EVALUATION OF FARM-MADE AND COMMERCIAL FEEDS ON GROWTH AND ECONOMIC PERFORMANCE OF NILE TILAPIA (*Oreochromis niloticus* LINNAEUS, 1758) IN LIBERIA

BY

MANDELA KLON-YAN HINNEH

A THESIS SUBMITTED TO THE SCHOOL OF ENVIRONMENTAL SCIENCES AND NATURAL RESOURCE MANAGEMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY IN FISHERIES, UNIVERSITY OF ELDORET, KENYA

JANUARY, 2024

DECLARATION

Declaration by the Student

This thesis is my own work and has not been presented for a degree in any university. No part of this thesis may be reproduced without the prior written permission of the author and/or University of Eldoret.

MANDELA KLON-YAN HINNEH

______________________________ ____________________

(SNAT/FAS/P/004/19) **Date**

Declaration by the Supervisors

This thesis has been submitted for examination with our approval as the University Supervisors.

______________________________ ____________________

Prof. David Mbeva Litti **Date**
School of Science,
Department of Biological Science,
University of Eldoret, Kenya

______________________________ ____________________

Dr. Geraldine K. Matolla **Date**
School of Natural Resource Management,
Department of Fisheries and Aquatic Sciences,
University of Eldoret, Kenya

DEDICATION

I dedicate this work to my mother, Mrs. Monica Kheshen Honore for Standing by my side through difficult times, especially for her encouragement towards my achievement of this level of my education endeavors and most importantly for her love, support and sacrifice. Mama, thank you for not giving up on me. God bless you.

ABSTRACT

A study on the effect of farm-made and commercial feeds on nutritional quality, growth, water quality and economic performance on Nile tilapia in landlocked Counties of in Liberia was done. Interviews and focus group discussions (FGDs) were used to collect information on farm made feeds. Moisture, crude protein, crude lipids and ash content of all feed ingredients were determined using AOAC procedures. Test diets consisted of two farmer diets, two commercial diets and one research diet. To determine the effect of these diets on fish growth, 450 male *O. niloticus* fingerlings of average weight of 13g were stocked in hapas mounted in 3 earthen ponds, each with 5 hapas at the Central Agriculture Research Institute in Liberia. The effect of diets on temperature, pH, and Dissolved Oxygen (DO) was determined using oxyguard and pH meters. Rate of returns on investment were used to evaluate the cost-effectiveness of all the diets. Of 120 farmers interviewed, 81.6% practice semi-extensive aquaculture in paddies, barrages, and earthen ponds. Farmers' annual yield was 165.7 kg ha^{-1}, translating to USD 414.25. The research diet had the greatest amount of crude protein (30.7%) while farmers' diet had the lowest crude protein (9%). The research diet had the highest growth performance in terms of weight, attaining 175.33g. There was a significant difference in growth of fish between research and farmer (F1) diets ($P = 2 \times 10^{-5}$).There was no significant difference on the effects of each feed on the quality of the pond water Economic analysis indicated that the commercial diet (C1) was most profitable (USD 259.5). For better fish performance and profitability, there is need for researchers and feed producers to develop quality and affordable feeds for Liberia's aquaculture sector while building capacity for farmers to formulate quality diets. Continuous monitoring of water quality is recommended for the sector.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABREVIATIONS AND ACRONYMS

°C	degree Celsius
APDRA	Alternative Procedure for Dispute Resolution Act'
BNF	British National Formulary
CARI	Central Agricultural Research Institute
CF	crude fiber
CL	crude lipids
CP	crude protein
DMRT	Duncan Multiple Range Test
EAA	Essential amino acid
EFA	essential fatty acids
FAO	Food and Agriculture Organization
FFDC	Faimba Fisheries Development Cooperative
FGD	focus group discussions
GIS	Geographical information systems
GPS	Geographical positioning systems
kg	kilogram
KMFRI	Kenyan Marine and Fisheries Research Institute
mm	milimeter
MWG	Mean weight Gain
NFE	Nitrogen-free extract
OECD	Organization for Economic Co-operation and Development ()
RCBD	Randomized Complete Block Design
SDG	Sustainable Development Goal
SL	standard length
SPSS	Statistical Package for Social Science
sq mi	square miles
SSA	small scale Aquaculture
TL	total length
TSP	teaspoonful
UN DESA	United Nations Department of Economic and Social Affairs
UNFCC	United Nations Framework Convention on Climate Change
USAID	U.S. Agency for International Development

USCED	U.S. Commission for Economic Development ()
USD	United States Dollar
WFP	World Food Program
WFP	World Food Programme

ACKNOWLEDGEMENTS

I give God the glory and honor for bringing me this far. Without God, I would not have reached this far.

I will also like to thank The Regional Universities Forum For Capacity Building In Agriculture (Ruforum), The University of Liberia (UL) and the Borlaug Higher Education For Agricultural Research and Development for their financial support.

I would sincerely wish to thank my supervisors Prof. David Mbevi Liti and Dr. Geraldine K. Matolla for their guidance. Their unwavering support in knowledge dispensation ensured that I completed my studies on time. I hope to always meet such wonderful people in my life. I’m also indebted to my family back in Liberia. Even though we were miles apart, their continuous encouragements always buoyed my spirits in times of despair.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Fish farming has received tremendous focus in the recent past due to its potential in alleviating the pressure exerted on wild stocks through over exploitation (Okeke *et al*, 2021). Currently, it is one of the key sectors which shape many nations' development agendas including improving the economic status of impoverished communities and providing affordable nutrition hence contributing to improvement of food security (Kaleem & Sabi, 2021). Aquaculture has grown tremendously across the globe and almost all nations are in some way engaged in some aspects of fish production. The high adoption rates of fish farming is motivated by dynamic innovations that have made the fish farming enterprise cheaper and profitable. The expanding demand for aquaculture products and increased consumption are among major reasons for the spiralling of aquaculture adoption (Finkbeiner *et al*., 2017). However, there exists a significant gap in production between developed and developing nations because aquaculture in developing nations face numerous challenges of inadequate supply of readily available feed stocks that meet the nutritional requirement of fish.

The depletion of wild fish stocks and increasing global food insecurity have fueled the rapid growth of aquaculture systems across the world (Halwart, 2020). Aquaculture, which encompasses the rearing of fish and other aquatic organisms (Gui *et al*., 2018), is currently the fastest-growing food sector in the world (Atalah & Sanchez-Jerez, 2020; Barman, 2020), such that in a span of 15 years from the year 2000 to 2015, production rose from 41,724,569.75 to 106,004,183.75 metric tons, representing 154% growth (FAO, 2018). Despite the impressive growth of aquaculture, Africa only contributed 2.5% to global production, with the least developed sub-Saharan Africa (SSA) nations contributing less than 1.0% (FAO, 2018). The latter, however, have a large percentage of the human population, which is estimated at 960 million, and is considered malnourished (FAO, 2018; UNESCO, 2006). Thus, embracing fish farming in these countries is critical in alleviating hunger and increasing the income base and, therefore, economic empowerment (Kassam & Dorward, 2017; Wuyep & Rampedi, 2018). Generally, there has been a slow adoption of aquaculture in some parts of the African continent (FAO, 2018). The poor aquaculture productivity, particularly in the poverty-stricken region, is underscored by several factors, including a lack of policy framework (Ragasa *et al*., 2022), weak supportive structures and infrastructure (Wuyep & Rampedi, 2018), inadequate aquaculture management skills, and most importantly, poor-quality feeds (Kaleem & Sabi, 2021).

The Nile tilapia (*Oreochromis niloticus*) is ranked as the primary culture fish species in the tropics and is preferred by tropical sub-Saharan Africa (SSA) farmers because of its versatility in feeding and fast attainment of market size, particularly with all-male populations (Adéyèmi *et al*., 2020). However, it requires feeds of adequate nutritional balance to achieve the target size within a culture season (Halwart, 2020). According to Authman *et al*. (2012), if the pond is sufficiently fertilized, natural food can sustain the juveniles for up to 80 days of grow-out, after which formulated feeds are needed to promote rapid growth (Prabhu *et al*., 2019). The low-quality feeds used by farmers have also been shown to contain high antinutritional factors (ANFs), thus decreasing the feed conversion rates and inhibiting growth (Adeleke & Omafuvbe, 2011).

Despite the high increase in demand for aquaculture products, development of the sector in developing nations especially in sub-Saharan countries is still sluggish (Thilsted, 2013). In these areas aquaculture is characterized by subsistencce small scale production in poorly managed systems (Seto *et al.*, 2021). Some of the challenges facing fish farming in the developing nations include but are not limited to; poor management, lack of skills, and most important improper feeding practices (Prabhu *et al.*, 2019).

Aquaculture enterprises have high input demands, with feeds making up more than 60% of the total expenses in fish farming (Adeleke & Omafuvbe, 2011). For a farmer to strike a significant profit in a shorter time, high-quality and nutritionally balanced feeds are paramount (Anetekhai *et al.*, 2004). However, the high cost of quality feeds impedes their accessibility by the low-resource- fish farmers (Honfoga *et al.*, 2017). Furthermore, the low quality and high cost of feeds make the sector less sustainable for large-scale productions, particularly in rural areas (Dorothy *et al.*, 2018). According to Singini *et al.* (2014) most rural fish farmers settle for low-quality fish feeds sourced from kitchen waste and agro-industry residues. Such feeds not only retard fish growth but also lengthen the time to reach market size as well as reducing the resilience of fish to bio-physical stresses also in addition to degrading the quality of pond water (Hossain *et al.*, 2016).

Liberia is one of the African nations struggling to make fish farming a success. Most of the fish farming or aquaculture activities usually take place in landlocked counties (Honfoga *et al.*, 2017). The aim of the government to encourage aquaculture in these landlocked counties was to boost access to fish, which is the primary source of animal protein for the Liberian people (IMF & UNCTAD, 2011). Prior to the introduction of aquaculture in the 1970s, landlocked counties faced a dual challenge: limited access to animal protein from sources like beef and chicken, compounded by the prevalence of impoverished households (Van der Knaap, 2017). Thus, the counties experience widespread malnutrition among individuals of different age groups. For instance, a USAID report indicated that by 2013 more than 40% of Liberians were food insecure while more than 30% of the population depended on a diets considered to be protein deficiency. It has also been established that malnutrition is a significant contributor to high mortality rates in children under the age of five years (Dipasquale *et al*., 2020).

