered them valuable foodstuffs beneficial for human health. These fish are widely accepted as good source of protein and other elements for the maintenance of healthy body (Adeniyi *et al.*, 2012). They also provide high quality essential fatty acids, vitamins and variety of minerals (Khalili and Sampels, 2018). Fish is considered a good source of polyunsaturated fatty acid particularly omega 3's eicosapentaenoic and docosahexaenoic. High omega 3 concentration has been linked to prevention and treatment of numerous inflammatory diseases (Calder, 2015; Kromhout *et al.*, 2012).

1.4 Objectives of the study

1.4.1 General objective

To determine the influence of fish sources on the physicochemical characteristics and heavy metal contamination of Tilapia and African Catfish in Kenya

1.4.1 Specific objectives

i. To determine proximate composition, fatty acid, mineral and heavy metal profiles of wild Tilapia and Catfish in Kenya
ii. To determine the influence of fish sources on the fatty acid, mineral and heavy metal profiles of Tilapia & Catfish in Kenya.
iii. To assess the stability of farmed and wild fish fatty acids after cooking
iv. To compare physical, sensory characteristics and acceptability of wild and farmed Tilapia and Catfish

1.5 Research questions

i. Are there significant inter farm variations in the physicochemical composition and sensory characteristics of farmed Tilapia and Catfish?

ii. Are there variations in the physicochemical composition and sensory characteristics between farmed fish and wild fish?

iii. Are there heavy metal contaminants in wild and farmed Tilapia and Catfish? If yes, in what proportions?

iv. Are there variations in fatty acid stability after cooking between wild and farmed fish?

CHAPTER TWO

LITERATURE REVIEW

2.1 Fish Production in Kenya

Kenya's fish production mainly comprises of inland and marine fisheries (FAO, 2016) and this has largely been underexploited (Aloo *et al.*, 2017). Inland capture fisheries accounted for over 90% of the total national fish production while marine capture and aquaculture fisheries contributed about 10% in the last decade (Aloo *et al.*, 2017). The common species of fresh water fishes are Tilapia, Nile perch, *Dagaa*, Mud fish, Salmon, Trout and Black bass (Mogeni and Oyaya, 2005). Kenya's biggest inland fishery is Lake Victoria, the world's second largest lake. Lakes Baringo, Naivasha and Turkana, and rivers Sagana, Burguret and Nzoia are also important fishing grounds. Fishing is also carried in dams, like Kiambere and Masinga. Marine fishing is carried out in the Indian Ocean with the most popular areas being Mombasa, Malindi, Shimoni, and Vanga. The common sea fish species that dominate capture fisheries include kingfish, queenfish, parrotfish, silver sardine and lungfish (Annual Fisheries Statistical Bulletin, 2013).

Fish farming is also being promoted by the Kenyan government where farmers are assisted to construct fish ponds on their farms and raise fish for sale (Figure 2.1). Kenya is endowed with several inland natural water resources such as Lakes Victoria, Turkana, Baringo, Naivasha, Chala, Kanyaboli, and Jipe, among others. Major rivers include the Tana, Athi, Nyando, Nzoia, Gucha, Migori, Yala, and Mara (Munguti *et al.*, 2014). In addition to artificial water bodies from dams, which are spread across the landscape, Kenya boasts approximately 600 km of coastal shoreline with an Exclusive Economic Zone of 200 nautical miles, which could be harnessed to enhance aquaculture. Although most parts of the country are suitable for aquaculture, only about 0.014% of the 1.4 million ha of potential aquaculture sites are used for aquaculture and about 95% of fish farming is on a small scale (Otieno, 2011). Fish farming has also been practiced mostly in the central, Nyanza, western provinces, and parts of Rift Valley and coastal provinces (Nyonje *et al.*, 2011).

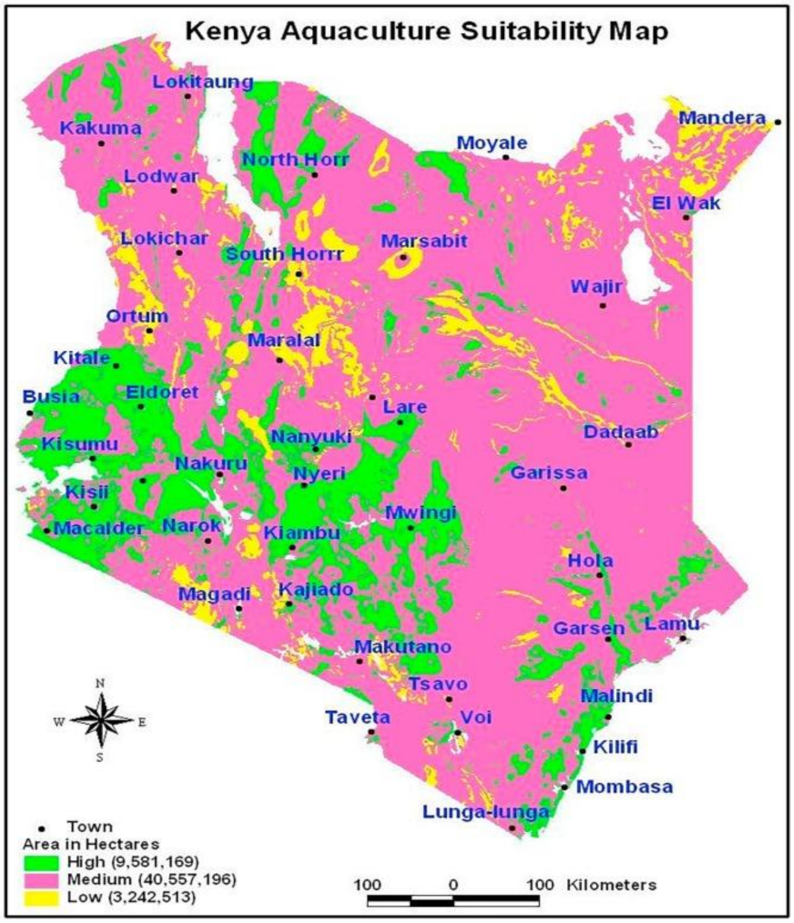


Figure 2.1: Map of Kenya indicating areas suitable for freshwater aquaculture: green, highly suitable, pink, medium suitable and yellow, low suitable aquaculture areas based on water availability, climatic conditions, soil type, topography, land use, access to inputs and markets.

Source: https://www.ajol.info/index.php/ajfand/article/view/149194. Ogello and Munguti, (2016) Over the years, there has been a decrease in fish production from inland waters due to over fishing and contamination of the water bodies which has led to the death of fish stocks. In addition, freshwater fish production has significantly dropped propelling the steady growth of aquaculture in Kenya (National Economic Survey, 2016). As a result the Kenyan government has aggressively promoted fish farming as a way of increasing food security through enhanced fish production and also providing employment for many especially the youths. With the advent of government-funded Economic Stimulus Program (ESP) coupled with several aquaculture facilities in various parts of the country to serve as research centers, training facilities, and sources of fingerlings and feed for fish farmers, the national aquaculture production was estimated at 12,000 MT/y, equivalent to 7% of the total production and valued at $21 million by 2011 (Nyonje *et al.*, 2011). The increased interest in fish farming stimulated by the ESP comes with challenges including poor knowledge of ideal management practices, nutritional requirements for optimum productivity, environmental pollution, biosecurity and spread of fish diseases (Munguti *et al.*, 2014). While fisheries contribute less than one percent to the country's GDP, they are of and recognized for their strategic value. The marine sector is outshone by the freshwater sector (Smart Fish, 2011; FAO, 2016) producing less than 9,000 tonnes per year, which compared to neighboring countries is low (FAO, 2016). Whereas the marine fishery is largely artisanal, the fresh water sector is both industrial and artisanal (Smart Fish, 2011). Capture fisheries contributes approximately 140,000 metric tonnes of fish products annually (Annual Fisheries Statistical Bulletin, 2013; KMFRI, 2017). Out of this, Kenya exports only about 7000 metric tonnes of fish annually (Annual Fisheries Statistical Bulletin, 2013) which means that the bulk of fish landings is sold domestically. This probably explains why Tilapia, Silver sardine, Nile perch and Lungfish were found to be the widely consumed fish species.

Although the fish industry in Kenya has developed over the years, Kenya is still facing some challenges such as dwindling fish stocks attributed to but not limited to increased pressure due to rapid population, deteriorating environmental conditions of lake ecosystems and poor resource governance. This has led importation of fish from China as well as from neighboring countries.

2.2 World Fish Farming

Fish is widely consumed in many parts of the world and is a good source of micronutrients known to support good health. With increased demand for fish and fish products, many countries have practiced aquaculture (aqua farming) to boost supply for fish. Aquaculture is the farming of aquatic animals (such as finfish, mollusks, and crustaceans) and seaweeds (FAO, 1988). It is the fastest growing food production sector in the world (Toufique and Belton, 2014), with an annual rate of 8.8% (Toufique and Belton, 2014). The global aquaculture sector has grown continuously from about 13% to 53% (FAO, 2018) over the past 40 years, though unevenly among countries (Nadarajah and Flaaten, 2017). During the period 2000–2016, global fish production reported an average annual growth rate of 5.8%, which peaked to about 171 million tonnes by 2016 (FAO, 2018). Inland aquaculture produced 51.4 million tons (64%) while both coastal aquaculture and mariculture (aquaculture in marine environment) produced 28.7 million tons (36%) (FAO, 2018). The rapid development of aquaculture has been considered the blue revolution, which is an approach to increasing global fish production in order to contribute to human nutrition and food security (Ahmed and Thompson, 2019). This will close food and nutrition gaps in many African regions as well as contributing to the socio economic development. Furthermore, aquaculture plays a major role in the achievement of the first three Sustainable Development Goals on poverty, hunger, food security and healthy lives of people from developing countries (Aloo *et al.*, 2017). This is significant especially in the developing countries where poverty and malnutrition are a reality. According to FAO, (2018), the increase in fish consumption is largely driven by population growth, urbanization, change in food preference, rising income levels and efficiency in the aquaculture industry (FAO, 2018). In addition, a growing knowledge on the health benefits of fish consumption across the world has increasing demand for fish and fish products (Thilsted *et al.*, 2016). With the growing benefits in quality, efficiency, technology, and knowledge, farmers are developing freshwater aquaculture farms. As a result, about 58.3 million people are directly involved in the global aquaculture industry (FAO, 2014). The rise in global aquaculture production will bring down the wild capture production to safer more sustainable levels and improve economy.

The total sale value of fisheries and aquaculture production in 2016 was estimated at USD 362 billion, of which USD 232 billion was from aquaculture production (FAO, 2018). The international aquaculture statistics of the FAO (2018) states that countries in Asia accounted for about 89% of global production in 2016 with about 62% taking place in China, which is the largest aquaculture producer (FAO 2018) and has been, since 2002, the largest exporter of fish and fish products, although the rapid growth of the 1990s and 2000s has subsequently slowed. Apart from China, other major exporters in 2016 were Norway, Viet Nam and Thailand. However, fish production in some non-Asian countries has been reported to grow more rapidly than the major Asian producers (Garlock *et al.*, 2020). Europe has been shown to be the second largest region by production, followed by South America, Africa, North America, and Oceania. The European Union (EU) represented the largest single market for fish and fish products, followed by the United States of America and Japan; in 2016 these three markets together accounted for approximately 64% of the total value of world imports of fish and fish products. Over the course of 2016 and 2017, fish imports grew in all three markets as a result of strengthened economic fundamentals. However, Africa and America (mainly South America) has much lower per capita fish consumption levels and supply per capita than the global average. Therefore they have much more potential to increase its production and per capita consumption of fish. African aquaculture development has seen the greatest growth per continent at 11.7% in the past 12 years (FAO, 2014). Despite the wealth of natural and human resources, Africa ‘s contribution to global farmed fish production is very low, at 2.23% of global production (FAO, 2014) with North Africa making up 69% of the total African production. Egypt is the leading producer in Africa, producing 630 000 tonnes in 2007 (Rana, 2011). Despite the economic importance of aquaculture, global wild capture fishing remains under threat to overexploitation especially in certain regions where catches are concentrated.

2.3 Fish farming in Kenya

Fish farming began in Kenya in the 1920s and was initiated by colonialist through the introduction of trout in rivers for sport fishing before culture of species such as Tilapia, common carp, and Catfish came into place (FAO 2014). In the late 1960s, the Kenyan government promoted the "eat more fish campaigns" and this accelerated the interest in rural fish farming (Ngugi *et al.*, 2007). In 2003, the production rose from 1000 metric tons to 4000 metric tons following numerous efforts to boost the government's campaign. Between the years 2006 and 2009, aquaculture production remained below 4895 metric tons until 2010 when 12,153 metric tons was realized (Table 2.1) (FAO 2016)

Table 2.1: Total Capture and Aquaculture Production for Kenya (Tonnes) (B) Capture Production by Inland And Marine Waters for Kenya (Tonnes) (C) Total Imports and Exports of Fish And Fishery Products for Kenya (Usd 1000)

(a) Year	**Dataset**	**Quantity [T]**
2018	Aquaculture	15 124
	Capture	122 805
2018		
2017	Aquaculture	12 360
	Capture	121 650
2017		
2016	Aquaculture	14 957
	Capture	141 947
2016		
2015	Aquaculture	18 658
	Capture	165 181
2015		
2014	Aquaculture	24 098
	Capture	168 967
2014		
(b) Year	**Area**	**Quantity [t]**
2018	Inland	98 000
	Marine	24 805
2018		
2017	Inland	98 579
	Marine	23 071
2017		
2016	Inland	127 238
	Marine	14 709
2016		
2015	Inland	156 468
	Marine	8 713
2015		
2014	Inland	159 212
	Marine	9 755
2014		
(c) Year	**Export value [1000 USD]**	**Import value [1000 USD]**
2017	20 579	24 980
2016	18 344	23 244
2015	33 688	20 243
2014	48 195	22 284
2013	39 044	15 535
2012	62 836	12 300

2011	54 778	11 644
2010	63 829	7 785
2009	57 113	6 575
2008	75 312	6 236
Source: FAO Fish Statistics (FAO. 2016).		

As a result, Tilapia farming expanded rapidly with the construction of small ponds, especially in Kenya's Central and Western provinces (Table 2.2). Fish farming contributes to an estimated 2% of the total fish produced and is practiced mainly under smallholder mixed farming systems, where farmers grow crops and keep livestock in addition to fish farming (EPZA, 2005; Mbugua 2008). Currently, aquaculture only produces about 24,000 metric tonnes of fish annually compared to an annual average of 178,000 metric tonnes from natural fisheries (Aloo *et al.*, 2017).