Fish production (both capture and farmed) is ranked as the second most important largest industry after agriculture in Liberia. The sector is estimated to provide more than 15% of the national animal protein supply (FAO, 2018). More than 80,000 people are directly or indirectly employed in the fish value chain, thus accounting for almost 4% of the Liberian population. The sector also provides 10% of Liberian national gross domestic product (GDP) (Chavan, 2015).

Among the fish species that are farmed in Liberia, *O. niloticus* is the most reared fish due to desirable attributes that have been highlighted above (Atalah & Sanchez-Jerez, 2020). The species is also preferred by many consumers across the country as compared to other species. However, production of *O. niloticus* through farming is low in the country compared to other African countries like Egypt, Nigeria and Kenya (Honfoga *et al*., 2017). The low production of farmed *O. niloticus* in the country is attributed to numerous factors ranging from political conflicts and farmers' low resources capacity. However, use of inadequate and low-quality feeds is the major challenge constraining development of *O. niloticus* farming for many counties in Liberia (Jueseah *et al*., 2020).

Most fish farmers in Liberia use rice bran, local fodder leaves and leftover food to feed their fish while others produce their own farm-made feeds produced by blending one or two feed ingredients (Ministry of Agriculture, 2018). All the feeds used by Liberian fish farmers are incomplete in terms of meeting the nutritional requirement of *O. niloticus* because they do not contain all the necessary nutrients to promote good growth of the fish (FAO, 2018). However, there have been no studies on the nutritional quality of these farmers' made feeds in Liberia.

Liberia's fish farming is further hampered by financial constraints, which limit farmers from acquiring quality fish feeds (Jueseah *et al*., 2020). Insufficient supply of quality fish feeds is, therefore, a major hindrance to optimal economic benefits from *O. niloticus* farming in Liberia. Thus, this research aimed at evaluating the nutritional quality of commercial and farm-made feeds and their effects on *O. niloticus* growth and economic performance. The research was conducted in four Liberian counties, which were selected because of their fish production status. This study was also conducted to provide information on the status of *O. niloticus* farming intensities and the various types and quality of feeds used, and the impact of the feeds on growth as well the effect of their effect on water quality parameters.

1.2 Problem statement

Despite the nutritional insufficiency of fish feeds for *O. niloticus* in Liberia (Aklilu *et al*., 2013), no studies have been undertaken to provide an inventory of types of feeds available. Further, no studies have addressed their relative nutritional quality, and the impact on the growth and development of *O. niloticus* across four of major Landlocked fish farming Counties in Liberia.

Numerous studies have advocated for use of commercial fish feeds because of their standardized nutritional content (Bartlett, 1954; Anani, 2015; Chavan 2015). However, none of the studies especially with focus to Liberia, has ever evaluated the effectiveness of farm-made-feeds and commercial feeds on *O. niloticus* production. Furthermore, lack of such information limits the formulation of on-farm fish feeds that would lead to optimization of production and economic viability to resource-poor farmers.

Despite the fact that feed have the potential to contribute to deterioration of pond water quality parameters including pH, alkalinity, temperature, dissolved oxygen among others (Blasco *et al*., 2022), there are no documented studies on the same in Liberia.

The need for supportive infrastructure and policies in the fisheries sector in Liberia to achieve socio-economic development has been underscored by Honfoga *et al*. (2017); Edwards & Allan, (2004). All individuals who derive their livelihood from fish farming are sustained by the profits gained. Factors affecting profits in aquaculture are the feeds quantity and quality (Dunbar *et al*., 2021). Therefore, information on the ways of improving farmers' fish production and profitability using farm-made and commercial fish feeds is imperative for decision making. This study was therefore conducted with a cardinal aim of bridging the knowledge gap on fish feed quality and distribution in Liberian land-locked counties.

1.3 Justification

In Liberia, 25% of the nutritional requirements of the farmed fish are obtained through the provision of rice bran, kitchen leftover and other vegetable by-products. The remaining 75% of the food is produced in the pond. However, formulated feed is not commonly available due to the high cost. Approximately 2,500 people derive their livelihoods from the aquaculture sector in Liberia with some engaged in pond building and organization, extension activities and fish collecting (BNF 2007). Fish farming is therefore a suitable option of fish supply to some parts of Liberia, especially non-coastal counties. Despite the economic returns from aquaculture to food security and livelihoods in Liberia, the sector is impeded by several factors. Key among them are inadequate skilled personnel, poor transport system, land tenure issues, inconsistent electricity supply, difficulty in accessing loans and pollution and availability and access to quality fish feeds, which affects production and profits from fish farming.

1.4 Objectives

1.4.1 General Objective

To provide information on fish feeds to improve aquaculture production of O. niloticus in Liberia.

1.4.2 Specific objectives

i. To assess the nutritional quality of farm-made feeds in the major fish farming counties of Liberia.
ii. To compare effects of farm-made, commercial and research feeds on growth performance of *O. niloticus* in ponds.
iii. To evaluate the impact of farm-made, commercial and research feeds on pond water quality parameters.
iv. To evaluate the economic returns of *O. niloticus* fed on farm-made, commercial and research feeds.

1.4.3 Hypotheses

This study was guided by the following hypotheses:

i. H01: There is no significant difference in the nutritional quality of farm-made feeds in the major fish farming counties of Liberia.
ii. H02: There is no significant difference in growth *O. niloticus* fed on farm-made, commercial and research feeds.
iii. H03: Farm-made, commercial and research feeds do not have any significant impact on pond water quality parameters.
iv. H04:There is no significant differences in economic performance of *O. niloticus* fed on farm-made, commercial and research feeds.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

2.1.1 Nile tilapia

Nile tilapia belongs to the Kingdom Animalia, Phylum Chordata, Class Actinopteri, Order Cichliformes , Family Cichlidae, Genus *Oreochromis* and Species: *O. niloticus* with the scientific name *Oreochromis niloticus* (Linnaeus, 1758) cited in (Behera *et al*., 2018)

The Nile tilapia, *Oreochromis niloticus*, is a species of cichlid fish native to half of the African continent including Levante area, as well as Israel and Lebanon (Zengeya *et al*., 2015). There are numerous introduced species of *Oreochromis*. *O. niloticus*, are grayish or brown in colour, usually with distinct banding and a vertically stripped tail. *O. niloticus* reproduces through mass spawning, typically initiated by the male, in a brood nest (Beletew *et al*., 2016). Females in the presence of the same sex visually or chemically exhibit shortened inter-spawning intervals. To increase their reproductive advantages, females extend the inter-spawning period by leaving their young in the care of males. This strategy allows them to take advantage of longer inter-spawning periods. (Vajargah, 2021; Zengeya *et al*., 2015).

Males have different levels of gonadotropic hormones for spermatogenesis with dominant males having higher levels of the hormone. Dominant males also have the best territory in terms of resources and mating access is often greater. Fry are cared for by mouth-brooding females through oral incubation of eggs and larvae. Before spawning, the nest is first made by the male, and the young fry or eggs are carried orally by the mother for approximately 12 days (Vajargah, 2021; Zengeya *et al*., 2015).

2.1.2 Range and habitat

Nile tilapia is native to of Africa, except for the Maghreb region and Southern Africa. This species may be found in West Africa, the Lake Chad basin, the River Nile system as a whole, including the Awash and Omo Rivers, the lakes Kivu, Tanganyika, and Turkana, as well as the lakes Tana, Albert, and Edward-George. Only Israel's coastal river basins are inhabiteded by the fish. It has been extensively adopted by many nations in Asia, Europe, North America, and South America. Africa has also generally adopted it. It frequently becomes invasive in these areas, endangering the local wildlife and ecosystems. However, a number of imported fish populations were once mistaken for Nile tilapia (Shechonge *et al*., 2019).

The *O. niloticus* may be found in many different freshwater habitats, such as ponds, rivers, streams, canals, and lakes, ranging from the sea level up to the altitude of 1,830 m (Behera *et al*., 2018). It is also found in brackish water, but it may not last long in highly saline water (Shechonge *et al*., 2019; Stauffer *et al*., 2022). The species has been spotted in water with temperatures as low as 8 °C and as high as 42 °C, despite the fact that the upper lethal limit is often about 39–40 °C (Vajargah, 2021). Unlike the northern African populations, isolated groups in hot springs within the Awash basin and at Suguta River often inhabit water temperatures of at least 32-33 °C, whereas the northern populations can withstand cold temperatures as low as -4 °C.. Although *O. niloticus*, can endure relatively low temperatures, breeding often doesn't start until the water reaches 24 °C (Blasco *et al*., 2022; Shechonge *et al*., 2019).

2.1.3 Feeding behaviour

O. niloticus shows omnivore tendencies while being mostly herbivorous, but are usually carnivorous when young (Blasco *et al.*, 2022). Majority of adult *O. niloticus* consume phytoplankton and macroalgae, while some populations also eat macrophytes, detritus and aquatic insect larvae, including mosquito larvae, as feed sources. When transferred outside its normal habitat, *O. niloticus*, typically displays invasive tendencies, harming other local species (Swar, 2016). The fact that *O. niloticus*, eats throughout the day suggests that , like trout and salmon, it has a behavioral response to light that serves as a key predictor of feeding activity. *O. niloticus*, commonly overpopulate culture facilities due to their rapid reproductive rate.

Because of the competition for food during the day, night feeding may occur to obtain the nutrients required. Despite widespread perception, a recent study reported that gender differences in food intake are not the primary cause of growth dimorphism. As a result, even when females and males eat the same quantity of food, females usually gain weight because they are more efficient at turning food into body weight (Blasco *et al*., 2022)

2.1.4 Reproduction

Social hierarchies exist in *O. niloticus* communities with dominant males receiving precedence for both food and mating. Males dig circular nests using their lips to serve as future spawning sites (Gonçalves-de-Freitas *et al*., 2019). These nests are commonly utilized for lengthy courtship rituals as well as parental care. Like other fish, *O. niloticus* travel almost exclusively in schools. Males build nesting zones, while females travel across zones to find mates, resulting in male competition for females. Male dominance is established first by noncontact displays like lateral displays and tail beats, as seen in other tilapias such as Mozambique tilapia. Contact conflict for the purpose of inflicting injury is the result of failed attempts to reconcile the hierarchy. Individuals' aggressiveness varies as a result of their exposure to various types of agonistic behavior (Ama, 2019). Once the social hierarchy of a society is established, dominant males benefit from higher food availability as well as an increased number of mates. In the presence of females, social interactions between males result in higher energy expenditures as a result of courting displays and sexual rivalry (Ama, 2019; Gonçalves-de-Freitas *et al*., 2019; Blasco *et al*., 2022).