In mid 1990s fish farming in Kenya developed rapidly following a pattern similar to other African countries which is characterized by small ponds, subsistence- level management, and very low level of production (Ngugi *et al.*, 2007). Today there is a renewed interest in fish farming in Kenya following the renovation of several government fish rearing farms, the establishment of research programs to determine best practices for pond culture, and intensive training for fisheries extension workers (Opiyo *et al.*, 2018). Therefore farmers in most parts of the country are again turning to fish farming as a way of producing high quality food, either for their families or for the market, and as a way of earning extra income (Opiyo *et al.*, 2018).

Fish farming is included in the vision 2030 as part of the strategy to reduce poverty and improve livelihoods of the communities depending on aquaculture (Opiyo *et al.*, 2018). The Government of Kenya has also launched an economic stimulus programme to improve the use of inland water resources which cover between 10,500 and 11,500 km^2, through the adoption of commercial aquaculture. The programme aimed to construct 200 fish farming ponds in each of the 140 constituencies found in the country. The ponds are to be stocked with appropriate fingerlings determined by the different communities (Alal, 2018).

Farming systems found in Kenya include semi-intensive culture (Munguti *et al.*, 2014) of Nile Tilapia (*Oreochromis niloticus*) and African Catfish (*Clarias gariepinus*), practice by small –scale fish farmers in static ponds, and intensive culture of trout in raceways (Opiyo *et al.*, 2018). Tilapia represents 75% of the total fish produced from aquaculture, followed by African catfish (18%), common carp (6%) and trout (<1%) (Farm Africa, 2016). The species used at any given site are mainly endemic to the region and more or less to the agro climatic zone. For example, Tilapia is a warm water fish and is mainly cultured in a fresh water environment. Catfish are also grown in the same agro climatic region as Tilapia, but trout is best grown in high altitude region where the water is cooler. There is a major drawback when it comes to culturing Tilapia, is uncontrolled reproduction, and the challenge with Catfish is high mortality of sac fry, especially during the first 14 days after the egg hatch. However, trout production is limited by availability of seed and quality feeds in the country (Munguti *et al.*, 2014).

One of the greatest challenges to fish farmers in Kenya is the cost of fish feeds, therefore there is need to develop cost effective fish feeds without compromising the growth rate and quality of the fish flesh (Munguti *et al.*, 2014). Previous studies have shown that the composition of the fish carcass is not only genetically controlled, but that the type of diet affects significantly both the composition and sensory quality of the meat (Muchiri *et al.*, 2015). Fish feeds formulated using agricultural by products is economically viable

(Munguti *et al.*, 2014).

Table 2.2: Area under Aquaculture and Productions By Province

Province	Number of Production unit	Surface area under aquaculture (ha)	Productivity MT/ha/yr	Annual total Production (Kgs/yr)
Coast	362	3.4	0.38	19,856
Eastern	636	46.9	0.59	273,896
Rift valley	1,285	372	73	2,172,480
Central	1,628	219.2	6.58	1,280,128
Nyanza	1,841	40.8	13.32	238,272
Western	2,274	40.1	13.45	234,184
Total	8,026	722.4		4,218,816

Aquaculture survey Nov. 2006 (Mbugua, 2008).

2.4 Challenges facing the fish industry

Lake Victoria is the major source of fish consumed both locally in Kenya and internationally. However, this Lake has experienced many threats which have jeopardized the industry. Population pressure has contributed to contamination of the lake water through discharge of human waste, urban runoff, and discharge from industries such as breweries, tanning, paper processing and coffee washing stations (Sumaila *et al.*, 2016). In addition, pollution of fish supply sources through inflow of chemical residues (herbicides and pesticides) and biological effluents discharged into the lake adversely affects the fish industry. Fish production in Kenya is also threatened by ineffective management of fisheries sources, over-fishing using destructive gears and methods, unsustainable catch levels, siltation of rivers and dams, uncontrolled invasion of aquatic weeds such as water hyacinth and increased cross-border conflicts in the use of fishery products. Climate change is also expected to profoundly impact fish production for example increased sea surface temperature is altering the productivity and distribution of marine ecosystems, therefore potentially cascading impacts on people's livelihoods in areas dependent on fisheries (Cinner *et al.*, 2015; Serdeczny *et al.*, 2017). These factors have contributed to reduced oxygen levels in the lake, therefore endangering the aquatic organisms. Other challenges facing the fish industry are high cost of artificial production (aquaculture), erratic supplies, inadequate statistical information of fish stocks, and cultural beliefs and taboos that do not allow people to eat fish (Cinner *et al.*, 2015).

2.5 Common species of fish

Over 32,000 species of fish have been described, making them the most diverse group of vertebrates. In addition, there are many species of shellfish but only a small number of fish species are commonly consumed by humans. The two common fish species are Tilapa and Catfish.

2.5.1 Tilapia (Oreochromis niloticus)

Nile Tilapia (*Oreochromis niloticus)*, (Linnaeus, 1758) is a tropical fresh water and estuarine species of fish native to Central and North Africa and the Middle East (Boyd, 2004). Tilapia is a generic name of a group of cichlids which consist of three aquaculturally important genera; *Oreochromis*, *Sarotherodon* and *Tilapia* (Wang and Lu, 2016). The scientific names for Tilapia has been revised a lot in the last 30 years creating some confusion in naming Tilapia with names given as *Tilapia niloticus*, *Sarotherodon niloticus* and currently *Oreochromis niloticus* (El-Sayed, 2019). Their reproductive behavior is the most notable characteristic which distinguishes these genera with Tilapia being nest builders while the other genera being mouth breeders.

Tilapia is one of the first fish species cultured due to their aquacultural characteristics which include among others tolerance to poor water quality and the fact that they eat a wide range of natural food organisms (Wang and Lu, 2016). The most commonly cultured species are Tilapia genus widely distributed in West and Central Africa, (examples *Tilapia rendalli and T. zillii), Sarotherodon genus,* restricted to West Africa and also East wards towards the Nile (example *Sarotherodon galilaeus*) and *Oreochromis genus,* distributed more in the Central and Eastern African regions (rift valley lakes in East Africa) examples are *Oreochromis mossambicus, O. aureus, O. niloticus, O.machrochir, O. shiranus)* (Yadav, 2006). More than 90% of commercially farmed fish are Nile Tilapia. *Oreochromis niloticus* is important in both capture and aquaculture production in Africa and accounts for over 90% of total Tilapia aquaculture in Africa. It has been widely reported to be a threat to local or indigenous Tilapias. *Tilapia rendalli* on the other hand may be the best candidate for extensive, and semi extensive culture, as it feeds on higher plants and has a reasonable growth rate when reared in extensive systems and supplemented with plant material (Hlophe *et al.*, 2013).

Nile Tilapia is laterally pressed and deep-bodied fish with cycloid scales and long dorsal fins (Plate 1). The forward portion of the dorsal fin is heavily spined with spines also found in the pelvic and anal fins. It is silver in color with olive or gray or black body bars and often flushes red during the breeding season (Picker and Griffiths, 2011).

It can easily be identified by interrupted lateral lines, a characteristic of cichid family of fishes. The cultured species is distinguished by different banding patterns on the caudal fin. They are generally omnivorus or macrophyte-feeders, feeding on a diverse range of phytoplankton, zooplanktons and filamentous algae (El-Sayed, 2019).

They prefer shallow, still waters on the edge of lakes and wide rivers with sufficient vegetation (Picker and Griffiths, 2011). Besides, they grow best in waters with temperature range of 20-35℃ attaining a weight of 500g in eight months if breeding is controlled and food supply is adequate. They can grow to a maximum length of 62 cm with an average size of 20 cm and weigh 3.65 kg (at an estimated 9 years of age) (FAO, 2012; Bwanika, *et al.* 2004). Higher yield has been realized in semi-intensive system of fish farming, which requires much greater investment in terms of management and stocking. For commercial significance, male Tilapia is known to grow almost twice faster as females thus it is preferable to stock only males (monosex culture) to achieve the fastest growth and reach market size in the shortest period of time. Tilapia has also been known to do well in polyculture ponds with cat fish and other predatory fish (Wang and Lu, 2016).

In terms of nutritional importance, Tilapia is generally a good source of both macro and micro nutrients, but wild is a little bit superior compare to their farmed counterparts in terms of proximate, fatty acids and mineral composition (El-Zaeem *et al.*, 2012). The chemical concept from differences between wild and farmed fish species and groups can therefore be attributed to some environmental factors.

Plate 2.1: Tilapia (Oreochromis niloticus) (source Baroiller, 2012)

2.5.2 African Catfish (Clarias gariepinus)

African Catfish (*Clarias gariepinus)* (Burchell, 1822) is one of the most important tropical fish with an almost pan-African distribution, ranging from the Nile to West and from Algeria to Southern Africa. It is omnivorous, grows fast, and tolerates relatively poor water quality and extreme environmental conditions (Rad *et al.*, 2003).

There are more than 100 different species of the genus Clarias that have been described in Africa and are of interest for aquaculture. A systematic revision based on morphological, anatomical and biographic studies was carried out by Teugels (1982 and 1984), and recognized 32 valid species. These species are excellent for aquaculture and are mostly cultured in earth ponds. Their nutritional requirements in fish pond are highly variable and are influenced by factors such as management practices, stocking densities, availability of natural foods, temperature, fish size, daily feed ration and feeding frequency. The optimal temperature for growth appears to be 30℃. However, temperature in the range of 26-33℃ are known to yield acceptable growth performance.

The Catfish are usually dark gray or black coloration on the back, fading to a white belly (Yalcin *et al.,* 2002). They have slender body, a flat bony head and a broad, terminal mouth with an average adult length of 1-1.5 meters reaching a maximum length of 170 cm (Plate 2). They are recognized by four pairs of barbells which give them the image of cat-like whiskers. In addition, they have long dorsal and anal fins which give them rather eel-like appearance. They also have a large accessory breathing organ composed of modified gill arches. Besides, they are appreciated by consumers for the quality of its meat (Tiamiyu *et al.*, 2019).

Plate 2.2: African Catfish (Clarias gariepinus) (source GOA, 2016)

2.6 Nutritional profile of fish

Fish are an important source of food with good nutritive value; it provides high quality protein, vitamins and a variety of minerals such as calcium, potassium, phosphorus, iron, copper and iodide (Tacon and Metian, 2013; Khalili and Sampels, 2018). Fish protein accounts of approximately 16% of animal protein consumed worldwide has a good balance of essential amino acids (Aguiar *et al.*, 2011). In addition fish also contains highly unsaturated n-3 fatty acids such as Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA). A lot of health benefits associated with fish consumption is attributed to these fatty acids (Balami *et al.*, 2019), such as reducing the incidence of cancer and heart attack (Peter *et al.*, 2013), as well as the treatment of many disorders including arthritis, ulcerative colitis among others (Lorente-Cebrián *et al.*, 2015).

The nutritional profile and organoleptic characteristics of fish are affected by rearing conditions, so the composition and sensory parameters are expected to be different between wild and farmed fish (Fuentes *et al.*, 2010). In farmed fish, artificial diets provide a wide range of nutrients, which not only determine the growth rate but also flesh composition, in particular the lipid content, which may be qualitatively and quantitatively modified (Fuentes *et al.*, 2010). Recent studies have demonstrated that wild fish have superior proximate composition, fatty acid composition and mineral content than farmed fish (El-Zaeem *et al.*, 2012; O'Neill *et al.*, 2015). And this is mainly attributed to the fact that in the wild there is wide diversity of microscopic organism and macrophytes which fish species generally feed on (Job and Udo 2002; Olojo *et al.*, 2003). These may be lacking in controlled systems like ponds (El-Zaeem *et al.*, 2012). But then again the levels of proximate constituents of the whole body as well as the fillets of fish are readily manipulated by feed composition and feeding strategies, whereas sensory parameters are less affected by these variables (Favalora *et al.*, 2012). The interplay therefore of the aforementioned factors have been previously advanced as reasons responsible for the usually observe differences in wild and farmed fish species (El-Zaeem *et al.*, 2012).

2.7 Methods of fish preparation and consumption

Fish is prepared in a variety of ways, for example it can be uncooked (taken raw) or cooked by baking, frying, grilling, poaching, or steaming. It can also be cured by marinating, pickling, or smoking (Sampels, 2015). Different preparation methods have been shown to result in nutritional quality changes in fish and fish products (Vanitha *et al.*, 2015). Understanding these effects is important in satisfying consumer's needs relating to nutritional composition of fish. However, many preservation techniques used in different cultures have since become unnecessary but are still performed for their resulting taste and texture when consumed. Studies of fish consumption are limited although consumption of fatty fish has been reported to reduce the risk of cancer.

2.8 Fish as a source of polyunsaturated fatty acids

Besides being a protein source, fish is also a source of long-chain polyunsaturated fatty acids (PUFA, both n-3 and n-6), such as linolenic acid (LA), y-linolenic acid (GLA),alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Hossain, 2011), which are associated with a wide range of human health benefits (Zárate *et al.*, 2017; Rimm *et al.*, 2018). Of late there has been increased scientific interest in the role of omega-3 fatty acids found in fish oils in prevention and management of cardiovascular diseases such as hypertension (Connor, 2000). The bases of this heightened interest in dietary intakes of EPA and DHA comes partly from epidemiological and population studies indicating that increased consumption of fish as a source of omega-3 fatty acids are often associated with decreased mortality as well as morbidity from cardiovascular diseases such as coronary heart disease (CVD) (Connor, 2000). This reduction in coronary risk has been related to the capacity of the omega-3 fatty acids such as EPA and DHA of marine lipids to lower serum triglyceride levels and decrease platelet aggregation (Harris, 2008) and blood pressure (Bønaa *et al.*, 1990). The Dietary Guidelines for Americans -2010 (DGA) recommends that people consume 200g of fish per week- especially marine-derive "oily" fish such as tuna, sardines, salmon and mackerel- to provide an average consumption of 250 mg EPA and DHA per day (Miller *et al.*, 2008; Cladis *et al.*, 2014). Other fish, including freshwater fish species, can also provide these fatty acids, but the levels are generally lower than those in marine fish species, so that higher consumption is needed to meet the recommendations (Matos *et al.*, 2019).

2.9 Heavy metal residues in fish

Fish are often at the top of the aquatic food chain, so it may contain large amounts of some heavy metals such as lead, cadmium, chromium, copper, zinc and iron (Muiruri *et al.*, 2013). Heavy metals are not biodegradable and their concentration actually increases through bioaccumulation (Sthanadar *et al.*, 2015). The bioaccumulation of heavy metals is largely attributed to differences in uptake and depuration period for various metals in different fish species (Muiruri *et al.*, 2013). Considering lead as an example; it has been found out that lead is a cumulative poison that causes both chronic and acute intoxication, most important it causes permanent damage in the central nervous system in children and adults respectively (Salim *et al.*, 2003).

Heavy metals are normal constituents of the marine environment, so traces are always found in marine organisms. Thus people who eat large amounts of fish or shell fish from estuarine or coastal areas that are associated with the chemical industry are at higher risk of heavy metals poisoning (Bosch *et al.*, 2016). Generally, the accumulation of metals in fish is observed in various tissues like liver, gills and muscles, on the other hand accumulation of metals have even been found in canned sardines, of course after processing (Bosch *et al.*, 2016). A study by Kinyanjui (2009) on heavy metals in wild fish in Kenya reveals that most of the fish consumed had acceptable levels of heavy metals such as cadmium, arsenic, lead and mercury.

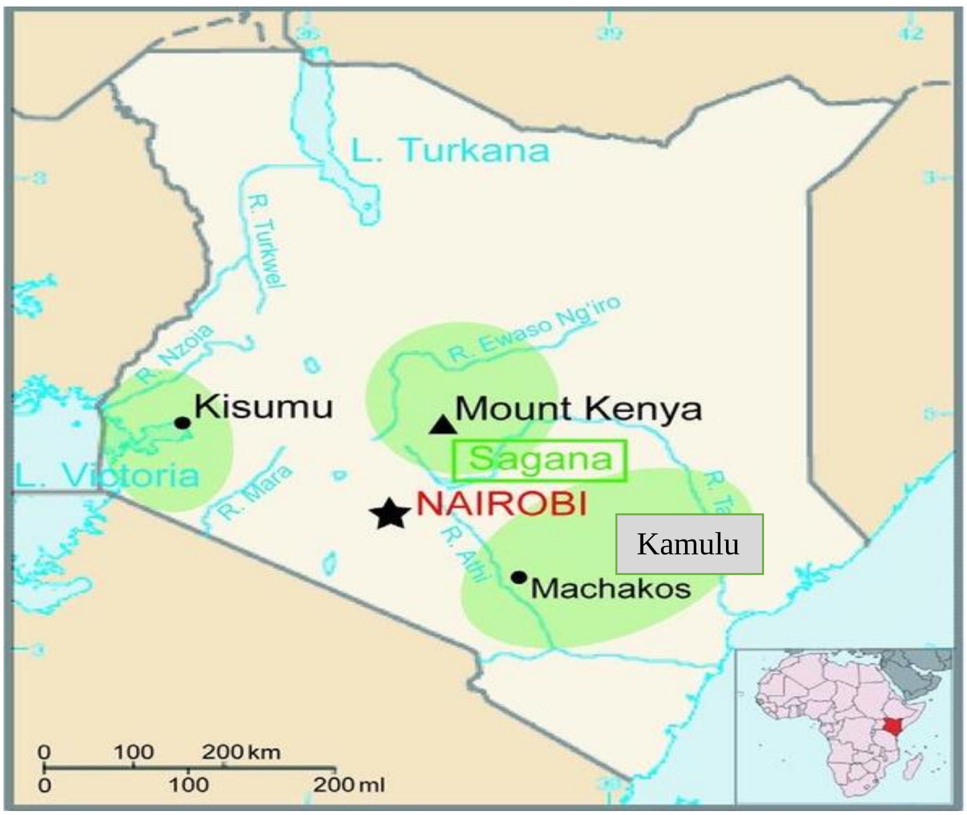
Farmed fish can also have some levels of heavy metals because most of the times fish ponds are situated in or near agricultural farms where inorganic fertilizers, herbicides and pesticides are used and they are washed into the ponds by rain water, and these are direct sources of heavy metals (Ngugi *et al.*, 2007).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

Sampling of farm fish was conducted in Sagana, Kirinyaga County and Kamulu in Machakos County whereas fish from Lake Victoria was purchased from fishermen at a fish landing site in Kisumu through known fish vendors in city market, Nairobi as depicted in Figure 3.1.



. Figure 3.1: Map of Kenya showing the sources of fish samples Sagana in Kirinyaga County, Kamulu in Machakos County and Lake Victoria

3.2 Study Species

Fish species for the study were Tilapia (*Oreochromis niloticus*) and African Catfish (*Clarias gariepinus*) as shown in Plate 3.

a)

b)

Plate 3: Images showing the fish species studied; (a) Oreochromis niloticus (Tilapia) and (b) Clarias gariepinus (African Catfish)

3.3 Study design

Six fish farmers and four fish vendors were the sampling units used for farmed and wild fish respectively. I collected the first batch of wild fish samples from fishermen at a landing point in Kisumu, subsequent samplings were done by fish vendors from city market (Nairobi) after undergoing some training.

A list of fish farmers who owned at least a pond was obtained from the County Fisheries Officers in Kirinyaga and Machakos Counties which formed the sampling frame for farmed fish. On the other hand, four fish vendors were identified using questionnaires at the city market in Nairobi. The vendors liaised with two fishermen in Lake Victoria who delivered the fish samples for wild fish throughout the study. The study design approached randomized block design of Sagana, Kamulu , Kisumu and six farmers who represented different feeding systems.

3.4 Sampling and sample collection

The wild fish and farmed fish sampling plan is shown in Table 3.2. Sampling was done four times during the study period (February, March, May and June) in order to generate more data. Eight wild fish each of different weights; small fish (between 0.4 – 1.5 kg) and big fish (>1.5 kg) were randomly purchased from fishermen at their landing site in Kisumu through fish vendors in city market. During sampling the fish were obtained early in the morning immediately on arrival from Lake Victoria. This was done once every week during the four months of the study. On the other hand, farmed Tilapia and African Catfish each of similar weight, approximately 1 kg were randomly purchased from six farmers in Sagana and Kamulu regions. Sampling was done once every week during the four months of the sampling period. The six farmers were subdivided into three depending on the feeding systems used (A , B , and C) respectively, each feeding system is represented by two farmers.

Fish samples were put in cool boxes and transported to the department of Food Science and Technology laboratory in JKUAT.

Table 3.1: Showing Feeding systems, feed composition, number of fish per week and total number of farmed fish throughout the study

Feeding system	**Composition of feed**	**Total number of fish per week**	**Total number of fish per feeding system**
A	Omena (*Rastrineola argenta*) mixed with lake shrimps*(Caridina nilotica)*	6 3 Tilapia +3 Catfish	96
B	Wheat bran mixed with cotton seed meal	6 3 Tilapias+3 Catfish	96
C	Chicken droplets and maize flour	6 3 Tilapias+3 Catfish	96

Table 3.2 below shows how the fish were sampled with 1, 2 , 3 and 4 representing sampling months. Big (≥1.5 kg) and small (0.4-1.5 kg) represent the sizes of wild fish while A, B, C represents the feeding systems of farmed fish.

Table 3.2: Sampling of the wild fish from city market Nairobi and farmed fish

Month		**Week 1**	**Week 2**	**Week 3**	**Week 4**
1	Big	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
	Small	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
2	Big	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
	Small	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
3	Big	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
	Small	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
4	Big	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
	Small	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish	2Tilapia+2Catfish
1	A	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	B	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	C	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
2	A	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	B	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	C	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
3	A	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	B	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	C	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
4	A	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	B	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish
	C	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish	3Tilapia+3Catfish

3.5 Sample preparation

The fish sample were degutted, filleted and kept in the freezer at -18 $^{\circ}$C prior to analyses.

A portion of the fillet was used for analyses of pH and firmness while the rest was minced using a meat mincer (Model, M12 Tk) and packed in polythene Ziplock bags and kept in a freezer at -18 $^{\circ}$C for analysis of proximate composition, fatty acid profile, mineral composition, heavy metal profile and Thiobarbituric Acid Reactive Substances (TBARS). For sensory evaluation, the fish sample was degutted, salted and immediately deep fried using corn oil (elianto).

3.6 Moisture content determination

Moisture content was determined using oven drying method according to the method described by the AOAC (2006). Approximately 5 g of the sample was weighed, put into a steel container, the container and the lid were pre-weighed (Wo), then the sample, container plus the lid were reweighed accurately (W1). The sample was heated at 105^{o}C for 1-2 hours while the lid was open, the lid was then closed and cooled in a desiccator at room temperature and the weight determined. Heating was repeated at 105^{o}C for 2 hours until a constant weight was attained (W2), and the moisture content calculated as a percentage as follows:

$$\% \text{ Moisture} = \frac{\text{wt before drying (W1)} - \text{wt after drying (W2)}}{\text{wt before drying (W1)} - \text{wt of container (W0)}} \times 100$$

3.7 Crude ash content

Ash content was determined using muffle furnace incineration method. Constant weights of crucibles were taken by heating in a muffle furnace at 550-600^{o}C for 1hr then cooled in a desiccator at room temperature. Two grams of the sample were weighed accurately with the crucible (W1) and incinerated at 550-600^{o}C in a muffle furnace for

2-5 hours without the lid. At the end, the dish together with the lid was weighed accurately (W2), and crude ash content calculated using the following equation:

$$\% \text{ crude ash} = \frac{\text{wt after ashing (w2)-wt of crucible (w0)}}{\text{Wt before ashing (w1)-wt of crucible*100}}$$

3.8 Crude protein content determination

Protein content was determined by semi Kjeldhal method as described by AOAC (2006). Exactly 1 g of the sample was weighed into digestion flask and 3 g of a catalyst was added. Ten ml of conc. H_2SO_4 was then added and the content digested. Gradual heating was done to enable water to evaporate from the sample. The temperature was then increased gradually to allow the acid to boil gently until the liquid was almost colorless for 1hr. After digestion, the flask content was then cooled to room temperature and diluted exactly to 100 ml with water in a volumetric flask. The digested solution was then made alkaline by adding 5ml of 40% NaOH through a separatory funnel; a burner was then placed under the boiling flask so that 40-50 ml of the distillate collects in 10-20 minutes. The steaming was continued until about 50 ml liquid was collected. The distillation continued for 2 to 3 minutes, flask was then removed for titration with standard 1/50N H2SO4. Protein content was then calculated using the nitrogen conversion factor 6.25 (N x 6.25).

3.9 Crude lipid content determination

The crude lipid content was extracted using Bligh and Dyer method. Approximately 2 g of sample was placed in 50 ml glass-stoppered centrifuge tube and immediately denatured at 100°C for 3 minutes. Four ml of water and 150 ml of methanol-chloroform

(2:1 v/v) was then added to the sample and shaken and left at room temperature for several hours, then centrifuged. After that the supernatant extract was decanted into another 50ml glass-stoppered centrifuge tube and re-suspended in 19 ml of methanol-chloroform-water (4:20:16 v/v). The homogenate was then shaken and centrifuged and this extraction was done two times. 15 ml each of chloroform and water was added to the combined supernatants and the mixture centrifuged. The lower chloroform phase was withdrawn and brought to dryness under rotary evaporator, and the lipid residue in the flask was completely dried under vacuum in a desiccator over fresh KOH pellets for about 1-2 hours and the weight of the lipid was then measured.

3.10 Fatty acid composition determination

Fatty acid composition was determined according to the method described by the AOAC (2006). The extracted lipid was methylated by adding a solution which composed of 95 ml methanol and 5 ml HCl acid, and then the mixture was placed in a reflux for one hour. The mixture was then cooled and separated using hexane. The acid traces was then washed using distilled water, and the separated solvent was dried using anhydrous sodium sulphate then evaporated to 1ml and kept in a sample vial to be concentrated using nitrogen gas. To analyze the Fatty Acid Methyl Esters (FAMEs), 0.3µl of the concentrated sample were injected into GC equipped with split/splitless, flame ionizer detector and a fused silica capillary column (SUPELCO Column Omegawax^{tm}530, 30m x 0.5mm x 0.5µm). Nitrogen was used as carrier gas with temperature programming from 170 ^{0}C to 220^{0}C for 18 min^{-1} and final time of 47 minutes totaling to a run time of 75minutes. Injection and detection temperatures were 240^{0}C and 260^{0}C respectively. All the GC analyses were done under same conditions. Individual methyl esters in the sample were identified by comparison with known FAME standards (Kobian chemicals, Kenya).

3.11 Determination of thiobarbituric acid reactive substances (TBARS)

The fish were degutted and filleted; the fillets were then cut into portion of 5 cm cubes.

The fillet portions (500 g) were then placed in a cooking saucepan filled with one liter of distilled water, the saucepan was then brought to boil using a gas cooker for 30 mins.

The Stability of fatty acids after cooking was then determined by comparison of fatty acid profiles and measurement of Thiobarbituric Acid Reactive Substances (TBARS). The levels of TBARS were determined by the extraction method according to Izumimoto *et al.* (1990). Ten (10) g of sample was placed in 50 ml of distilled water stirred and left for 30 minutes. The mixture was then homogenized with 20 ml of 20% trichloroacetic acid (TCA) and filtered to obtain the extract after 30 minutes. Active charcoal was used to eliminate interferences caused by the colour pigmentation in the extract. Equal volumes of 5 ml of the extract and 0.02 M thiobarbituric acid (TBA) solution was mixed and heated in a boiling water bath for 35 minutes. The absorbance of the resulting red chromophore was measured at 532 nm using a Shimadzu UV-VIS spectrophotometer mini 1240. A factor of 12.9 was used to convert absorbance to malonaldehyde (mg MA/kg) of the sample.

3.12 Mineral and heavy metals determinations

Mineral analysis was done using AOAC method of analysis (AOAC, 2006). Two grams from ash sample were placed in a digestion tube and pre-digested using 10 ml of HNO_3

and 1ml of $HClO_3$ acids were added and temperature maintained at 135^oC until the liquor was colorless. The digested liquors were then filtered through a whatman 1 filter paper and diluted to 25 ml with distilled water. The digested samples were then used for analysis of selected minerals (Mg, Fe, Mn, Cu, Zn) and heavy metals (Hg, Pb, Cr, Cd) using atomic absorption spectrophotometer (AAS) (Model A A-6200, Shimadzu, Corp., Kyoto, Japan). Suitable standard solutions were prepared and their absorbance measured to prepare a standard curve. The standard curve was used to calculate the concentration of minerals.

3.13 Firmness

Firmness was measured at three different spots of the un-minced fillet of wild and farmed fish by shear force and compression test using a penetrometer (Model CR-100D, Sun Scientific Co. Ltd, Japan) fitted with a 5mm probe. All measurements were performed using pieces of the flesh of the fish fillet (Fuentes *et al.*, 2010). The probe was allowed to penetrate the flesh to a depth of 1.5 cm and the corresponding force required to penetrate this depth was determined. Firmness was then expressed as Newton (N) (Jiang *et al.*, 1999).