Nile tilapia, like other fish, reproduce by mass spawning within a nest made by the male (Fagbemi *et al*., 2021). Male territoriality and sexual competition result in significant differences in reproductive success for individuals in a group under such arrangement. Inbreeding is likely to occur throughout generations as a result of unequal male reproductive success, resulting in less genetic variability in the long run (Carbonara *et al*., 2019). Tilapias reproduce after a few months, presumably as a result of reproductive competition. Because sexual development in *O. niloticus* occurs at a young age, birth and turnover rates are high. As a result, a individual's rapid reproductive rate may actually have a negative impact on growth rate, leading in the formation of stunted tilapia due to a reduction in somatic growth in favor of sexual maturation (Carbonara *et al*., 2019; Fagbemi *et al*., 2021).

When female *O. niloticus* are in the presence of other females, their interspawning intervals are reduced, either visibly or chemically (Carbonara *et al*., 2019; Tatemoto

& Serra, 2021). While female *O. niloticus* that provide parental care can extend the interspawning period, those that leave their offspring to a male have longer intervals between spawning events. One ostensible purpose of this procedure is to increase the reproductive advantage of females who do not have to care for young, allowing them to spawn more frequently. .

Males produce different quantities of gonadotropic hormones, which are responsible for spermatogenesis, with dominant males producing more. As a result, selection has rewarded more successful males with larger sperm production. Similarly, dominant males have the best territory in terms of resources and access to mates. Visual communication between *O. niloticus* couples also stimulates and alters reproductive behavior such as courting, spawning frequency, and nest building (Akian *et al*., 2020).

Oreochromis species usually care for their young via mouthbrooding and oral egg and larvae incubation (Kone *et al*., 2022). Nile tilapia, like other tilapia, are maternal mouthbrooders, hence the female provides almost all of the critical care. The small fry or eggs are carried in the mother's mouth for 12 days after spawning in a male-made nest. If the mother determines her offspring are not ready for the outside world, she will suffocate them in her mouth (Carbonara *et al*., 2019; Tatemoto & Serra, 2021). *Oreochromis niloticus* show parental concern in times of danger. When attacked, the young typically swim back into their mother's mouth for protection (Fagbemi *et al*., 2021). Mouthbrooding, on the other hand, produces significant metabolic alterations in the parents, most notably the mother, as seen by fluctuations in body weight and poor fitness. As a result, the costs and benefits of mouthbrooding may be used to track parental-offspring conflict. Care for the young ensures that an individual's genes are passed down to future generations, but it also reduces an individual's reproductive fitness(Akian *et al*., 2020; Blasco *et al*., 2022).

Female *O. niloticus* under parental care have longer interspawning intervals, which has the advantage of slowing vitellogenesis (yolk deposition) and so increasing the survival rate of one's own children (Sultana, 2020). Because larger eggs provide more nutrition for the growing young, egg size closely correlates with improvements in hatching time, development, survival, and feeding onset. Thus, one of the reasons female Nile tilapia delay interbreeding might be to ensure offspring survival.

2.1.5 Culture of Nile Tilapia

Aquaculture has been a fast growing sector as world demand for fish and seafood has increased dramatically (Lutterodt, 2018). Tilapia is a low-cost, and frequently consumed fish that is cultivated across the world *O. niloticus* has a high economic value, grows well in aquaponic systems using vegetables and has a good tolerance level to a wide range of environmental conditions. It is growing faster than any other aspect of the animal culture industry (Tacon & Metian, 2013). It is a high-protein diet rich in vitamins and minerals such as selenium, vitamin B12, niacin, and potassium. *O. niloticus* grows faster and to greater sizes in a shorter amount of time (Arlinghaus *et al*., 2021; Shechonge *et al*., 2019). Because this fish is affordable to the lowest income level in this area, demand is great, particularly among the poor.

2.2 Aquaculture production

2.2.1 World Overview of Aquaculture

Aquaculture involves cultivating aquatic organisms in various environments and includes interventions to enhance production and ownership of the raised stock (Monticini, 2019). Over the preceding five decades, worldwide fish output has steadily expanded, with edible fish supply increasing at a 3.2 percent yearly pace, outpacing global population growth of 1.6 percent (Vannuccini *et al.*, 2019). According to FAO (2013), worldwide fisheries and aquaculture production reached 157 million tons in 2012 and was predicted to increase to around 172 million tons by 2021, with aquaculture accounting for the majority of the increase. Global per capita apparent fish consumption increased from 9.9 kg in the 1960s to 19.2 kg in 2012 (ACTION, 2020).

In 2018, an estimated 59.51 million people were engaged in the primary sector of fisheries and aquaculture, 14 percent of them women (ACTION, 2020). In total, about 20.53 million people were employed in aquaculture and 38.98 million in fisheries (FAO, 2016). Overall, total employment in the primary sector has grown slightly, following measured increases in both fisheries and aquaculture employment. FAO carried out this work through an extensive set of consultations with members to revise historical data, uncover new data source, check data errors, and make imputations as necessary. Of all those engaged in fishing and fish farming, most are in developing countries, and the majority are small-scale, artisanal fishers and aquaculture workers. The various types of work in the primary sector cannot be considered equal as the forms of employment or engagement vary from occasional to full-time and between seasonal temporary and permanent occupations (Stauffer *et al*., 2022; Vannuccini *et al*., 2019).

In the past few years, major increases in the quantity of fish consumed have originated from aquaculture (FAO, 2021). The average contribution of aquaculture to per capita fish available for human consumption rose from 14 percent in 1986, to 30 percent in 1996 and to 47 percent in 2006, and it can be expected to reach 50 percent in the next few years (Mathiesen, 2015; Stauffer *et al*., 2022; Vannuccini *et al*., 2019). China is mainly responsible for this increase. In 2006, overall per capita fish supply from aquaculture was estimated at 7.8 kg, but it was 26.5 kg in China and only 3.3 kg for the world excluding China (FAO, 2016).

In 2014, fish harvested from aquaculture amounted to 73.8 million tonnes, with an estimated first-sale value of US$160.2 billion, consisting of 49.8 million tonnes of finfish (US$99.2 billion), 16.1 million tonnes of molluscs (US$19 billion), 6.9 million tonnes of crustaceans (US$36.2 billion), and 7.3 million tonnes of other aquatic animals including frogs (US$3.7 billion) (FAO, 2016). Almost all fish produced from aquaculture are destined for human consumption, although by-products may be used for non-food purposes. Given the practice by some countries of reporting to FAO post-first-sale prices as farmgate prices, the values of aquaculture production are likely to be overstated to some extent (FAO, 2016). World aquaculture production of fish accounted for 44.1 percent of total production (including for non-food uses) from capture fisheries and aquaculture in 2014, up from 42.1 percent in 2012 and 1.1 percent in 2004 (FAO, 2016).

All continents have shown a general trend of an increasing share of aquaculture production in total fish production, although in Oceania this share has declined in the last three years. However, the share of fish from aquaculture has increased steadily in the world excluding China, rising from 9 percent in 1986, to 15 percent in 1996 and 24 percent in 2006 (FAO, 2016). Further growth in the availability of fish for human consumption is expected to come mainly from aquaculture.

Aquaculture production has pushed the demand for and consumption of several freshwater species, such as tilapia and catfish (including *Pangasius* species) as well as for high-value species, such as shrimps, salmon and bivalves (Stauffer *et al*., 2022). Since the mid-1980s, these species have shifted from being primarily wild-caught to being primarily aquaculture-produced, with a decrease in their prices and a strong increase in their commercialization. Aquaculture has also had a major role in terms of food security in several developing countries, particularly in Asia, with significant production of some low-value freshwater species, which are mainly destined for domestic consumption.

2.2.2 Aquaculture in Liberia

Fish farming in Liberia began in 1950s, with fish ponds that were built at the Central Agriculture Experimental Stations in Suakoko, Bong County, purposely for culturing tilapia and catfish varieties (Tacon & Metian, 2013). After forty years, more than 500 ponds have been constructed all over the country and stocked with fingerlings (Mmanda *et al*., 2020). During the period characterized by the civil crisis (1990s to 2004), the aquaculture sector in Liberia benefited enormously from several donorsupported projects. Floating cages were also introduced in 2009 in the St. Paul River through the initiative of a private farmer (www.thefishsite.com).

The most common form of aquaculture in Liberia is pond aquaculture with ponds mostly ranging in sizes from 200 m^2 to 400 m^2 or even less, depending on land availability. The pond management practices vary from extensive to semi-intensive. Fish farmers mostly use small-sized fish left during harvest to restock their ponds. On average, the stocking density employed by many Liberian fish farmers is approximately 2.5 fish per m^2 (www.thefishsite.com). Productivity of fish ponds is mostly achieved through fertilization using poultry, goat and cattle manure. Left over from livestock and agricultural by-products are mostly used to feed farmed fish in Liberia (www.thefishsite.com). However, the introduction of cage culture in 2009 was to complement the production output from pond culture as well as ensuring maximum use of the existing water bodies in Liberia.

In the quest of developing the aquaculture in Liberia, technical and financial support provided by NGOs cannot be ignored. For instance, the European Union sponsored the rehabilitation of three hatcheries, Klay (Bomi County), Duoyee Town (Grand Gedeh County) and Salayea (Lofa County) from 1999 to 2000. Through the project, brood stocks of *Oreochromis niloticus* were introduced for seed production and further distributed to fish farmers. Rehabilitation and development of ponds in four counties, with some 380 farmers profiting from pond building materials, training and extension services were done by the project (Pauly & Zeller, 2019). In 1950, the U.S. Commission for Economic Development (USCED) initiated a long-term joint Liberian-USCED cooperative program in agriculture, forestry and fisheries. Funded from 1951 through 1967, the project provided technical assistance in fish propagation and pond construction for freshwater fisheries. The Peace Corps groups, established in 1961 during President J. F. Kennedy's administration, were formed to assist third-world countries in addressing their critical basic needs. In 1973, they conducted a feasibility study for inland fisheries. In 1979, two trained Peace Corps Volunteers were deployed to focus on fish culture development, and in 1981, eight additional PCVs were trained and assigned to expand fish culture activities in Liberia (Lunnan & Sandberg, 1983). Currently, seven NGOs work with the aquaculture sector under the thematic framework of food security in Liberia. These NGOs include Concern Worldwide, Samaritan Purse, APDRA, Africare, German Agro Action (Welt Hunger Hilfe), Care International, Faimba Fisheries Development Cooperative (FFDC), and Solidarites International (Belton & Thilsted, 2014).

Majority of fish farmers in Liberia practice the integrated aquaculture-agriculture technologies with the aim of increasing productivity at a relatively low cost as well as promoting ecological integrity (Hendrick, 2008). Meanwhile, semi-intensive form of culturing fish is being practiced in north and southeastern regions (Jauncey, 2000). Key freshwater fishes that are cultured in Liberia include tilapia and catfish (www.thefishsite.com). In terms of production proportions, Nile tilapia and *Tilapia zili* cover 95% of production while African catfish and *Heterobranchus* spp. account for the remaining 5% (Vannuccini *et al*., 2019). In Liberia, 25% of the nutritional requirements of the farmed fish are obtained through the provision of rice bran, kitchen leftover and other vegetable by-products are inexpensive feed ingredients. The remaining 75% of the food is produced in the pond. However, formulated feed is not commonly available due to the high cost of overland transport.

Furthermore, the number of stakeholders in aquaculture (mostly fish farmers) increased from 350 in 2000 to 1050 in 2004 (Belton & Thilsted, 2014). Approximately 2,500 people are employed by fish farming activities with some engaged in pond building and organization, extension activities and fish collecting (BNF 2007). Additionally, fish production emanating from aquaculture doubled in 2004 (BNF 2007). Fish farming is a suitable option of fish supply to some parts of Liberia, especially non-coastal counties because frozen fish retailed in these counties are of bad quality. Despite the economic returns from aquaculture to food security in Liberia, the aquaculture industry in Liberia is bedevilled by the following factors: inadequate skilled personnel, poor transport system, land tenure issues, inconsistent electricity supply, difficulty in accessing loans and pollution.

2.3 Farm made feeds and their relative nutritional content in fish farming

2.3.1 Nutritional requirements of tilapia

Like any other finfish, *O. niloticus* requires ten essential amino acids. However, protein content for ideal growth relies on quality, source, fish size and age. Diets used in culturing *O. niloticus* mostly possess dietary protein values between 45-50% for first feeding larvae, 35-40% for fry and fingerlings, 30-35% for juveniles and 28-30% for on-growing (www.Food and Agriculture Organization.org). Edwards & Allan (2004), reported that the best protein digestibility occurs at 25 °C. The appropriate protein - energy ratio ranges from 110 to 120 mg per kcal for fry and fingerling whiles 40-45% of protein is ideal for brooders (FAO, 2016).

Though the amount of carbohydrate for optimum growth of tilapia is unknown, they provide energy. Tilapia can proficiently exploit 35-40% of digestible carbohydrate based on a number of factors like source, size and feeding frequency (El-Sayed, 2006). Complex carbohydrates tend to be better assimilated by tilapia species than disaccharides and monosaccharides related diets (FAO, 2016). Stickney (2006) conveyed that soluble non-starch polysaccharides in diet of tilapia amplifies organic content of culture system while insoluble NSP performs otherwise.

Though vitamins are vital for proper growth of tilapia in intensive culture facilities, they are not important for extensive and semi-intensive farms. The content of vitamins in tilapia are mostly influenced by dietary lipid level and the unsaturation index as well as the stability and bioavailability of the materials used in preparing the vitamin (www.Food and Agriculture Organization.org). Even though limited knowledge on mineral requirements is available for tilapia, these species are able to absorb minerals from the culture water. Gabriel *et al*. (2007) reported that phosphorous significantly affects weight gain, food conversion ratio and protein efficiency ratio for tilapia. Despite the presence of minerals in feed, diets should contain supplemental mineral premixes to certify that sufficient levels are available for protection. Ferric citrate is hemi- functional compared to ferrous sulphate in satisfying iron demand of tilapia, thus addition of minerals to fish diet relies on the source of mineral (FAO, 2016).

A number of plant-based feed ingredients possess huge amount of phytic acid which has huge affiliation for metal ions. However, fish including tilapia cannot assimilate the phytate bound metal ions. As such, the inclusion of microbial phytase Nile tilapia' feed meaningfully advances the growth of the fish, though variations in amount available depends on dietary ingredients used (Fitzsimmons *et al*., 2011).

Presence of nutrient deficiency in fish results in low profits, thus it is crucial for fish farmers to know some of these nutrient related diseases. For instance, absence of essential amino acid promotes loss of appetite, poor growth and feed utilization efficiency. In other fish species, deficiency in lysine, methionine or tryptophan deficiency results in scoliosis, lordosis, fin erosions and cataracts. Regarding mineral deficiencies in fish, Dabrowska *et al*. (1989) mentioned that excess magnesium in a poor protein diet results in intense growth retardation, hematocrit and hemoglobin content. Nonetheless, magnesium deficiency in a high-protein diet leads to hyper calcinosis. Hence, dietary magnesium content of 0.06 - 0.08 % is known to be adequate for ideal performance of tilapia. Missing vitamins in fish diets exposes farmed fishes to anorexia, reduced growth and death while incorporating antibiotics into fish feed reduces the vitamin synthesizing capacity of fish (FAO, 2016).

2.3.2 Feeding habits of *Oreochromis niloticus*

Nile tilapia is mostly herbivorous, with omnivorous inclinations. Early juveniles and young fish are omnivorous, feeding mainly on zooplankton and zoo-benthos but also ingest detritus and feed on phytoplankton. At around 6 cm TL the species becomes almost entirely herbivorous feeding mainly on phytoplankton, using the mucus trap mechanism and its pharyngeal teeth (Tiamiyu *et al*., 2016). The pH of the stomach varies with the degree of fullness and when full can be as low as 1.4, such that lysis of blue-green and green algae and diatoms is facilitated.

Enzymatic digestion occurs in the intestine where the pH increases progressively from 5.5 at the exit of the stomach to 8 near the anus. Nile tilapia exhibit a diel feeding pattern. Ingestion occurs during the day and digestion occurs mainly at night (Gaillard *et al*., 2016). The digestive tract of Nile tilapia is at least six times the total length of the fish, providing abundant surface area for digestion and absorption of nutrients from its mainly plant-based diets (Mmanda *et al*., 2020). Their behavioral response to light is a main factor of their feeding activity. Dimorphism between sexes results from differential food conversion efficiency, rather than different amounts of food consumed. Although males and females eat equal amount of food, males tend to grow larger due to higher efficiency of conversion of food to body weight (FAO, 2016).

2.3.3 Nile tilapia - Supplemental feeds & feeding

Supplemental feeding compensates for natural food nutrient deficiencies in fertilized ponds and is the usual feeding method for semi-intensive tilapia culture systems. A comprehensive review of supplemental feeding practices and of various supplementary feeds is provided by (Tacon &Metian, 2013). The use of supplemental feeds leads to significant increases in tilapia yield in comparison to fertilized ponds alone. However, farmers must be aware of the complex interactions between the natural food supply and supplemental feeds and that incorrect feeding strategies can lead to financial loss. Supplemental feeding should be carried out properly coupled with a good understanding of the nutrient content of the various feed ingredients. Supplementary feeds can be made up of single ingredients or combinations of ingredients either simply mixed together or powdered and compounded into moist dough before feeding. The most common feedstuffs are agricultural by-products such as rice bran, broken rice and maize with occasional use of grass and leaves (FAO, 2016). Dry ingredients are normally ground before being dispersed throughout the pond. However, many raw ingredients of plant origin are inappropriate for tilapia fry, but can be used for fingerling and larger fish. It should be mentioned that commercially formulated pellets can also be considered as supplementary feed when used in combination with a pond fertilization regime, or used in combination with cheap feed ingredients. Some farmers often use formulated feed as a single feed source for a particular life stage.

2.4 Fish feeding & Growth

Aquaculture contributed 43 per cent of aquatic animal food for human consumption in 2007 (e.g., fish, crustaceans and mollusks, but excluding mammals, reptiles and aquatic plants) and is expected to grow further to meet the future demand. It is very diverse and, contrary to many perceptions, dominated by shellfish and herbivorous and omnivorous pond fish either entirely or partly utilizing natural productivity (Mmanda et al., 2020). The rapid growth in the production of carnivorous species such as salmon, shrimp and catfish has been driven by globalization trade and favorable economics of larger scale intensive farming. Most aquaculture systems rely on un-costed environmental goods and services, so a critical issue for the future is whether these are brought into company accounts and the consequent effects this would have on production economics (Gabriel *et al*., 2007). Aquaculture is of two types; fed aquaculture (aquaculture with feeding) and non-fed aquaculture (aquaculture without feeding). Fed aquaculture production has outpaced that of the non-fed subsector in world aquaculture (FAO, 2016).

The contribution of non-fed aquaculture in total farmed aquatic animal production continued to decline from 43.9 percent in 2000 to 30.5 percent in 2018, although its annual production continued to expand in absolute terms (Adéyèmi *et al*., 2020; Mmanda *et al*., 2020). In 2018, total non-fed aquaculture production increased to 25 million tonnes, consisting of 8 million tonnes of filter-feeding finfish raised in inland aquaculture (mainly silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys nobilis*) and 17 million tonnes of aquatic invertebrates, mainly marine bivalve mollusks raised in seas, lagoons and coastal ponds (FAO, 2016).

In polyculture operations, feeds used for fed species may also be harvested by filter-feeding species, depending on the type and quality of feeds. At the same time, specially designed feeds are commercially produced and used by some farmers for bighead carp in southern China, for razor clams in east and northeast coastal provinces in China, and for hard clams in Taiwan Province of China (Gui et al., 2018). In Europe, a new practice has emerged of keeping oyster juveniles in indoor tanks for grow-out to marketable size by feeding them with microalgae of selected species artificially produced in outdoor ponds. Stocking of filter-feeding carps in multispecies polyculture farming systems is a common practice in Asia, Central and Eastern Europe and Latin America. It enhances overall fish productivity by utilizing natural food and improving the water quality in the production system (FAO, 2016). In recent years, another filter-feeding finfish species, Mississippi paddlefish (*Polyodon spathula*), has emerged in polyculture in a few countries, particularly in China, where the production volume is estimated to be several thousand tons (Gui *et al*., 2018).