3.14 Determination of pH value

The pH of the minced flesh of the fish was measured at room temperature using an electronic PH/ORP meter (Model HI-2211-02, Woonsocket, USA) with a glass electrode using expandable scale.

3.15 Sensory analysis for consumer acceptability

Fish were cut into portions of 7 cm diagonally depending on their sizes (1 kg, 1.5 kg and 2 kg) respectively, the portions were then washed, dry salted using 1 g of salt each, the portions were then deep fried for 30 mins until golden brown using corn oil (Elianto). The panelists were then presented each with 3 plates containing the same fish sample in different arrangement which was identified by a three digit code that was randomly chosen and assigned to each sample.

Sensory evaluation was then conducted by means of questionnaires administered to 20 semi-trained panelists. Sensory attributes such as color, smell, taste, texture, aroma/flavour and overall acceptability were evaluated. The recruited participants/panelists were of mixed gender, chosen from students and staff of the Food Science and Technology Department, JKUAT and had no particular knowledge of the study. Prior to the experiments, they were trained on the evaluation procedures.

A 9- point hedonic scale with 1 representing the least score (dislike extremely) and 9 the highest score (like extremely) was used where the participants evaluated the attributes by grading and scoring (Appendix XI). This was done according to the method by Eboh *et al.* (2005) with slight modification.

3.17 Data analysis

Data on proximate composition, fatty acid composition, mineral and heavy metal profiles, pH, firmness, TBARS and sensory evaluation were tabulated on spreadsheet and analyzed using one-way analysis of variance (ANOVA) under Genstat analytical tool. Individual means were compared and separated using Duncan's multiple range test with significance level at $p<0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Proximate composition

The proximate composition results of the wild and farmed fish are presented below in Table 4.1.

Table 4.1: Proximate composition of both wild and farmed fish

Feeding system		Fish type	Sample size (n)	Proximate composition (%)			
				Moisture	**Ash**	**Fat**	**Protein**
Farm	A	Catfish	24	73.83^{b}±0.62	1.49^{c}±0.09	3.54^{b}±0.09	19.20^{c}±0.65
		Tilapia	24	75.17^{b}±1.12	1.35^{c}±0.21	3.39^{b}±0.39	18.85^{c}±1.44
	B	Catfish	24	76.05^{a}±1.01	1.38^{c}±0.02	4.92^{a}±0.17	16.94^{d}±1.29
		Tilapia	24	76.31^{a}±1.72	1.29^{c}±0.06	4.78^{a}±0.25	16.55^{d}±0.92
	C	Catfish	24	77.31^{a}±1.19	1.25^{c}±0.12	1.95^{c}±0.58	16.32^{d}±2.03
		Tilapia	24	78.06^{a}±0.92	1.17^{c}±0.16	1.88^{c}±0.17	15.98^{d}±1.76
Wild	Big fish	Catfish	24	70.88^{c}±1.74	2.08^{a}±0.19	3.84^{b}±0.33	22.14^{a}±0.96
		Tilapia	24	71.23^{c}±1.06	1.93^{a}±0.17	3.42^{b}±0.37	21.85^{a}±1.57
	Small fish	Catfish	24	72.35^{c}±1.14	1.88^{b}±0.30	3.11^{b}±0.26	20.97^{b}±1.07
		Tilapia	24	73.09^{c}±0.38	1.79^{b}±0.21	3.02^{b}±0.15	20.19^{b}±1.48

* Values are given as means ± Std dev. Means with different superscript letters within a column are significantly different ($P < 0.05$).

The moisture contents ranged between 70.9 - 78.1 %. Farmed fish had significantly ($p<0.05$) higher moisture content compared to wild fish. The moisture content of farmed

Tilapia ranged between 75.2 – 78.1% whereas the moisture content of wild Tilapia ranged between 71.2 – 73.1%. The farmed Catfish on the other hand had moisture content ranging from 73.8 - 77.3 % whereas the wild counterparts had moisture content ranging from 70.9 - 72.4 %. From the results, it is evident that both farmed and wild Tilapia fish had slightly higher moisture content as compared to the Catfish. On the other hand farmed fish from system B (feed consisted of wheat bran + cotton seed) and C (feed consisted of chicken droplets + maize flour) had significantly (p<0.05) higher moisture content than those from feeding system A (feed consisted of omena + lake shrimps). Moreover, it was observed that the moisture content of the wild fish decreased with increasing body weight with the small Catfish and Tilapia reporting 72.4% and 73.1%, respectively while the big Catfish and Tilapia having 70.9% and 71.2%, respectively.

The ash content of fish ranged between 1.2 - 2.1% with the wild fish reporting significantly higher contents as compared to the farmed fish (p<0.05) (Table 4.1). The farmed Tilapia and Catfish had ash content ranging from 1.2 – 1.4% and 1.3 - 1.5% respectively, whereas the wild counterparts had ash contents ranging from 1.8 – 1.9% and 1.9 - 2.1%, respectively. For the wild fish, big Tilapia and Catfish had significantly higher ash contents of 1.9% and 2.1% as compared to the small fish with values of 1.8% and 1.9% respectively. However, there was no significant ($p<0.05$) difference between the ash content of the fish from the three feeding systems (A, B and C).

Protein content ranged from 16.0 – 22.1% with wild fish having significantly ($p <0.05$) higher protein content (20.2 – 22.1%) than farmed fish (16.0 – 19.2%). Farmed Catfish had protein content ranging from 16.3 - 19.2% as compared to 21.0 - 22.1% for the wild type. Farmed Tilapia on the other hand, had protein content ranging from 16.0 – 18.9%, while its wild counterpart had values of 20.2 – 22.0%. For the different feeding systems, feeding system A (feed consisted of omena + lake shrimps) reported significantly ($p<0.05$) higher contents of protein as compared to the other two feeding systems (B and C). However, there was no significant ($p>0.05$) difference between feeding system B and C ($p>0.05$). For the wild fish, the big Tilapia and Catfish reported significantly higher protein content of 21.9% and 22.1% respectively as compared to the small Tilapia and Catfish with protein values of 20.2% and 20.8% respectively.

The fat content of the fish ranged from 1.9 – 4.9% with farmed Tilapia and Catfish reporting 1.9 – 4.8% and 2.0 – 4.9% respectively. Fat content for wild Tilapia and Catfish ranged from 3.0 – 3.4% and 3.1 - 3.8% respectively. There was no significant (p <0.05) difference in the fat content of fish from feeding system A (feed consisted of omena + lake shrimps) and wild fish. On the other hand, farmed fish from feeding system B (feed consisted of wheat bran + cotton seed) had higher fat contents than farmed fish from feeding system A, whereas farmed fish from feeding system C (feed consisted of chicken droplets + maize flour) had lower fat contents than those from feeding system A. Therefore fish from Feeding system C reported significantly (p<0.05) lower fat content among the farmed fish. For the wild fish, the big fish had slightly higher fat content than small fish.

This study shows that proximate composition of farmed fish is directly influenced by their diet. According to Fuentes *et al.* (2010) and Rani *et al.* (2016), the variation in proximate composition of fish is as a result of differences in nutrition, living area, fish size, catching season, seasonal and sexual variations as well as other environmental conditions. This study concurs with the findings by Bhouri *et al.* (2010) which showed higher ash content in wild fish as compared to the farmed fish. The observed range of ash content in this study indicated that Catfish is a good source of minerals since ash is a measure of the mineral content of food (Oladipo & Bankole, 2013). Adebayo *et al.*

(2016) similarly reported that Catfish contain slightly higher ash, fat and protein contents than the Tilapia. In addition, other studies reported that the moisture and ash contents of fish decrease with an increase in fat and protein contents and vice versa (Mahboob *et al.*, 2019; Jim *et al.*, 2017). The increased water content is due to decreasing fat and protein contents in the fish body (Jim *et al.*, 2017). In addition, it may be attributed to more physical efforts performed by the wild fish species to capture food organisms in the natural habitat than the farmed fish which has plenty of food supply in the ponds (Jim *et al.*, 2017). The high protein content in feeding system A may be attributed to the diet which comprised of *Omena* and lake shrimps which are richer in proteins. In addition, the higher fat content in feeding system B may be contributed to diet which comprised of wheat bran and specially cotton seed which high rich in fat. Other factors included availability and type of food, dietary ingredients (commercial diets usually high in fat content and dietary carbohydrate), higher energy consumption in farmed fish as compared to wild fish (Grigorakis *et al.*, 2002). Furthermore, the results indicate that the wild fish is richer in most of the nutrients than the farmed fish from the three non-intensive feeding systems used by farmers in the study. The results agree with the findings of other studies which compared the composition of wild and farmed fish (Job *et al.*, 2015). According to these studies, the proximate composition differed based on the type of food and habitat of the fish. Similarly, the wild fish feeds naturally from their ecosystem, while farmed fish are fed according to farmer affordability (Orban *et al.*, 2003).

4.2 Fatty acid composition of fish

Table 4.2: Fatty acid profile of farmed and wild fish.

	Farmed fish						**Wild fish**			
Fatty acid	**A**		**B**		**C**		**Big Fish**		**Small Fish**	
Saturated Fatty Acids	**Catfish**	**Tilapia**	**Catfish**	**Tilapia**	**Catfish**	**Tilapia**	**Catfish**	**Tilapia**	**Catfish**	**Tilapia**
C8:0	0.63±0.08^{bc}	0.43±0.01^{cd}	1.1±0.06^{a}	0.87±0.03^{ab}	0.23±0.01^{d}	0.33±0.07^{d}	1.03±0.02^{a}	1.03±0.01^{a}	0.77±0.01^{b}	0.77±0.01^{b}
C10:0	0.06±0.01^{b}	0.06±0.01^{b}	0.09±0.01^{b}	0.06±0.02^{b}	0.04±0.01^{b}	0.02±0.00^{b}	0.09±0.01^{b}	0.39±0.01^{a}	0.06±0.01^{b}	0.05±0.01^{b}
C12:0	1.0±0.01^{de}	0.73±0.01^{e}	1.4±0.08^{abc}	1.27±0.02^{bcd}	0.33±0.06^{f}	0.3±0.00^{f}	1.7±0.11^{a}	1.5±0.12^{ab}	1.33±0.07^{bc}	1.1±0.05^{cd}
C14:0	3.47±0.24^{a}	3.17±0.75^{bc}	3.00±0.12^{bcd}	3.8±0.17^{e}	2.17±0.09^{e}	1.87±0.11^{f}	3.23±0.04^{ab}	3.10±0.09^{bc}	2.90±0.02^{cd}	2.77±0.06^{d}
C16:0	32.4±0.78^{d}	30.8±2.58^{f}	25.30±0.96^{g}	24.30±3.11^{h}	32.30±2.01^{d}	31.47±3.25^{e}	33.63±1.38^{c}	32.33±2.19^{d}	38.20±0.94^{a}	37.30±1.09^{b}
C18:0	8.4±0.91^{g}	8.1±0.58^{g}	11.63±1.62^{hc}	10.27±1.45^{e}	9.53±0.25^{f}	10.20±0.64^{e}	12.20±0.05^{b}	12.13±0.08^{b}	10.80±0.81^{d}	14.37±0.24^{a}
C20:0	0.3±0.01^{de}	0.30±0.00d^{e}	0.63±0.02^{abc}	0.57±0.05^{bcd}	0.20±0.00^{e}	0.20±0.01^{e}	0.87±0.06^{a}	0.7±0.01^{ab}	0.4±0.02^{cde}	0.33±0.08^{de}
ΣSFAs	**46.26**	**43.59**	**43.16**	**39.6**	**44.81**	**44.38**	**52.76**	**51.19**	**54.46**	**56.68**
Unsaturated Fatty Acids										
C16:1	6.8±0.96^{c}	7.8±0.77^{c}	10.8±0.48^{a}	8.80±0.84^{b}	7.33±0.52^{c}	4.53±0.85^{d}	4.33±0.91^{d}	6.7±0.53^{c}	5.2±0.17^{d}	5.0±0.59^{d}
C18:1	21.9±1.05^{e}	21.27±1.75^{e}	25.4±2.33^{c}	24.30±2.01^{d}	26.50±1.33^{b}	28.73±0.15^{a}	20.5±0.98^{g}	21.00±1.37^{fg}	22.4±0.90^{e}	20.7±1.51^{fg}
C18:2	12.1±0.71^{a}	11.77±0.08^{a}	9.17±1.03^{e}	9.2±0.90^{e}	9.47±0.19^{de}	9.80±0.05^{c}	8.60±0.45^{f}	9.6±0.28^{cd}	6.6±0.31^{g}	6.9±0.15^{g}
C18:3	1.1±0.01^{bcd}	1.07±0.04b^{cd}	1.70±0.03^{a}	1.5±0.09^{a}	0.7±0.04^{e}	1.40±0.02^{ab}	1.17±0.07^{bc}	0.8±0.05^{de}	0.6±0.03^{e}	0.53±0.01^{e}
C18:3	0.6±0.09^{def}	0.53±0.07^{def}	0.67±0.08^{cdef}	0.96±0.10^{abc}	1.27±0.06^{a}	1.20±0.03^{ab}	0.9±0.08^{bcd}	0.8±0.03^{cde}	0.5±0.07^{ef}	0.40±0.05^{f}
C20:5	1.67±0.08^{b}	1.50±0.04^{b}	0.87±0.01^{cd}	0.63±0.05^{d}	1.0±0.06^{c}	0.83±0.02^{cd}	2.23±0.07^{a}	2.17±0.04^{a}	1.57±0.03^{b}	2.41±0.02^{a}
C22:6	2.80±0.02^{c}	2.40±0.07^{c}	1.57±0.04^{e}	1.90±0.01^{e}	2.07±0.02^{e}	2.03±0.01^{f}	3.77±0.11^{a}	3.70±0.09^{a}	3.33±0.17^{b}	3.03±0.07^{c}
ΣUFAs	**46.97**	**46.33**	**50.17**	**47.29**	**48.33**	**48.53**	**41.4**	**44.77**	**40.2**	**38.98**
ΣOther FAs	6.77	10.07	6.68	13.11	6.86	7.08	5.84	4.04	5.34	4.34
Total Fatty acids	100	100	100	100	100	100	100	100	100	100

n=3, Values are mean ± SD, Values with different superscripts in the same row are significantly different at $p<0.05$ A,B,C = feeding systems.

A total of 14 fatty acids from C8:0 to C22:6 n-3 were identified in the two fish species from the farmed and wild systems. The numbers of unsaturated fatty acids were similar to the saturated fatty acids. Five of the 7 unsaturated fatty acids were PUFAs and 2 were monounsaturated fatty acids (MUFAs).

Saturated fatty acids were predominant in both Catfish and Tilapia and from all the feeding systems, with palmitic acid ($C_{16:0}$) values ranging from 24.30 – 32.4 % followed by stearic acid ($C_{18:0}$) with values ranging from 8.4 – 11.63% and capric acid ($C_{10:0}$) was the saturated fatty acid with lowest percentage. The saturated fatty acids varied between the different feeding systems, with fish from feeding system A (feed consisted of omena + lake shrimps) having significantly ($p<0.05$) higher levels of saturated fatty acids (43.56-46.26%) compared to fish from both feeding systems B and C respectively. The sum of all identified saturated fatty acids ranged from 36.9% to 46.26% whereas the sum of all the unsaturated fatty acids ranged from 46.33% to 50.17%. However, higher values of saturated fatty acids were reported in fish from feeding system A as compared to the fish from the other feeding systems. Fish from feeding system B (feed consisted of wheat bran + cotton seed) reported significantly ($p<0.05$) higher unsaturated fatty acids as compared to saturated fatty acids; whereas there was no significant ($p<0.05$) difference between the saturated and unsaturated fatty acids in fish from feeding system A (feed consisted of omena + lake shrimps).

On the other hand, substantial amounts of monounsaturated fatty acids were reported with palmitoleic acid ($C_{16:1}$) and oleic acid ($C_{18:1}$) being the predominant MUFA with values ranging between 4.6– 10.8 and 18.9 – 25.6%, respectively. The principal PUFAs were linoleic acid ($C_{18:2}$), docosahexaenoic acid (DHA) ($C_{22:6}$), eicosapentaenoic acid (EPA) ($C_{20:5}$) and linolenic ($C_{18:3}$). The contents of these PUFA ranged from 9.17 – 12.1% for linoleic acid, 1.57 – 2.8% for DHA, 0.63 – 1.67% for EPA and 0.7– 1.7% for linolenic acid. The PUFA composition of farmed fish also varied between the different feeding systems. Although fish from feeding system B reported higher values of unsaturated fatty acids as compared to fish from other feeding systems, fish from feeding system A had higher saturated fatty acid composition.

The observed increase in oleic acid at the expense of palmitic acid in system B is of interest due to the health benefits of the former versus the undesirable effects of the latter (Huynh and Kitts (2009), that is to say oleic acid reduces the risk of cardiovascular disease by reducing blood lipids, mainly cholesterol while palmitic acid increases the risk of cardiovascular disease by increasing blood cholesterol concentration. In addition, the composition of PUFA present in fish, especially Omega-3, is important for health, as they have been reported to reduce incidences of cardiovascular disease (Din *et al.*, 2008; Myhoursbad *et al.*, 2011). In addition, the unsaturated fatty acids are essential in the human diet since they cannot be synthesized by the body. The higher level of linoleic acid in farmed fish has been related to the diet ingredients of farmed fish (Sérot *et al.*, 1998). This fatty acid is present in plant oils used in the manufacture of farmed fish feed e g (feed used in feeding system B) and is largely accumulated in an unchanged form in the lipids of fish. This is evident in fish from feeding system B. Therefore this is attributed to the feed since the fish was fed on cotton seed and wheat bran which are known to contain a substantial amount of fatty acids especially the unsaturated fatty acids. On the other hand, lauric acid and myristic acid which promote hypercholesteromia were detected at low concentration in the studied species across all the feeding systems, a positive factor in their consumption

Similar to their farmed counterparts, the fatty acid composition of wild fish also varied between the two fish. Catfish had higher values of saturated fatty acids than unsaturated fatty acids, with palmitic acid reporting higher values of 38.2% and 33.62% for small and big Catfish, respectively. Oleic acid was the predominant unsaturated fatty acid with values of 20.5% and 22.4% for big and small Catfish, respectively. Tilapia also had higher levels of saturated fatty acids than unsaturated, with bigger fish having higher levels of unsaturated fatty acids than the smaller fish, this shows that the concentration of unsaturated fatty acid increases with increase in body weight, and this is in agreement with the results of the studies by Muhammad *et al.* (2010). In addition, since there was slight variation between the fatty acid values of the fish, the difference could be attributed to seasonal variation, size or location of the catch and water temperature.

According to Budge *et al.* (2002) the variability in fatty acid values of marine fish indicates that a number of species exhibit changes in fatty acid composition with increasing size. This happens because as fish grow, they tend to feed on different diet compared to when they are small, for instance, feeding on other small fish.

In general, the fatty acid composition of the fish in this study was similar to available data on other Tilapia and Catfish. According to Secci and Parisi (2016), fish lipids comprise of 40% of long chain fatty acids (14–22 carbon atoms) which are highly unsaturated. Fernandes *et al.* (2014) on the other hand it has been reported that palmitic acid (C16:0) is a key metabolite in fish whose level is not influenced by diet. Oleic acid was the major monounsaturated fatty acid in this species and although they can be synthesized *de novo* by animals including fish, they can also be derived exogenously since they are common components of diet especially in animal derived foods (Kabeya *et al.*, 2018). On the other hand, vertebrates including fish, cannot produce PUFA *de novo* as they lack the Δ_{12} and Δ_{15} desaturases required to desaturate oleic acid (C18:1 n-9) to linoleic acid (C18:2 n-6) and then to α- linolenic acid (C18:3n-3) respectively.

The fatty acid of wild and farmed fish was reported to vary mainly with fish natural diet (González *et al.*, 2006). The fatty acid composition of fish may also be influenced by intrinsic factors such as fish species, size and sexual maturity and extrinsic factors such as season, water salinity and temperature (Shi *et al.*, 2013). However, similar studies on tropical and temperate freshwater fish indicated the dominance of saturated fatty acids particularly palmitic and stearic acids in the tissue lipids of fish (Logue *et al.*, 2000).

Fish oil contains essential fatty acids (omega-3), essential to the maintenance of cell membrane structure throughout the body and people who consume more fish containing n-3 fatty acids consistently have lower incidence of heart disease (Kromhout *et al.*, 1985). They are also very important to human immune system, as they help regulate blood pressure. However, Catfish and Tilapia contained modest but useful amounts of the essential fatty acid, linoleic acid. This is an important component of membrane phospholipids, a precursor to arachidonic acid which is a critical fatty acid found in virtually all tissue membranes of humans (Glew *et al.*, 2004). These fatty acids are therefore important from the nutritional and stability point of view thus the intake of fish is of importantance.

The recommended daily intake of EPA and DHA is 1g/day (Zhang *et al.*, 2018), therefore substantial amounts of fillets are needed to provide this requirement. However, EFSA (2010) reported that a daily intake of 250–500mg of EPA and DHA decreases the risk of mortality from coronary heart disease and sudden cardiac death. This supports the previous funding that EPA in blood is an extremely potent antithrombotic factor (Simopoulos, 1991). On the other hand, Sargent (1999) noted that n-3 polyunsaturated (PUFA), principally DHA, has a role in maintaining the structure and functional integrity of fish cells. In addition, DHA has a specific and important role in neural (brain and eyes) cell membranes. Moreover, DHA is considered a desirable property in fish for human nutrition and health.

The findings from this study suggest that fish has more saturated fatty acids than unsaturated, contrary to common belief that fish are high in unsaturated and low in saturated fatty acids. Given the low levels of PUFAs, the relatively higher levels of oleic acid may play a key role in improving the health benefits of these fish species, since oleic acid help in reducing inflammation, prevent heart diseases and related heart conditions. Oleic acid improves heart health by decreasing blood cholesterol levels and may also have beneficial effects on genes linked to cancer (Sales-Campos *et al*., 2013).

4.3 Thiobarbituric acid reactive substances (TBARS) content

Thiobarbituric Acid Reactive Substances (TBARS) values are presented below in Table 4.3.

Table 4.3: TBARS values composition (mg MA/kg) of both cooked wild and farmed fish

Feeding system		Fish type	TBARS (mg MA/kg)
Farmed	A	Catfish	1.57 ± 0.14^{c}
		Tilapia	1.26 ± 0.13^{b}
	B	Catfish	5.44 ± 0.25^{g}
		Tilapia	1.22 ± 0.21^{b}
	C	Catfish	4.81 ± 0.10^{f}
		Tilapia	0.23 ± 0.06^{a}
Wild	Big fish	Catfish	7.38 ± 0.16^{i}
		Tilapia	5.77 ± 0.02^{h}
	Small fish	Catfish	4.66 ± 0.70^{e}
		Tilapia	3.93 ± 0.17^{d}

n=3, Values are mean ± SD, Values with different superscripts in the same column are significantly different at $p<0.05$

These values were analyzed after cooking of fresh fish because heat accelerates lipid oxidation by causing membrane disruption that leads to release of membrane lipid, and also denaturing myoglobin and iron storage proteins, resulting in release of iron that acts as a pro-oxidant (Liu *et al.*, 2007). From the study, the TBARS values varied greatly for both farmed and wild Catfish reporting significantly $p<0.05$ higher values than the Tilapia. Farmed Catfish from feeding system B (feed consisted of wheat bran + cotton seed) reported significantly at $p<0.05$ higher TBARS values of 5.44mg MA/kg as compared to fish from the other feeding systems. In addition, for the wild type, the Catfish also reported significantly higher values of 7.38mg MA/kg and 4.66mg MA/kg for both big and small fish, respectively. Tilapia on the other hand reported low TBARS values ranging from 0.23 – 3.96mg MA/kg and 3.92 – 5.77mg MA/kg for both farmed and wild fish, respectively.

From the results, wild fish showed higher levels of TBARS than farmed fish. This is because wild fish were excellent source of unsaturated long chain fatty acids EPA and DHA. This indicates that the fatty acids in the farmed fish are more stable than those of wild fish after cooking. In addition, Catfish from feeding system B also reported high values of TBARS and this indicates that the values also depends on the content of PUFAs in the diet, this is because PUFAs has more than one double in its carbon chain which are more prone to oxidation . On the other hand, these fish fed on cotton seed and wheat bran which contain a lot of unsaturated fatty acids. This concurs with study by Husveth *et al.* (2000) which found that the degree of oxidation of chicken meat fed on a vitamin E-deficient diet varied significantly with the PUFA content of the diet, with the TBARS being greater in animals fed on a diet with a higher PUFA content. The TBARS levels recorded in both wild and farmed Tilapia fish was within the range reported for fresh water fish species by Huang *et al.* (2004). According to Freeman and Hearnsbarger (1994), TBARS levels below 6 mg MA/kg in fresh fish will be regarded as good quality. Although these fatty acids are of therapeutic interests in the prevention of diseases as described by Willett (2007), they make fish muscles more susceptible to oxidation by a classical free radical autocatalysis mechanism (Bragadóttir, 2001). This is because, it has been reported that a high relative proportion of tissue fat is indicative of high levels of PUFAs (Trbović *et al.*, 2018). Therefore the highly unsaturated nature of the fish lipids could have been responsible for the rapid oxidative reactions. The TBARS value in this case therefore, is generally regarded as a good indicator of the degree of deterioration of the organoleptic characteristics of fish meat as a result of oxidation. Thus, higher TBARS value indicates a greater degree of oxidation of fish meat. Therefore the fish meat in this study is less susceptible to oxidation and therefore has less degree of deterioration of organoleptic characteristics.

4.4 Mineral composition of both fresh wild and farmed fish

The results for the mineral composition of the two fish are shown below in Table 4.4.

Table 4.4: Mineral composition of farmed and wild fish

Feeding system	Fish type	Mineral composition of fish sample (mg/100g)				
		Calcium	Iron	Magnesium	Phosphorus	Zinc

Farm	A	Catfish	35.03^{b}±2.03	2.35^{b}±0.13	117.23^{b}±2.06	24.96^{b}±1.79	4.95^{b}±0.16
		Tilapia	36.95^{b}±1.01	2.37^{b}±0.24	124.15^{b}±1.27	25.31^{b}±1.09	4.39^{b}±0.48
	B	Catfish	34.12^{b}±1.28	2.32^{b}±0.11	126.04^{b}±1.96	24.16^{b}±1.77	4.80^{b}±0.37
		Tilapia	31.51^{c}±1.75	1.85^{c}±0.07	112.14^{b}±2.74	21.20^{b}±0.42	4.58^{b}±0.64
	C	Catfish	28.20^{c}±2.01	2.18^{b}±0.21	106.13^{b}±7.17	23.18^{b}±0.40	4.34^{b}±0.45
		Tilapia	30.24^{c}±1.24	2.24^{b}±0.31	118.21^{b}±2.28	24.39^{b}±0.85	4.39^{b}±0.25
Wild	Big	Catfish	43.75^{a}±2.23	3.04^{a}±0.59	134.18^{a}±4.25	29.53^{a}±1.49	5.46^{a}±0.76
	fish	Tilapia	39.90^{a}±2.16	2.82^{a}±0.17	129.22^{a}±7.09	28.27^{a}±1.07	5.40^{a}±0.81
	Small	Catfish	42.42^{a}±1.10	2.78^{a}±0.43	131.29^{a}±3.92	30.42^{a}±2.10	5.27^{a}±0.89
	fish	Tilapia	46.77^{a}±1.92	2.95^{a}±0.12	137.22^{a}±5.14	30.89^{a}±1.90	5.56^{a}±0.62

* Values are given as means ± Std dev. Means with different superscript letters within a column are significantly different ($P < 0.05$).

All the fish samples examined contained appreciable concentrations of calcium, zinc, magnesium, phosphorus and iron. The data revealed wide variations in the mineral contents of the wild and farmed fish. The concentrations ranged from 1.9 - 3.0 mg/100g for iron, 4.3 - 5.6 mg/100g for zinc, 21.2 - 30.9 mg/100g for phosphorus, 28.2 - 46.8 mg/100g for calcium, 106.1 - 137.2 mg/100g for magnesium.

Wild fish were found to contain significantly ($p<0.05$) higher concentrations of all the minerals than the farmed fish. On the other hand, there were no significant differences in Mg, P, and Zn in fish from the feeding systems A (diet consisted of omena + lake shrimps), B (diet consisted of wheat bran + cotton seed) and C (diet consisted of chicken droplets + maize flour).

There was no significant ($p<0.05$) difference between the mineral contents of the big and small fish from the wild habitats. Although the mineral content of big Catfish was slightly higher than that of big Tilapia, the content of minerals in small Catfish was lower than that of small Tilapia.