In addition to filter-feeding finfish, freshwater bivalves, including those species that are produced for freshwater pearl production, are now utilized for aquaculture-effluent treatment on individual farms as well as under communal-setting clustering of several farms (Tacon & Metian, 2013). Marine bivalves, filter-feeding organisms that extract organic matter from water for growth, and seaweeds, which grow by photosynthesis by absorbing dissolved nutrients, are sometimes described as extractive species. When farmed in the same area with fed species, they benefit the environment by removing waste materials, including waste from fed species, thus lowering the nutrient load. Culture of extractive species with fed species in the same mariculture sites is encouraged in aquaculture development planning and zoning exercises in the European Union and North America (FAO, 2016).

2.5 The impact of farm-made and commercially feeds on pond water quality

2.5.1 Water quality parameters for Tilapia

Each water quality parameter interacts with and influences other parameters, sometimes in complex ways. Concentrations of any one parameter that would be harmless in one situation can be toxic in another. For example, when aeration and degassing problems occur, carbon dioxide levels will generally become high while at the same time dissolved oxygen levels become low (Bhateria & Jain, 2016; Barman, 2020). The result of this particular situation is that not only is there less oxygen available to the fish, the fish are less able to use the oxygen that is available. The high carbon dioxide level of the water affects the fishes' blood capacity to transport oxygen, aggravating the stress imposed by low dissolved oxygen levels. Another excellent example of the complex interaction among water quality elements is the relationship between pH and the toxicity of ammonia. As will be discussed later, only the unionized fraction of the total ammonia concentration is toxic, and at low pH, most of the ammonia in the water is in the non-toxic ionized form. However, increasing the pH by only one unit, i.e., from 6.5 to 7.5, increases the concentration of the toxic unionized ammonia concentration by a factor of ten. Simply adding baking soda to a system to increase its alkalinity can inadvertently but easily create this extremely undesirable condition (Shechonge *et al*., 2019).

The relationship between water quality factors and their effect on fish growth rate and health is complicated. For example, fish lack the means to control their body temperature and maintain it independent of the environment. Environmental temperature changes affect the fishes' rate of biochemical reactions, which leads to different metabolic and oxygen consumption rates (Sultana, 2020). At the lower ranges of the species tolerable temperature range, these rates decrease. As water temperatures increase, fish become more active and consume more dissolved oxygen, while simultaneously producing more carbon dioxide and other excretory products, such as ammonia. These increasing rates of consumption of necessary elements and production of detrimental elements can have a direct effect on overall fish health and survival if these parameters are allowed to exceed nominal values. If not corrected, the fish will become stressed to some degree. Even low levels of stress can have adverse long-term consequences in the form of reduced growth rates or mortality due to opportunistic organisms that take advantage of the stressed fish (Delincé, 2013).

2.5.2 Temperature

Environmental variables such as solar radiation, the presence of vegetation, cloud cover, geographical location, and variations in daily diurnal cycles all influence temperature (Mathiesen, 2015; Stauffer *et al*., 2022). Temperature influences metabolism, physiology, reproduction, and, ultimately, fish development. The majority of fish are poikilotherms, which means they don't create their own heat and instead rely on the temperature of their environment. Each fish species has a thermal optimum value that ensures survival; the ideal temperatures for warm water fish are 28-32°C (Bhateria & Jain, 2016). Similarly, fish cannot regulate their body temperature and must rely on the temperature of the surrounding water.

Temperatures that are higher or lower than the specified range can be stressful or fatal. Fish eggs hatch only at specific temperatures. Temperature rises diminish the solubility of dissolved oxygen and other gases. A rise in temperature hastens eating, activity, and breathing (Fitzsimmons *et al*., 2011; Mmanda *et al*., 2020). Temperature is important because it affects the amount of dissolved oxygen and the metabolic rate of aquatic species, impacting both their survival and growth (Kassam & Dorward, 2017).

Temperatures that are too hot or too low are stressful or fatal. Fish eggs will hatch only at certain temperatures. The solubility of dissolved oxygen and other gases decreases as temperature rises. Temperature increases hastens eating, activity, and breathing (Gaillard *et al*., 2016). Temperature is important because it affects the amount of dissolved oxygen and the metabolic rate of aquatic organisms, impacting both survival and development.

2.5.3 Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is necessary for living creatures' respiration, the breakdown of biodegradable organic matter, and the chemical oxidation of water and sediments. It enters the water body by diffusion and photosynthesis (Xu *et al*., 2006). It is influenced by temperature, which impacts the rate of oxygen diffusion into water (Boyd & Tucker, 2012). It is measured in milligrams per liter or parts per million.

Planktonic algae abundance has a significant influence on photosynthesis, which releases oxygen and therefore boosts DO in aquaculture ponds, whereas respiration consumes oxygen and hence reduces DO in water (Delincé, 2013; Kassam & Dorward, 2017). Organic material in water produces decomposition, which needs the usage of oxygen, resulting in low DO (Belton & Thilsted, 2014; Arlinghaus *et al*., 2021). A shortage of DO is the most common cause of pond fish mortality. Optimal DO levels for aquaculture should be larger than 5mg/L, with catfish and tilapia fish tolerant of levels as high as 3mg/L. Less than 5mg/L concentrations result in lower feed intake, a higher feed conversion ratio (FCR), delayed growth, stress, and illness. DO levels of less than 1 mg/L can be fatal. The FAO (2016) recommended guideline for water quality is 4-6mg/L. Low DO levels can be regulated by limiting algae growth or employing aeration equipment.

2.5.4 pH

pH is the negative logarithm of the hydrogen ion (H^+). In an aquatic environment, pH is determined by the balance of photosynthesis, respiration, and decomposition. It has a substantial influence on water chemistry because it affects the solubility and hydration of important nutrients (Gaillard *et al*., 2016). These variations have an effect on nutritional availability; for example, a rise in pH produces a decrease in phosphorous solubility (Mmanda *et al*., 2020). The pH of water varies with the amount of carbon dioxide (CO_2) in the water; diurnal pH fluctuations are explained by the fact that algae in water take CO_2 from the water for photosynthesis during the day, causing the pH to rise.

The pH of the water drops at night when CO2 builds in the water from the respiration of fish and algae. The pH of soils varies as well (Blasco *et al*., 2022; Fitzsimmons *et al*., 2011). Although various fish tolerate varying pH levels, the ideal pH range is 6.5 to 9.0. The pH of fish is 7.4, and the recommended pH for fish ponds should be close to 7-8 pH; excessive values are fatal to fish (Belton & Thilsted, 2014). The pH limit set by the WHO (2009) is 6.5-8.5. The pH of aquatic species impacts their survival or hatching rates, with high pH values of below 4 and above 9 being lethal to fish, producing a stressful environment that leads to delayed development.

2.6 The economics of farm-made and commercial fish feeds on O. niloticus

High quality formulated feeds are used to achieve high yields and large sized fish (600-900 g) within a short period of time. The maximum size at harvest of Nile tilapia reared in ponds that are only fertilized is generally less than 250 g after 5 months of on-growing. Under semi-intensive farming systems, most tilapia farmers in Asia fertilize their ponds and use formulated feeds. However, in intensive pond and tank culture systems or in cages, tilapia farmers mainly depend on commercial pelleted feeds. The nutrient inputs used and the yield and weight of tilapia at harvest in several Asian countries are summarized by Dey (2001). In terms of pond yields, Chowdhury *et al*. (2007) reported that overall, the average yield of pond farming in Taiwan, Province of China is very high (12 to 17 tonnes/ha) while ponds in Bangladesh, China, the Philippines, Thailand and Vietnam produce around 1.7, 6.6, 3.0, 6.3 and 3.0 tonnes/ha, respectively. (Tacon & Metian (2013) conservatively estimated that the global production of industrially manufactured aqua feeds in 2003 was about 19.5 million tons with projections of 27.7 million tonnes by the year 2010. Tilapia feeds accounted for about 8.1 percent of global aquafeed production in 2003. Commercial tilapia feeds are mainly dry sinking pellets and extruded floating pellets. Production estimates for farm-made tilapia feeds are not available as these are usually site specific and dependent on locally available feed ingredients. In countries such as the Philippines, on-farm feeds are not very popular as tilapia farmers find it more convenient to purchase formulated feeds from feed companies.

The main issue in formulating feed is to meet the protein and essential amino acids (EAAs) requirements of the species. Fishmeal is generally the preferred protein source because of the high quality of the protein and its EAA profile. However, fishmeal is generally expensive and is not always available. Nile tilapia can be fed with a high percentage of plant proteins. It is economically judicious to replace fishmeal with alternative protein sources including animal by-products, oilseed meal and cakes, legumes and cereal by-products and aquatic plants. Most of these ingredients are deficient in some EAA and hence require supplementation or be compensated with other feedstuffs. Although most of the oilseed cakes/by-products are generally deficient in lysine and methionine, blending of different oilseed cakes often provides a balanced amino acid profile. However, they contain many anti-nutritional factors (such as gossypol, glucosinolates, saponins, trypsin inhibitors etc.) Which limit their use in compound feeds or require removal/inactivation through specific processing (such as heating, cooking etc). There are also several non-conventional protein sources that may be suitable for *O. niloticus* such as silkworm pupae, snails, earthworms, Spirulina, corn and wheat gluten, almond cake, sesame cake, brewery waste, etc.