Magnesium content ranged from 129.2 - 137.2 mg/100g for wild fish and 106.1 - 126.0 mg/100g for the farmed fish. Farmed fish from feeding system A gave higher contents of calcium compared to fish from the other feeding systems, while Tilapia from feeding system B had lower iron levels than the rest. Tilapia fish from feeding systems A and C contained slightly higher mineral content compared to Catfish. This is contrary to feeding system B where Tilapia reported slightly lower levels of minerals than the Catfish. The reason for such differences in mineral uptake by Catfish and Tilapia in different feeding systems might be attributed to their feeds.

The findings of this study are comparable with the permissible mineral limits of fish which have been reported by FAO (2010) and USDA (2010). It also concurs with the finding of Adebayo *et al.* (2016) who reported calcium (6–825 mg/100g), zinc (1–12 mg/100g) and phosphorous (10–82 mg/100g). In contrast the magnesium content from this study was higher than the contents 4–12 mg/100g reported by Adebayo *et al.* (2016). On the other hand, iron content from the study was lower as compared to the 3–102 mg/100g observed by Adebayo *et al.* (2016). The variations recorded in the concentration of mineral in fish examined could be as a result of the rate in which they are available in the water body from where they were trapped. Alasalvar *et al.* (2002) and El-Zaeem *et al.* (2012) reported that mineral concentration of fish is affected by parameters such as feed type, level of dietary intake and growth. According to PfenningKurth *et al.* (2011), the wild fish feed on a wide diversity of microscopic organisms and macrophytes which may be lacking in controlled farmed systems. Therefore the feed composition of the farmed fish may also be major factor influencing their mineral content as reported by El-zaeem *et al.* (2012).

The minerals analysed in this study are known to be important in human health. Therefore the high concentration of minerals in the wild fish is advantageous since they are known to intervene in therapeutic aspects. Calcium is required as a component of the human diet, and it is essential for the full activity of many enzymes, such as nitric oxide synthase, protein phosphatases, and adenylate kinase. It is also necessary to maintain an optimal bone development (Beto, 2015). Besides, calcium is also good for growth and maintenance of bones, teeth and muscles (Pravina *et al.*, 2013). Normal extra cellular calcium concentrations are necessary for blood coagulation and for the integrity, intracellular cement substances (Mohanty *et al.*, 2019).

Magnesium is an essential mineral for cell function as it acts as a co-factor of pyruvate dehydrogenase, an enzyme which transforms pyruvate into acetyl-CoA used in the citric acid cycle to carry out cellular respiration to release energy. The recommended daily allowance (RDA) for Mg is 2000 mg per day for a healthy adult (Lenntech, 2013). Phosphorus is also an important mineral as it has been reported to form the structure of teeth, bones and cell membranes (Butusov & Jernelöv, 2013). It also acts as a cofactor for many enzymes and activates the vitamin B complex.

Other elements such as zinc and iron varied in concentration among all the fish studied. These elements are equally important in trace amounts as observed, but they tend to become harmful when their concentrations in the tissues exceed the metabolic demands (Adebayo *et al.*, 2016). Zinc is an essential element in human diet as it plays an important role in maintenance of normal glucose tolerance and in the release of insulin from beta cells of islets of Langerhans (Piero *et al.*, 2012; Praveeena *et al.*, 2013). Therefore the availability of zinc in fish could mean that the fishes can play valuable roles in the management of diabetes, which result from insulin malfunction. In addition, it is involved in most metabolic pathways in animals and humans (FAO, 2010).

Iron on the other hand, is important for metabolic reactions and the regulation of cell growth and differentiation. It is an essential trace element for haemoglobin formation, normal functioning of the central nervous system and in the oxidation of carbohydrates, protein and fats. Iron is important for children, women of reproductive age and pregnant women since they are most vulnerable to micronutrient deficiency and anemia (WHO, 2015). Iron deficiency occurs when the demand for iron is high, particularly in growth, high menstrual loss and pregnancy and the intake is quantitatively inadequate for or contains elements that render them unavailable for absorption (Kumaran *et al.*, 2012). Besides, iron acts as a cofactor in catalase, an enzyme that catalyzes the conversion of hydrogen peroxide to water and oxygen (Soetan *et al.*, 2010). Iron and zinc are also antioxidant micronutrients and their presence could boost the immune system (Prashanth *et al.*, 2015). Since deficiencies in calcium, iron and zinc are common in the developing world, and are the leading cause of many ailments (Mohanty *et al.*, 2016) fish eating is encouraged as this may contribute to alleviation of this problem in the vulnerable groups.

4.5 Heavy metal composition

The results for the heavy metal composition are presented above in Table 4.5.

Table 4.5: Heavy metal composition of farmed and wild fish

Feeding system		Fish	Chromium	Lead	Copper	Cadmium	Mercury
Farmed	A	Catfish	0.20^{b}±0.05	0.39^{b}±0.06	0.48^{b}±0.07	0.28^{b}±0.04	15.15^{b}±1.71
		Tilapia	0.23^{a}±0.01	0.42^{b}±0.05	0.44^{b}±0.01	0.23^{c}±0.02	15.39^{b}±1.65
	B	Catfish	0.17^{c}±0.06	0.36^{b}±0.01	0.39^{c}±0.04	0.24^{c}±0.02	11.92^{c}±0.98
		Tilapia	0.13^{c}±0.02	0.31^{c}±0.04	0.42^{b}±0.02	0.21^{c}±0.06	13.45^{c}±1.12
	C	Catfish	0.14^{c}±0.05	0.34^{c}±0.05	0.35^{c}±0.07	0.26^{b}±0.02	12.62^{b}±0.74
		Tilapia	0.19^{b}±0.09	0.37^{b}±0.09	0.44^{b}±0.03	0.27^{b}±0.01	14.77^{b}±0.92
Wild	Big fish	Catfish	0.27^{a}±0.07	0.58^{a}±0.04	0.59^{a}±0.02	0.34^{a}±0.05	17.63^{a}±1.47
		Tilapia	0.24^{a}±0.07	0.52^{a}±0.03	0.55^{a}±0.09	0.33^{a}±0.04	18.27^{a}±2.46
	Small fish	Catfish	0.26^{a}±0.03	0.61^{a}±0.02	0.62^{a}±0.08	0.39^{a}±0.06	16.15^{a}±1.50
		Tilapia	0.30^{a}±0.08	0.66^{a}±0.07	0.69^{a}±0.04	0.44^{a}±0.07	17.33^{a}±1.59
Codex/WHO (mg/100g)			**10**	**0.2**	**5**	**10**	**12 µg/100g**

* Values are given as means ± Std dev. Means with different superscript letters within a column are significantly different (P < 0.05). The concentration is expressed as mg/100g except for mercury which is expressed in µg/100g

The concentrations ranged from 0.1 - 0.3 mg/100g for chromium, 0.3 - 0.7 mg/100g for lead, 0.2 - 0.4 mg/100g for cadmium and 11.9 - 17.6 µg/100g for mercury. The heavy metal content of the wild fish was significantly higher with values ranging from 0.24 – 0.30 mg/100g chromium, 0.5 – 0.7 mg/100g lead, 0.3 – 0.4 mg/100g cadmium and 16.2 – 18.3 µg/100g mercury as compared to the farmed fish with ranges of 0.13 – 0.23

mg/100g chromium, 0.3 – 0.4 mg/100g lead, 0.2 – 0.3 mg/100g cadmium and 11.9 – 15.4 µg/100g mercury. Although there was no significant ($p < 0.05$) difference between the values for the small and big fish from wild habitat, the big Catfish reported slightly higher heavy metal contents as compared to the big Tilapia. This was contrary to the small Catfish which reported slightly lower heavy metal levels than the small Tilapia fish.

For the farmed fish on other hand, fish from feeding system A was significantly($P < 0.05$) higher in heavy metal content as compared to fish from the other feeding systems. But then fish from feeding system B reported significantly lower heavy metal content. The Tilapia fish from feeding systems A and C reported slightly higher($P < 0.05$) levels of heavy metals particularly chromium and lead whereas the Tilapia fish from feeding system B reported lower levels, and this might be attributed to their feeds which consisted of omena + lake shrimps and chicken droplets + maize flour. Heavy metals in system A may be at least partly derived from the *R. argentea* and *C. nilotica* components of the feed.

The high accumulation of heavy metals in wild fish as compared to farmed fish depends on the amount of these metals in water and feed. This may be attributed to sediments which act as important reservoir or sink of metals and other pollutants in the aquatic environment (Gupta *et al.*, 2009; González-Fernández *et al.*, 2011). Heavy metals affect the quality of water and bioaccumulation of these metals in aquatic organisms result in potential long-term implication on human health and ecosystem (González-Fernández *et al.*, 2011). Lead had a higher content as compared to the other heavy metals whereas mercury reported lower levels. According to WHO (2011), the maximum allowable concentration for Pb and Cd were 0.2 mg/100g and 10.0 mg/100g, respectively. However, these limits are not defined or similar for all the elements (Agah *et al.*, 2009). The heavy metal contents of fish muscles in this study were below the maximum allowable concentration suggested by WHO (2011) and therefore have no threat to public health. Although, fish is the main source of mercury in human diet (Mania *et al.*, 2012), mercury was found to be lower in this study. The present study agrees with the results obtained by Bosch *et al.* (2016) which found out that mercury is least accumulated in fish and is high in wild fish as compared to farmed fish. According to Perugini *et al.* (2014) the concentration of heavy metal contaminants in fish is strongly influenced by fish age, origin of the fish, its species and pH and temperature of water. It is also related to the tissue sampled, the season of harvest especially for farmed fish, and the composition of the diet (Hussain, Muhammad, Malik, Khan, & Farooq, 2014). The health and safety qualities of fish is an advantage to the fish farming industry owing to the fact that, unlike fishermen, fish farmers can control for the presence of toxic contaminants and pathogens in their fish throughout the production process. Whereas the diet of wild fish is totally beyond human control, the development of formulated diets, which are used in aquaculture, makes it possible to directly control contaminant levels (Craig *et al.*, 2017; Davidson *et al.*, 2016).

4.6 Firmness and pH

Texture and pH values are presented below in Table 4.6.

Table 4.6: Firmness and pH values of wild (7hrs after death) and farmed fish (4hrs)

Feeding system		Fish type	Firmness (N)	pH
Farmed	A	Catfish (1kg)	$3.65^{b}\pm0.13$	$6.80^{a}\pm0.00$
		Tilapia (1kg)	$2.08^{c}\pm0.39$	$6.75^{a}\pm0.21$
	B	Catfish (1kg)	$3.35^{b}\pm0.13$	$6.70^{a}\pm0.14$
		Tilapia (1kg)	$2.35^{c}\pm0.58$	$6.60^{a}\pm0.14$
	C	Catfish (1kg)	$3.45^{b}\pm0.13$	$6.75^{a}\pm0.07$
		Tilapia (1kg)	$1.63^{d}\pm0.31$	$6.55^{a}\pm0.07$
Wild	Big fish	Catfish (2kg)	$4.99^{a}\pm0.26$	$6.78^{a}\pm0.10$
		Tilapia (2kg)	$3.90^{a}\pm0.13$	$6.58^{a}\pm0.10$
	Small fish	Catfish (1kg)	$4.31^{a}\pm0.20$	$6.73^{a}\pm0.05$
		Tilapia (1kg)	$3.85^{a}\pm0.19$	$6.58^{a}\pm0.10$

Values with the same superscript letters within a column are significantly different. N - Newton

The pH values ranged between 6.58 - 6.80 while the firmness values ranged between 1.63 – 4.99 N. There was no significant ($P < 0.05$) difference between the pH values of both farmed and wild fish. The wild fish had a firm texture with significantly ($P < 0.05$) higher values of 3.85 – 4.99 N as compared to the texture of farmed fish with values of 1.3 – 3.65 N. Although the wild Catfish reported slightly firm texture as compared to the wild Tilapia,but there was no significant($P < 0.05$) difference between the values .Also there was no significant difference in texture of small wild fish compared to their big counterparts. In addition, the farmed Catfish had firm texture than the farmed Tilapia fish. The results concur with the findings of Haard (1992), which reported that farmed fish are less firm than wild fish. According to Verbeke *et al.* (2007), improved texture of fish is possibly attributed to a higher fat content in farmed fish as well as higher levels of activity in wild fish, and this explains the findings of this study. Fish firmness can also be influenced by various factors such as; pH, proteolysis, nutritional state of the fish, storage time, water holding capacity, size, and type of muscle protein (Huss, 1995; Ocaño-Higuera *et al.*, 2011).

4.7 Sensory evaluation

Sensory evaluation values are presented below in table 4.7.

Table 4.7: Sensory evaluation of farmed and wild fish

Feeding system		Fish type	Colour	Texture	Flavour	Taste	Acceptability
Farmed	A	Tilapia	6.8 ± 1.01^{bc}	7.0 ± 0.61^{b}	7.1 ± 0.85^{bc}	7.1 ± 0.44^{bc}	7.5 ± 0.47^{c}
		Catfish	6.6 ± 0.43^{cd}	6.8 ± 0.32^{bc}	6.9 ± 0.06^{c}	6.8 ± 0.56^{c}	7.1 ± 0.20^{d}
	B	Tilapia	6.8 ± 0.29^{bc}	7.1 ± 0.76^{b}	7.1 ± 0.44^{bc}	7.3 ± 0.88^{b}	7.1 ± 0.36^{d}
		Catfish	6.0 ± 1.11^{e}	6.3 ± 0.96^{d}	7.2 ± 0.57^{bc}	7.2 ± 0.94^{b}	6.6 ± 0.79^{e}
	C	Tilapia	7.4 ± 0.53^{a}	6.8 ± 0.55^{bc}	7.2 ± 0.45^{bc}	7.2 ± 0.39^{b}	7.6 ± 0.27^{c}
		Catfish	6.3 ± 0.29^{de}	6.0 ± 0.50^{d}	6.4 ± 0.46^{d}	6.2 ± 0.49^{d}	6.0 ± 0.20^{f}
Wild	Big	Tilapia	7.4 ± 0.27^{a}	7.7 ± 0.04^{a}	7.3 ± 0.05^{b}	7.3 ± 0.04^{b}	7.9 ± 0.14^{b}
		Catfish	7.0 ± 0.64^{b}	7.0 ± 0.53^{b}	6.3 ± 0.80^{d}	5.9 ± 0.86^{de}	6.5 ± 0.76^{e}
	Small	Tilapia	7.4 ± 0.60^{a}	7.7 ± 0.17^{a}	7.9 ± 0.56^{a}	7.9 ± 0.43^{a}	8.3 ± 0.36^{a}
		Catfish	6.9 ± 0.39^{bc}	6.6 ± 0.77^{c}	5.6 ± 1.15^{e}	5.7 ± 1.04^{e}	5.6 ± 0.79^{g}

n=3, Values are mean ± SD, Values with different superscripts in the same column are significantly different at $p<0.05$

In order to obtain quantitative insight into the consumer's perception of wild and farmed fish, sensory evaluation was carried out on the fish species. The results of the sensory analysis are presented in Table 4.8. The mean sensory scores obtained for the farmed Tilapia fish based on a 9 point hedonic scale ranged between 6.8 - 7.5, 6.8 – 7.3 and 6.8 – 7.6 for feeding systems A, B and C, respectively while for farmed Catfish, the scores ranged between 6.6 – 7.1, 6.0 – 7.2 and 6.0 – 6.4 for feeding systems A, B and C, respectively. On the other hand, the sensory scores for the wild fish based on a 9 point hedonic scale ranged between 7.3- 7.9 and 7.4 – 8.3 for big and small Tilapia, respectively and 5.9 – 7.0 and 5.6 - 6.9 for big and small Catfish, respectively. The Tilapia fish had the highest means for all the parameters evaluated whereas Catfish had low means, in indication to that Tilapia fish was the most preferred. Generally wild fish the more preferred than farmed fish. The sensory evaluation of fish meat is one of the most reliable methods to determine its taste (refers to the senses inside our mouth including our tongue) and flavor (is when taste and aroma converge) (Hassan and Ali, 2011). These quality parameters are influenced by fish species, size, sexual maturity, source of nutrients and season (Lall, 2006; Ye *et al.*, 2006). The results of this study concur with findings by (Delwiche and Liggett, 2004) which observed that farmed fish are known to express off-flavors. However in farmed fish, all the fish from the three feeding systems had similar flavor, suggesting that the system of rearing fish is not an important determinant with respect to off-flavors development. Several studies have reported a significant correlation between sensory scores and habitat of the fish (Oriakpono *et al.*, 2011). According to Faustman and Cassens (1990), color, texture, freshness, and taste are the principal factor determining the acceptability of meat to the consumer. Similarly, the organoleptic characteristics of fish can be affected by rearing conditions (Børresen, 1992). Usually, wild and farmed fish can diverge in flavor due to differences in fatty acid profile, oxidation processes, dietary ingredients, mineral, amino acid content and increasing activities (Haard, 1992) , and this confirms the findings of this study . Therefore this explains the differences between the sensory parameters of wild and farmed fish as well as the increased preference of the wild fish in this study as well as reported by Oriakpono *et al.* (2011).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the study, it is evident that fish are of nutritional value and can provide important nutrients mostly: proteins, fatty acids (largely polyunsaturated), and minerals (Fe, Zn, Ca). However, wild fish have a higher level of heavy metal compared to farmed fish. Although wild fish is rich in most nutrients as compared to farmed fish, there was variation in nutrient content with feeding systems, e.g. Farm B (feed consisted of wheat bran + cotton seed) showed a good balance in nutrient content (rich in nutrients) and heavy metals (low) content.

Farmed fish fatty acids are more stable after cooking relative to fatty acids in wild fish. This is because wild fish exhibited higher levels of TBARS after cooking and this was directly influenced by the fact that wild fish were excellent source of long chain fatty acids (EPA and DHA). On the other hand Tilapia was the most preferred fish. Sensory analysis results showed that wild fish was the most preferred, (except for farmed fish from feeding C, feed consisted of chicken droplets + maize flour) which exhibited similar sensory traits like wild fish. Finally wild fish might be superior to farmed fish in most of the contents analyzed in this study, I think fish farmers still do have un upper hand to manipulate different stages of the rearing, feeding systems of the fish to deliver a designer fish to consumers having preferred quality and nutritional compositions. Thus, manipulating the feeding systems will deliver fish having preferred quality and nutritional composition.

5.2 Recommendations

- Cost benefit analysis of the different farming system needs to be conducted.

- There is need to further investigate the attributes of wild fish regarding its superior nutritional status.
- Further studies need to be done to improve farmed fish feed to closely match wild/natural ecosystem.
- There is need to further investigate microbial and other aspects of chemical safety of both wild and farmed fish in Kenya.

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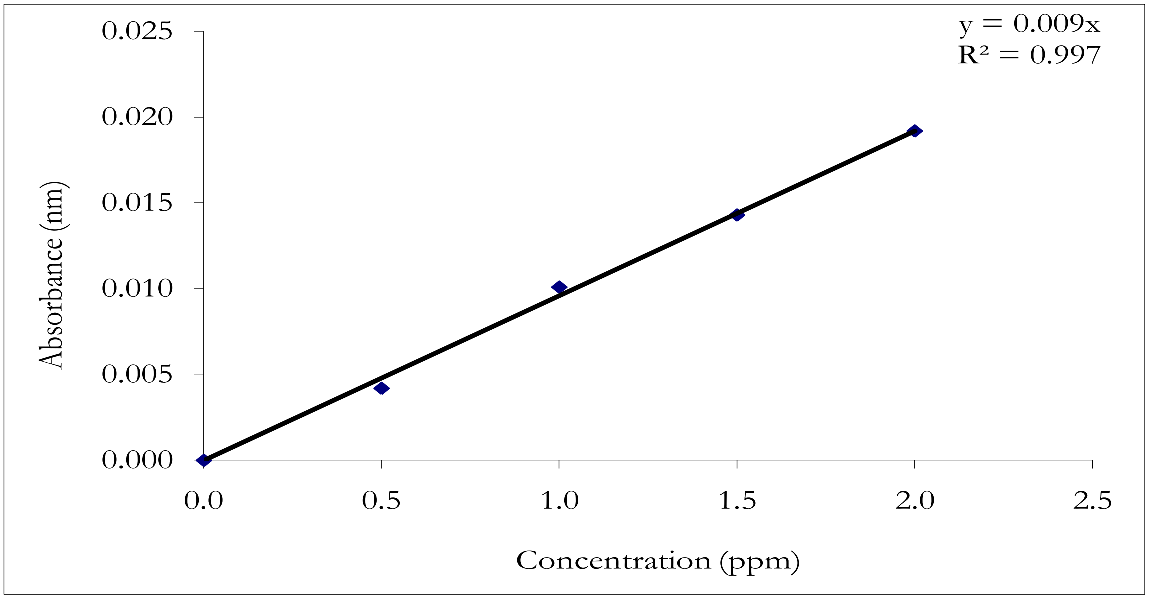
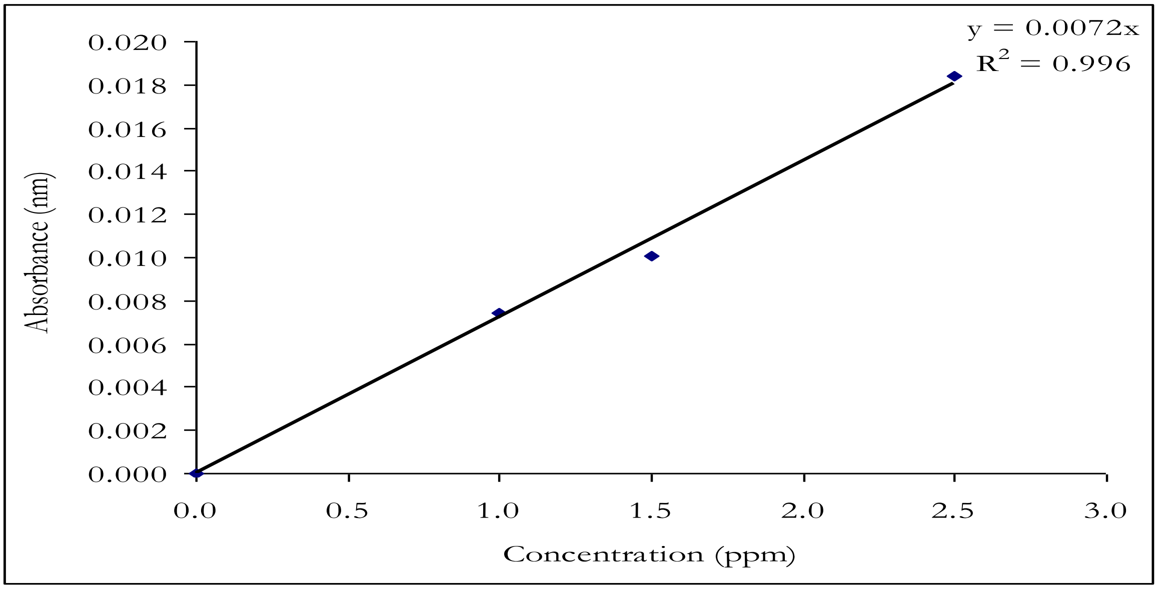
APPENDICES

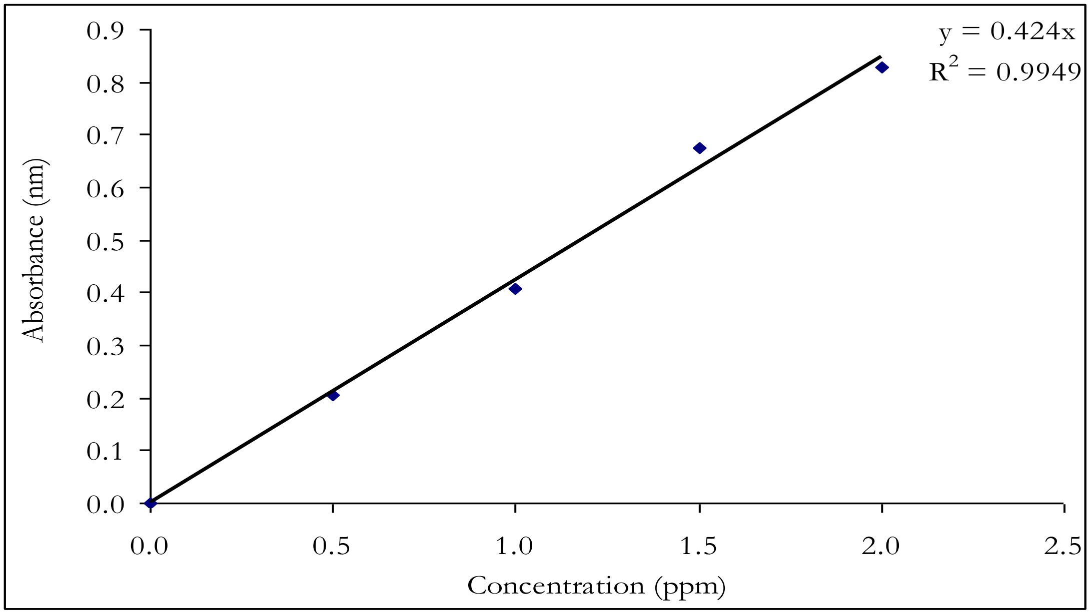
Appendices I: XI below are the standard curves for the mineral elements.