There are no generalized feeding tables for the use of supplementary feeds in Nile tilapia farming although feed manufacturers often provide recommended feeding rates for their feeds. However, there are some general rules. The population of natural food organisms in the culture system gradually decreases as the standing crop increases such that the number of supplementary feeds should be gradually increased as the fish grow. Feeding rates should be assessed according to the natural productivity of the ponds and the fertilization program. Thus, if transparency decreases, feeding rates should be reduced. Conversely, if transparency increases, feeding rates and/or nutrient quality (such as protein content) should be increased. Optimal feeding rates and frequency of feeding are site specific and also depends on the various types of supplementary feed items used. In a detailed profitability analyses of various inputs for pond culture of Nile tilapia in Thailand, Yi and Lin (2000) reported that fertilizing ponds with urea and TSP at 28 kg N and 7 kg P/ha/week, respectively, and supplementing with pelleted feed at 50 percent satiation level starting only when the fish reaches 100 g size, yielded the best economic returns. Leroy & Frongillo (2007) reported that red hybrid tilapia in floating cages fed a 25 percent protein diet three to four times a day resulted in better growth and feed conversion ratio than when fed twice a day.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The survey of feeds and collection of feed samples from farmers were conducted in the four landlocked counties of Liberia (West Africa), which included; Bong, Lofa, Nimba, and Grande Gedeh (figure 3.1). The survey also gathered information on farmers demographics, types of feeds and culture systems, costs of feeds and challenges faced by farmers. Geographically these counties are situated in the north (Lofa, Nimba), central (Bong), and southeastern (Grande Gedeh) parts of Liberia. Bong is a county in the north-central portion of Liberia. It is one of the 15 counties that comprise the first level of administrative division in the nation. It has a size of 8,772 km^2. The county is bordered by Lofa and Gbarpolu to the north (Figure 3.1). There are many policies that enhance aquaculture in Bong, especially, the Bong County Agricultural Development project II, which aims at enhancing small fish farmer holder's productivity and income.

Lofa is a county in the northernmost part of Liberia (figure 3.1). It is also one of the 15 counties constituting the first level of administrative division in the nation. Lofa has nine districts and measures 9,982 km^2. The county is bordered by Bong and Gbarpolu to the west and northeastern parts to the border of Guinea. Its landscapes comprise mountains including Mount Wuteve, the highest mountain in Liberia, coastal plains that raises to a height of 30m (98 ft) above sea level (Kouadio *et al.*, 2015). It is known for its swampy lands and rivers, which enhance aquaculture..

Nimba is a county that forms part of the southern extent of the Guinea highlands. The Nimba range is a narrow ridge extending approximately 40 km long, with an orientation of northeast-southwest (Berge, 1974). It is known for its diverse ecosystems and rocks; Precambrian, e.g., granite and quartzite of iron ore deposits (Butt & Bristow, 2013). Nimba ecosystems consist of terrestrial and freshwater habitats. Freshwater ecosystems play a key role in aquaculture farming in the county. The Guinea highlands, of which the Nimba range are part of, separate the coastal rivers and streams of the upper Guinea from the upper Niger River basin. The highlands form a barrier to inter aquatic species movement between these freshwater regions.

Grande Gedeh is a county bordered by Nimba to the west and Sinoe county to the southwest and River Gee to the southeast and Ivory Coast to the north. Its landscape consists of lower tropical forests, which has mid-size hills comprising of valleys and water courses. The uplands are conducive for rice cultivation as well as low lying areas for yam, cocoyam plantains. It has evergreen forests as well, it is known for aquaculture due to its swamps and water courses and high annual rainfall (3000 mm to 4,100 mm) (Thomas, 1995).

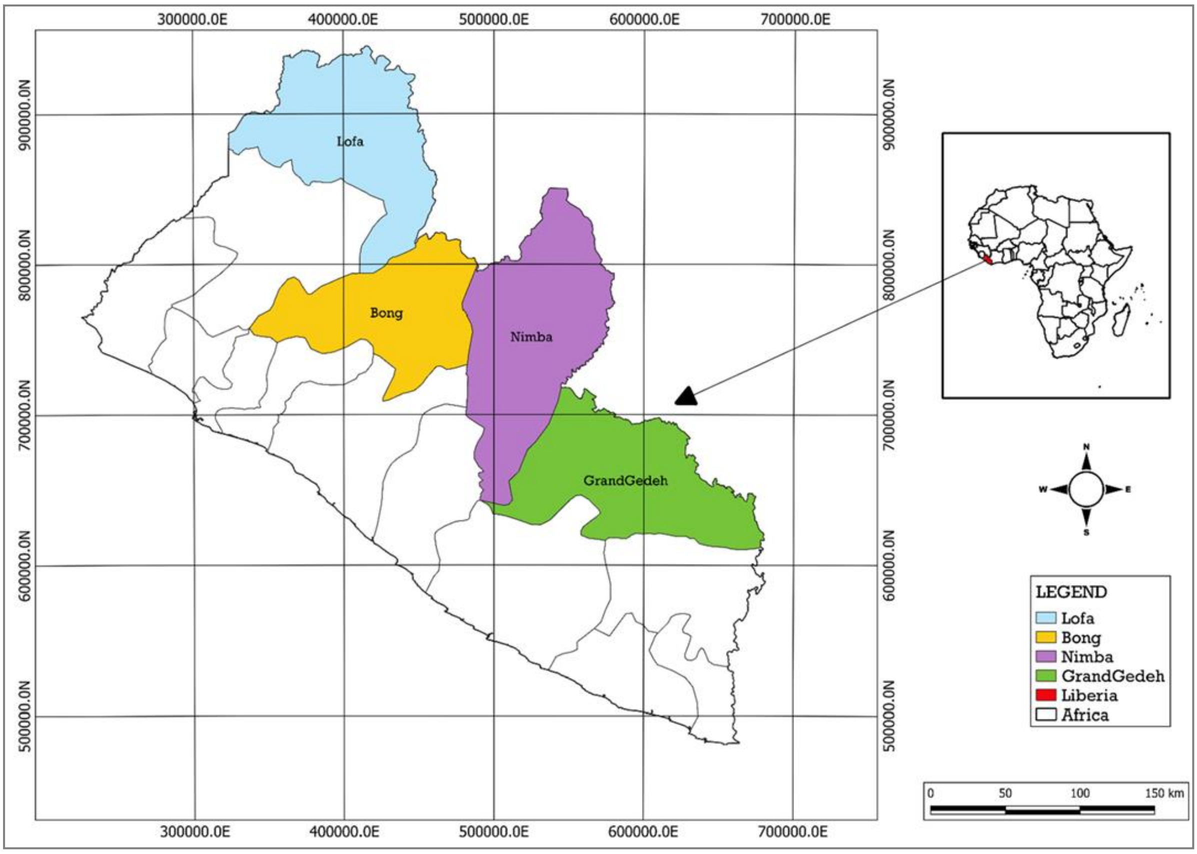

Figure 3.1: Map of Liberia indicating the Bong, Lofa, Nimba, and Grande Gedeh counties, which were part of the study.

3.2 Field work and sampling programme

3.2.1 Survey of commonly used feed ingredients and determination of their proximate nutritional content

A survey of aquaculture activities in the four counties was conducted. A cluster purposeful sampling methodology involving a combination of two social data collections approaches; one-on-one interviews and focus group discussions (FGDs (Taherdoost, 2017) was used in the survey. The survey was intended to establish the various types of feeds and ingredients that are used by the farmers in the four counties, determine the approximate economical returns of the Nile Tilapia production by farmers using different self-compounded feeds and to determine their sources and formulations. Baseline data on per capita production and income was also collected.

A total of 120 participants per county was identified using the formula below as described by (Bartlett *et al*., 2001; Taherdoost, 2017):

$$\eta = \frac{p(100-p)Z^2}{E^2},$$

Where,

η Is the required sample size

P is the percentage occurrence of a state or condition (50)

E is the maximum percentage error required (0.05)

Z is the value corresponding to the level of confidence (1.96)

A focus groups discussion (FGD) session was also conducted among different stakeholders and key informants. Four FGDs, constituting of women, youths, men and extension officers was conducted separately in each county. The discussions were led by semi-structured fish production questionnaire (Appendix 7) and each session consisted of 12 farmers, language interpreter and the researcher. All the four FGDs in each county were video recorded for further content archiving. The resulting qualitative data was used to reinforce the qualitative and quantitative data collected from one-on-one interviews.

3.2.2 The test feeds

The test diets consisted of diets formulated by farmers (2 diets) and that formulated by the researcher (1 diet) using the most frequently used ingredients from the selected counties (as per the baseline survey). On the other hand, commercial feeds were sourced from two local commercial feed manufacturers in Liberia because of the closure of border due to the Covid 19 virus. Otherwise, the initial plan was to obtain some commercial feeds from neighbouring Ghana where some farmers source their feeds. The two local commercial feed producers were selected based on the fact that they have been recognized by the government authorities (ministry of agriculture) as leading manufactures. The study utilized the five test feeds to evaluate their influence on some fish growth parameters. Three of the test feeds were locally formulated on-farm while the other two were commercial feeds commonly used by farmers.

3.2.3 Collection of farm-made feeds for analysis

Samples of feed ingredients were collected from five fish farmers in each of the four counties. They were packaged in separate polythene bags for each farmer per county and tightly sealed to prevent moisture. The bags were transported by road to the Central Agriculture Research Institute laboratory in Liberia for storage. They were later transported to Kenya for analysis. Proximate composition analysis was conducted on 100 grams of each feed ingredient from each county. The samples were analyzed at the Kenyan Marine and Fisheries Research Institute (KMFRI) Sangana and Sangoro stations since there was no suitable laboratory in Liberia or Eldoret in Kenya.

3.2.4 Proximate analysis for farm-feeds

For proximate composition of the feeds formulated by farmers, the moisture, crude protein, crude fat and ash were determined using standard procedures of the AOAC

(2005). The following nutrients were analyzed: crude protein (CP), crude lipids (CL), ash, nitrogen free extracts (NFE), and crude fiber (CF).

Crude protein was estimated from Kjeldahl nitrogen, while crude lipid was quantified through the loss in weight after extraction of the sample with petroleum ether (40-60 °C). Fish feeds samples from each of the feed types each weighing 2 grams was used. To each of the samples, a digestion mixture containing concentrated sulfuric acid and a catalyst tablet (K_2SO_4 and $CuSO_4$) was added. The mixture was digested in the Kjeldahl digestion apparatus until the mixture turned colorless. The clear mixture was then diluted with distilled water and thereafter mixture distilled and the ejected ammonia trapped in saturated boric acid solution.. The distillate was then titrated with a standardized solution of hydrochloric acid. The nitrogen content was obtained by the formular: Nitrogen (%) = (Titration volume × HCl normality × 14.007) / Sample weight. The Crude Protein (%) was then obtained by the formiula, Crude Protein (%) = Nitrogen (%) × 6.25 (conversion factor).

Ash was determined by burning 5g of dry samples of each type of feed in a muffle furnace at 550 °C for 4 hours. Crude fiber was determined by alkaline/acid digestion, followed by ashing of the dry residue at 550 °C in a muffle furnace for 4 hours.