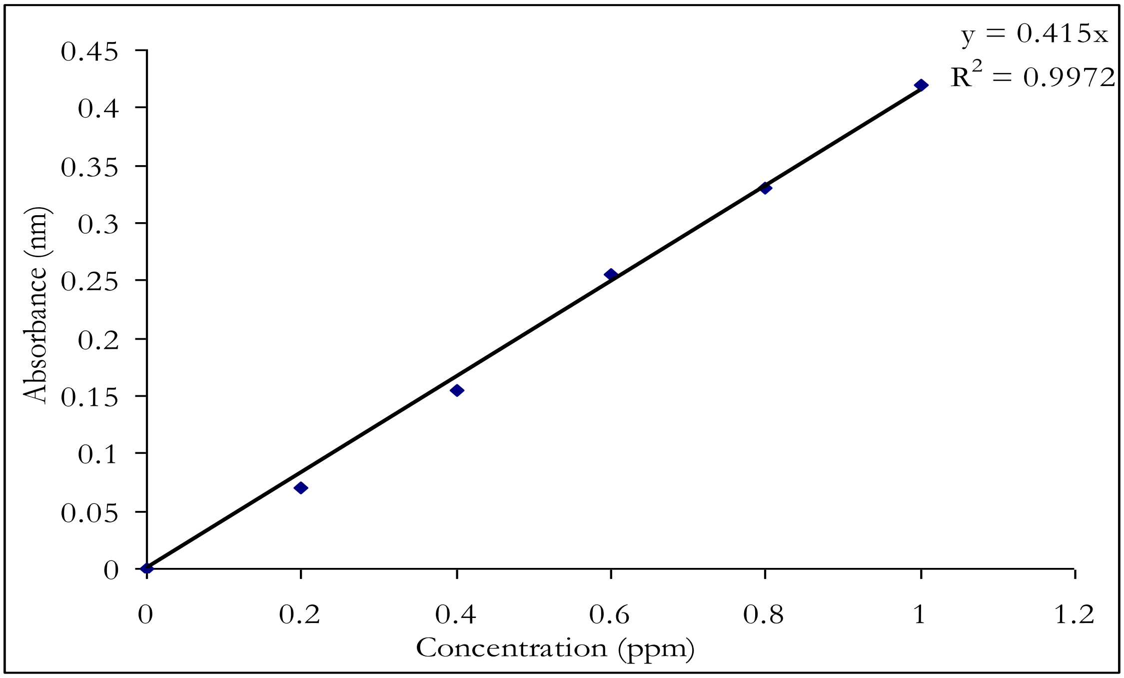
Appendix II: Calcium standard curve



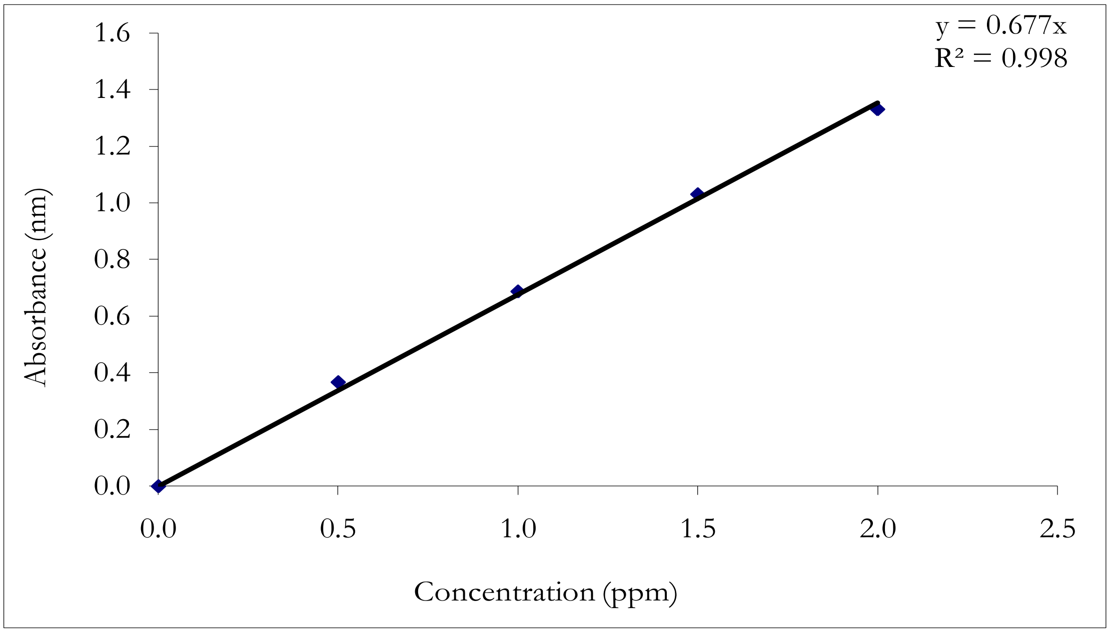
Appendix III: Iron standard curve



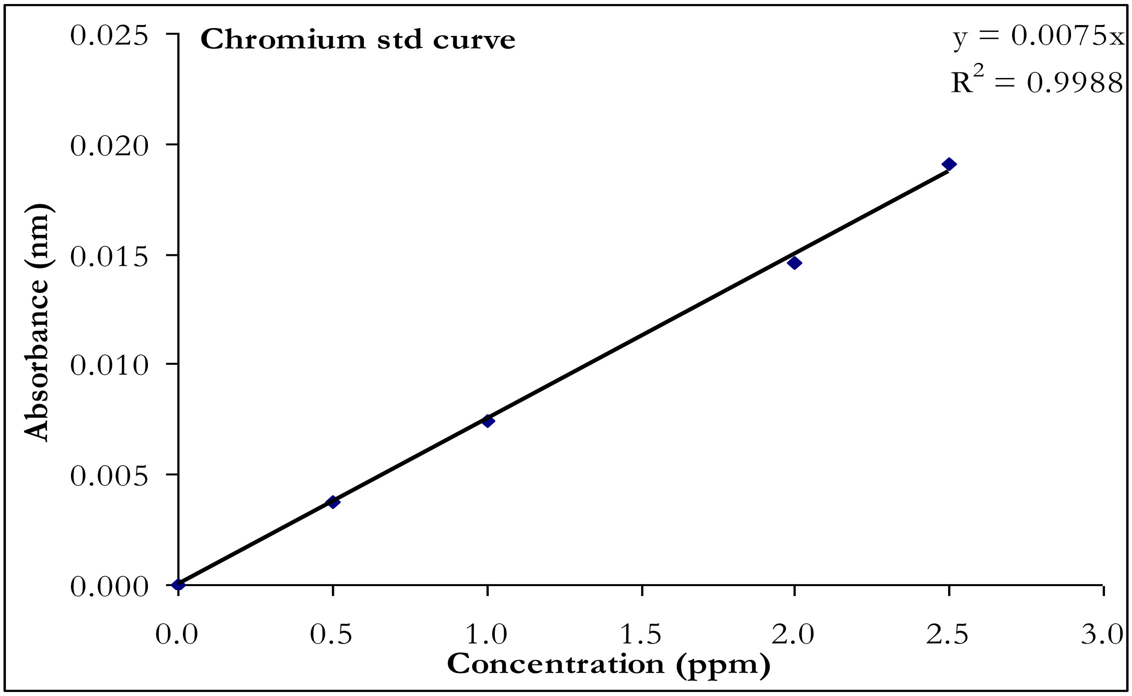
Appendix IV: Magnesium standard curve



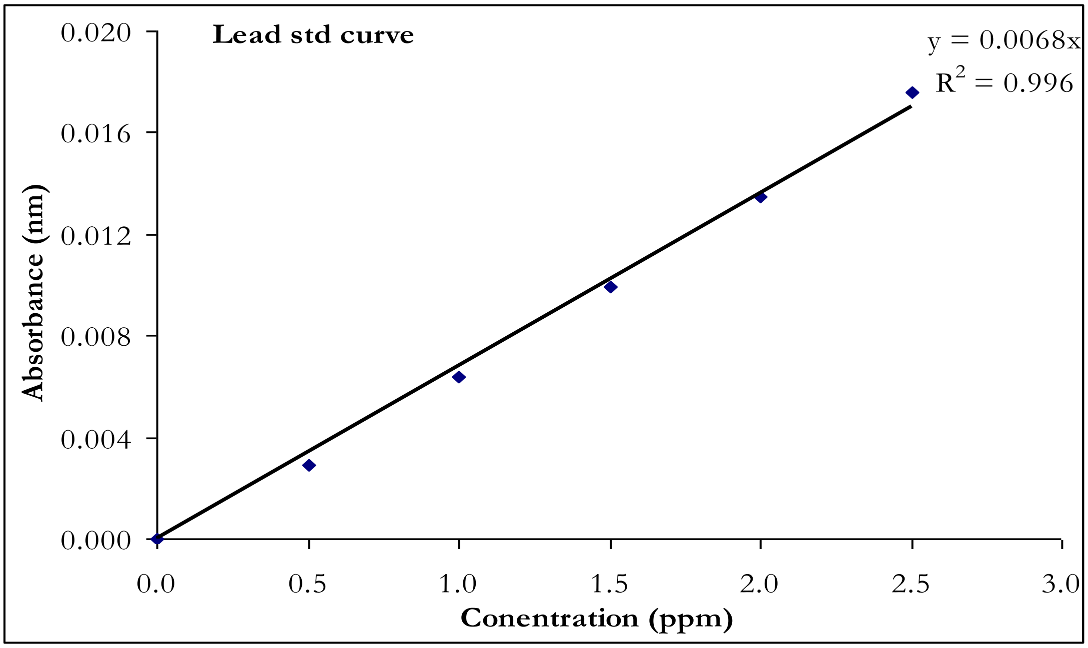
Appendix V: Phosphorus standard curve



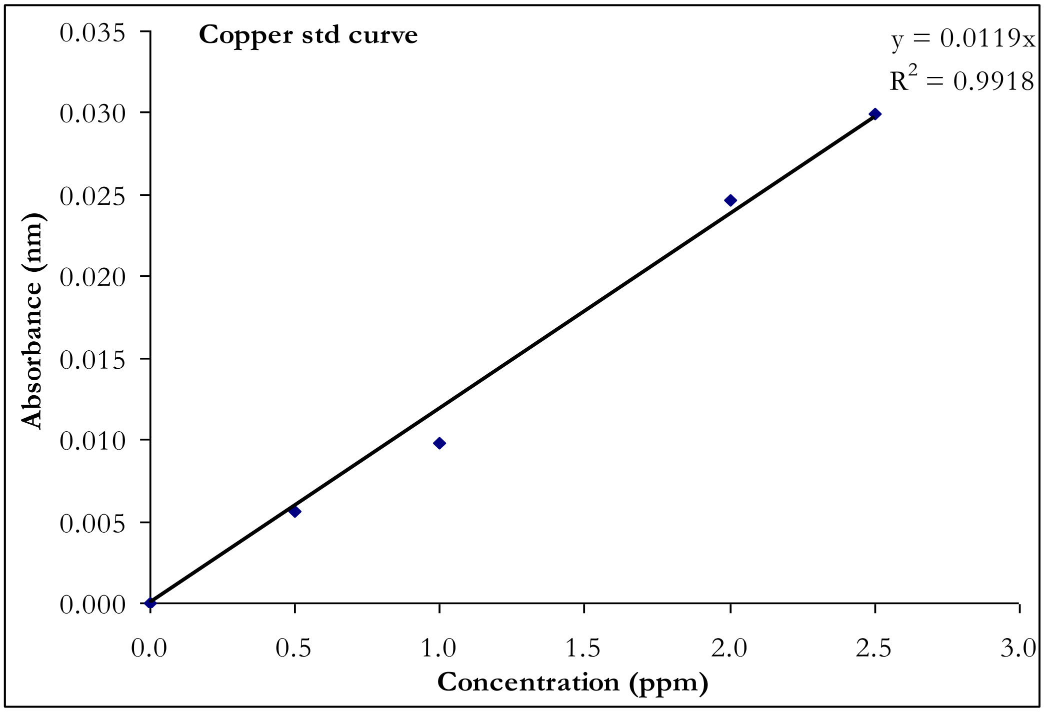
Appendix VI: Zinc standard curve



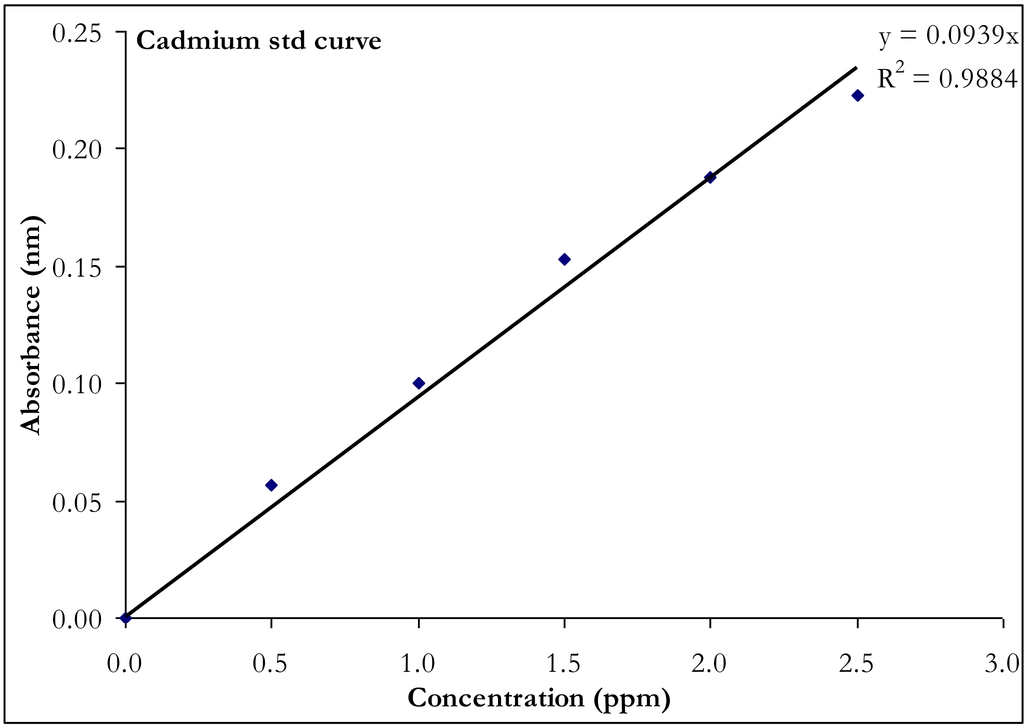
Appendix VII: Chromium standard curve



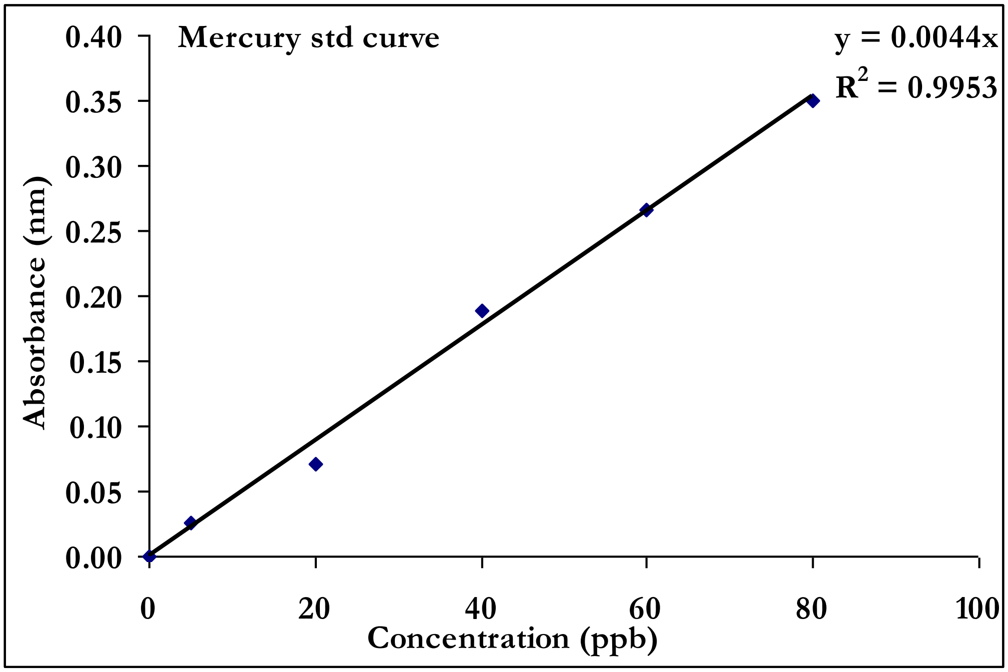
Appendix VIII: Lead standard curve



Appendix IX: Copper standard curve



Appendix X: Cadmium standard curve



Appendix XI: Sensory evaluation questionnaire

Date……………………….   Time…………….

Instructions:

You are provided with three sets of different coded samples of fish meat to carry out sensory evaluation on them and express how much you like or dislike them. You are also provided with water to rinse your mouth after tasting each sample. Use the scale below to express your attitude towards the meat color, texture, smell, taste and general acceptability of each of the samples by inserting the appropriate score in the space provided.

You are also requested to give any comments about the fish and please try to be as honest as possible.

Thank you.

Description **Score**

Like extremely...……………………………………………………..….9

Like very much...……………………………………………………..…8

Like moderately ………………………………………………….…...…7

Like slightly ………………………………………………………..….....6

Neither like nor dislike...…………………………………………...…5

Dislike slightly……………………………………………………..4

Dislike moderately ………………………………………………...3

Dislike very much …………………………………………………2

Dislike extremely …………………………………………………1

Sample codes	**Sensory attributes**				
Set (1)	**Color Appearance**	**Texture**	**Flavour**	**Taste**	**General Acceptability**
1234					
1243					
1342					
1324					
1432					
1423					
Set (2)					
2134					
2143					
2341					
2431					
2314					
2313					
Set (3)					
3124					
3142					
4134					

4143					
3134					
3241					

Remarks:

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Appendix XII: Sampling questionnaire

Name of Respondent: ………………………………………………………………………………………………..

Location of Retail market: ………………………………………………………………………………………....

Physical and Postal Address: ……………………………………………………………………………………...

1. Where do you get your fish from?

2. Which type of fish do you deal with mainly?

3. How do you transport, store your fish, at what temperatures and humidity?

4. What time do you get the fish?

5. After selling the fish, what do you do to the remaining fish?

Remarks

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