3.3 Evaluation of fish growth

O. niloticus fingerlings of mean weight of 13.0 g were obtained from Central Agricultural Research Institute (CARI) located in Suakoko Bong County, Liberia. All males of a particular strain of Nile Tilapia were identified and stocked in hapas at CARI. Before stocking, the initial standard length (SL), total length (TL) were measured to the nearest cm using a graduated trough. Further, the wet weight was measured using a top-loading electronic balance to the nearest gram. A total of 450 male fish was used in the growth study. The fish were divided into three groups of 30 fish, randomly picked and stock in 15hapas.

3.4 Experimental design and layout

Five dietary treatments (RF, C1, C2, F1, and F2) where RF represent Researcher formulated diet, C1 and C2 refers to the locally manufactured commercial feeds and F1 and F2 refers to farmer formulated feeds as informed by the results of the survey. The five feeds were administered to stocked fingerlings in a Randomized Complete Block Design (RCBD) with three replications (Shieh, & Jan, 2004) (Figure 3.2).

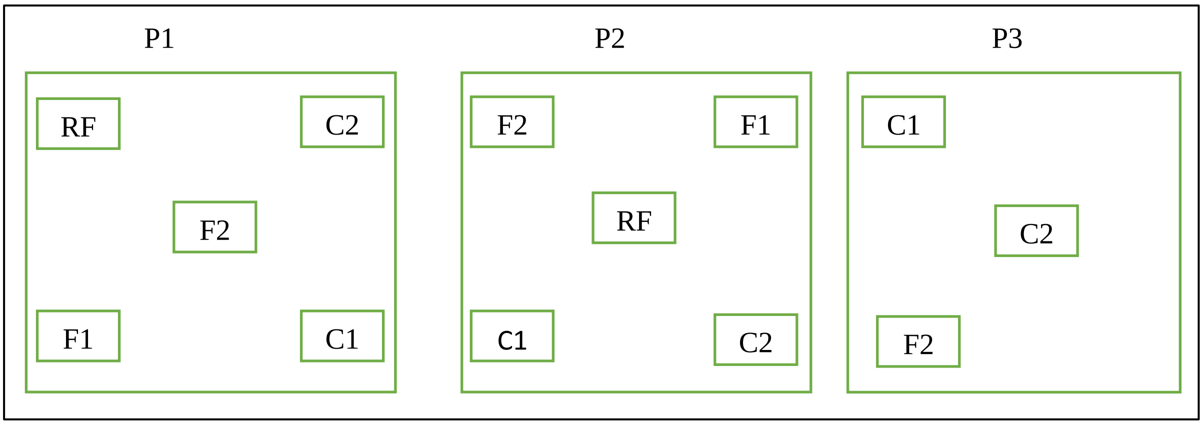

Figure 3.2: Experimental design for testing different feeds on fish in hapas within ponds

The treatments (test feeds) were randomly assigned to the experimental units (hapas). Numbers were assigned to the feeds and the hapas in each block. Random numbers were then generated from excel used to assign the placement of the experimental treatments. The test feeds were given to the fish twice every day for a period of six months.

3.5 Set-up of experimental hapas in earthen ponds

The evaluation of the fish growth was conducted in Earthen Fish Ponds with Hapas being mounted in each fish pond. Fifteen Hapas (5 hapas per pond), each with the size 3.0 m*2.0 m*1m, were installed in three ponds (Figure 3.2). Three fish ponds each with an average size of 1900-meter square were used during the research. The stocking density for each Hapas was 30 fingerlings/hapa. A total of 450 male fish were stocked evenly in the 15 Hapas. The bags containing the fingerlings were left to slowly submerge to allow gradual mixture of the pond water and let the fingerlings acclimatize to the temperature and water quality of the pond. The fingerlings were fed according to the average weight of the stock. The fish was fed twice a day for six months. There was an interdistance allowance of 1.5 meters between Hapas to allow the free-flow of water.

3.6 Water quality analysis

The effect of different feeds on water quality was studied at Central Agriculture Research Institute in Liberia. Water quality parameters were measured daily inside the 15 fish holding hapas in the three ponds for six months. The following water quality parameters were monitored: temperature, pH, Dissolved Oxygen (DO) and oxygen saturation. Water temperature, DO and oxygen saturation were measured using an Oxyguard meter (Oxyguard International A/S, Farum Gydevej 64, 3520 Farum, Denmark) while pH was obtained using the pH meter (Hanna Instruments HI-83141-1). Determination of the Dissolved Oxygen, water temperature and saturation % were done by placing the meters at a water depth of 50cm in the hapas.

3.7 Fish growth performance indices

The growth performance indices that were were measured included weight gain in grams, specific growth rate (SGR), feed conversion rate (FGR), and daily growth rate. Data on fish weight of each fish was collected biweekly for six months from each Hapa. The fish were removed from the Hapas and the weight, was measured and placed back into the Hapas. Weight gain was calculated by subtracting the final weight of the fish from the initial weight.

$$\mathbf{WG} = \frac{\text{(Final mean weight – Initial mean weight)}}{\text{Initial mean weight}}$$

Specific Growth Rate (SGR) was calculated from weight gain divided by the number of days and multiplied by 100%.

$$\text{SGR} = \frac{100*[\ \ln(\text{Final body weight}) - \ln(\text{Initialbody weight})]}{\text{culture period in days}}$$

The FCR was calculated by dividing the total feed consumed by the total fish weight gained. This was done for every feed type under study.

$$\mathbf{FCR} = \frac{\text{Total feed fed (kg)}}{\text{Live weight gain by fish (kg)}}$$

3.8 Economic analysis of diets

Return on Investment (RoI) was used for the assessment of economic returns of the diets. This was calculated using the market price of local ingredients and the market prices of commercial feed. Only the cost of the diet was calculated considering all other prices of other materials constant. The RoI was calculated from the formula below (Subedi *et al.*, 2019).

$$\text{RoI} = \frac{(\text{Net profit}) \times 100\%}{\text{Total cost of investment}}$$

Variables (quantity and cost) were calculated per hectare for uniformity and comparison among feed types. Total variable cost was summed from fish seed, feed, labor, pond care, equipment, irrigation, transport, maintenance, medicine, leased land, and working capital interest. Feed price was based on ingredient percentages. Fish price mirrored market carp prices.

The net profit was calculated by subtracting the total cost of implementing the respective fish feeds from the increased revenue generated from fish production. Cost of investment includes all the costs incurred depending on the type of feeds.

3.9 Data analysis

Qualitative data obtained from focus group discussions, by evaluating participants' contribution to the subject matter was subjected to content analysis where the data was grouped, summarized and tabulated. The data included information regarding the farmers' demographics and general fish farming practices. On the other hand, interview data was cleaned, ordered and subjected to descriptive analysis. Chi-square independence test at a 5% confidence interval was used to test for significant differences between observed and expected frequencies.

Multiple linear regression was used to model the relationship of fish feeds to the fish growth performance indices (standard growth rate and feed conversion ratio). Analysis of variance was employed to ascertain statistical differences among the measured parameters under various feed types, with a confidence level of 5%.The multiple range test was done using Turkeys' mean separation at a 5% confidence interval.

Other growth performance aspects such as; mean weight gain (MWG), specific growth rate and feed conversion ratio (FCR) were subjected to analysis of variance (ANOVA) using feed types as the factors at 95% confidence interval. The water quality parameters were also subjected to analysis of variance to assess the differences in the effect of the different feeds.

CHAPTER FOUR

RESULTS

4.1 Characterization of Aquaculture in Liberia

4.1.1 Farmers' Demographics in the study Counties of Liberia

Table 4.1 A brief summary of the participant's demographic information

		Bong	Lofa	Grand Gendeh	Nimba
Gender	Male	82.8	75.9	53.3	92.6
	Female	17.2	54.1	46.7	7.4
Literacy	No formal education	31	13.8	16.7	3.7
	Primary	37.9	41.4	46.7	44.4
	Secondary	27.6	44.8	36.7	29.9
	Vocational training	3.4	0.0	0.0	22.2
	University	0.0	0.0	0.0	3.7
Pond Type	Paddy	31.1	33.3	2.2	33.3
	Barrage	35	25	0	40
	Concrete	23.8	14.3	47.6	14.3
	Pit	10.3	20.7	65.5	3.4
Types of Fish	Cat fish	11.5	0	0	15.8
	Tilapia mossambicus	11.5	26.1	9.1	42.1
	Silver tilapia	0	0	31.8	0
	Tilapia zilli	23.1	13	22.7	52.6
	Heterotis niloticus	61.5	60.9	36.4	15.8

All the figure are expressed as percentages

A total of 120 farmers, 30 from each county were involved in the survey. Overall, the men form 75.7% of all the fish farmers in the study counties (Table 4.1). This percentage differ from one county to another at 82.8% (Bong), 75.9% (Lofa), 53.3% (Grand Gedeh), 92.6% (Nimba). The only exception of dominance was Grand Gedeh where a near gender parity was observed with men being 53.3% and women 46.7%. Fish farming is a male dominated activity as demonstrated by this study (Figure 4.1). The highest gender disparity was recorded in Nimba where males formed 92.6% and women being 7.4%.

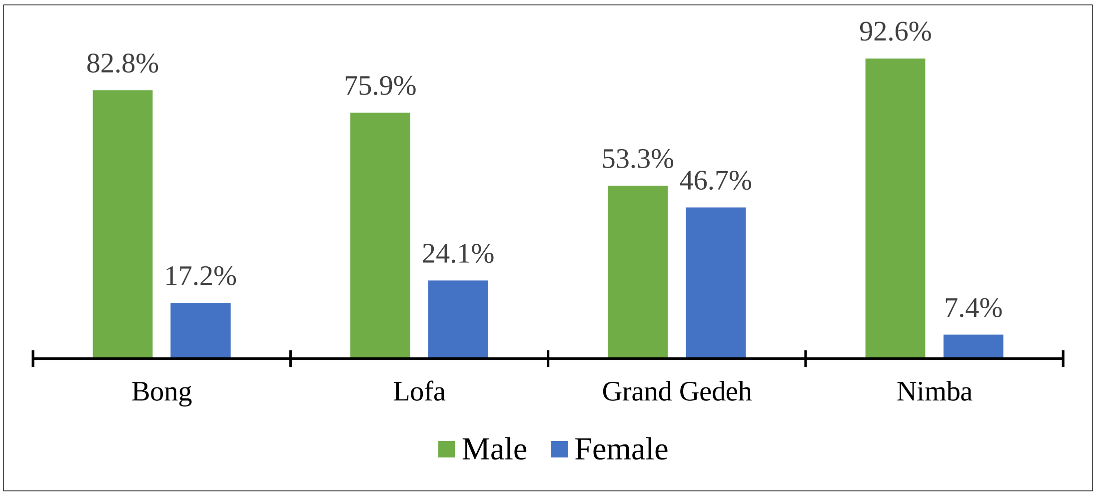

Figure 4.1: Gender composition of fish farmers in Bong, Lofa Grand Gedeh and Nimba counties, Liberia

The level of literacy showed significant variation among the study Counties,($\chi2$ (12) = 27.48, $p < 0.05$) (Figure 4.2). Among the farmers sampled from Bong' county, 31% did not have any formal education representing the highest proportion among all the counties in this regard (Figure 4.2). On the other hand, only 3.7% of the fish farmers sampled from Nimba was reported to have received any form of formal education. Further, university graduates were only recorded in Nimba County with 3.7% of the interviewed farmers having received the university education. Even though the number of the farmers with no formal education in Grand Gedeh and Lofa was about half of that found in Nimba, the highest level of formal education attained was secondary school level. In Bong' the highest level of education was college education with 3.4% reported to possess vocational education level.

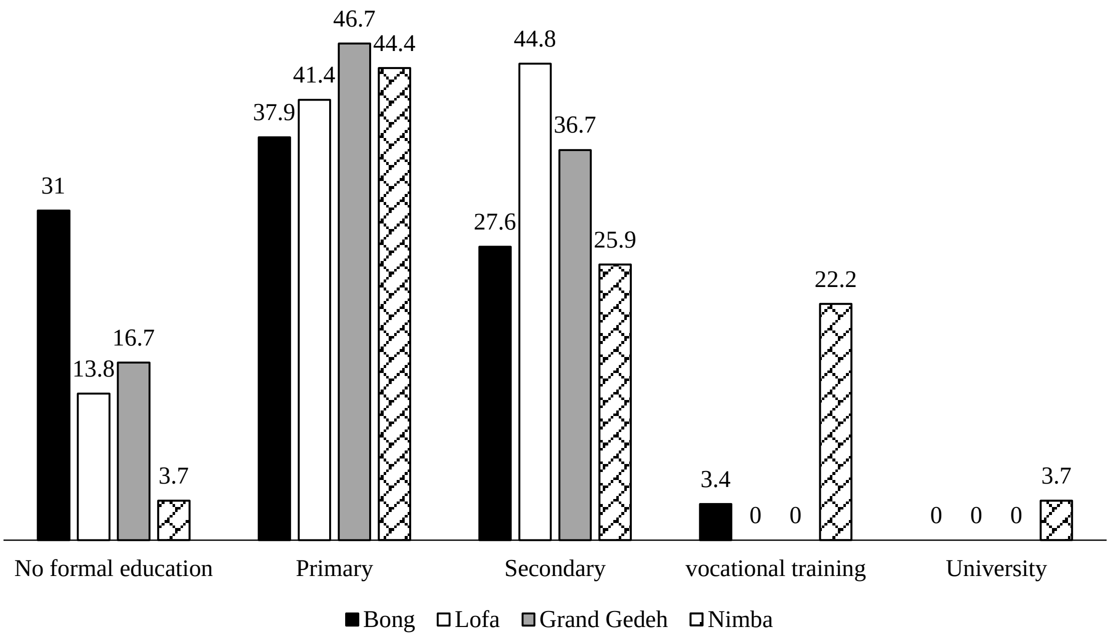

Figure 4.2: The percentage of farmers with different levels of formal education received

Nimba particularly stood out among the study counties due to her relatively high number of farmers (22%) who attained vocational level of education. Overall, most of the fish farmers interviewed during this study had achieved primary school level of education.

Fish farming in Liberia is primarily practiced by people above 35 years old (figure 4.3). The percentage ratio of the farmers above: below 35 years was as follows, Bong-82:18, River Gee-100, Lofa-75.9:24.1, Grapolu-100, and Nimba-95:5. Overall, the farmers above 35 years were 81.6%.

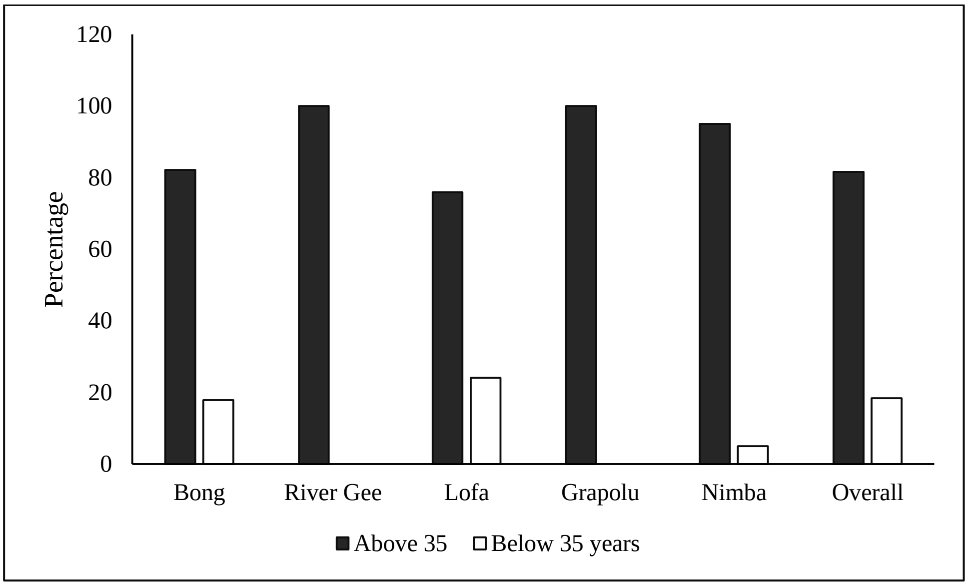

Figure 4.3: Age Distribution of Farmers by County: Above and Below 35 Years

4.1.2 Types of available aquaculture facilities

The types of ponds identified among the farmers were, paddy pond, barrage pond, concrete pond and barrage pond. Paddy pond was common in all the counties except for Grand Gedeh where only 2.2% of the respondents used it (Figure 4.4). Barrage pond was not found in Grand Gedeh. Concrete ponds and pit pond were most common in Grand Gedeh making 47.6% and 65.5% respectively. Nimba had the least number of pit ponds (3.4%). The proportions of the different types of ponds significantly differed from one county to another, ($\chi 2$ (12) = 18.21, $p < 0.05$) (Figure 4.4).

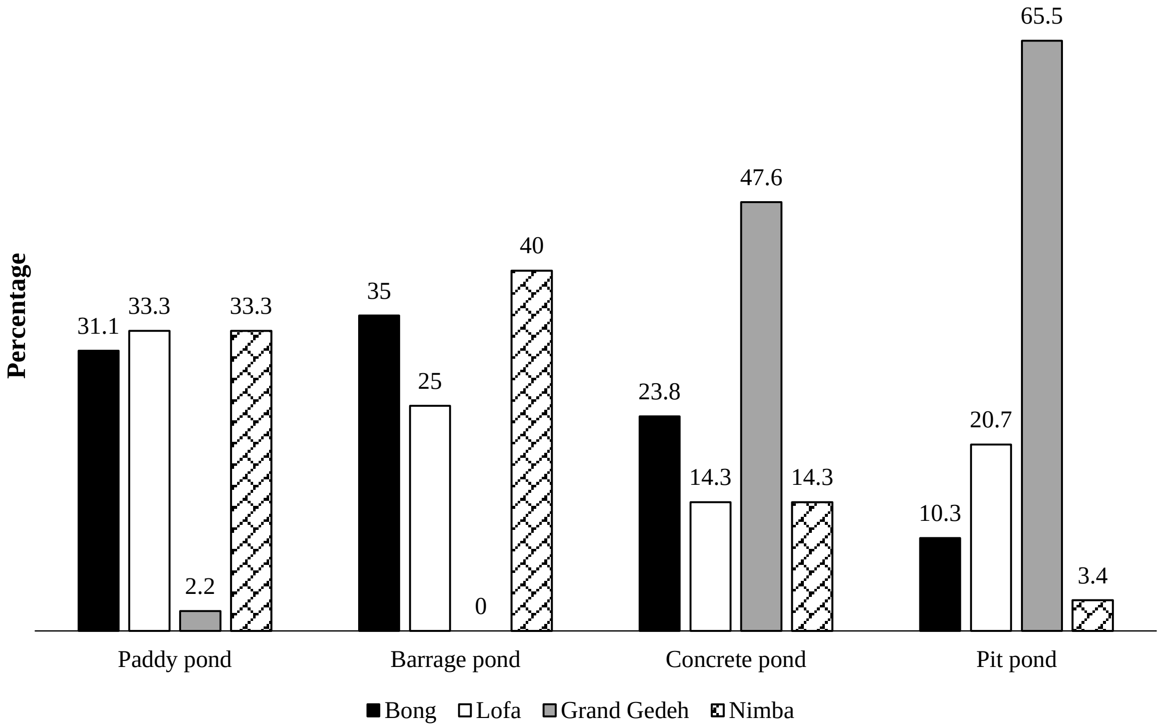

Figure 4.4: The percentage of different types of pond among the four counties in Liberia

4.1.3 Fish pond sizes and their influence on fish growth

Overall paddy pond is the most common aquaculture facility with a total area of 1531.1 m^2 (36%) closely followed by barrage pond with a total area of 1503.7 m^2 (36%) (Figure 4.5). Pit ponds are the least utilized with only a total of 478.6 m^2 used among all the sampled farmers. The pond sizes varied significantly Kruskal Wallis (KW); $\chi 2$ (3) = 42.812, $p < 0.001$.

The study also established a significant positive correlation between the size of the ponds and the yields of *O. niloticus* (R^2= 0.72, p=0.001) (Figure 4.6 and Table 4.2).

Table 4.2: Table Showing the Correlation between Pond Size and Yield.

	Pond size (m^2)	***Yield***
Pond size (meter squares)	1	
Yield	0.718646	1

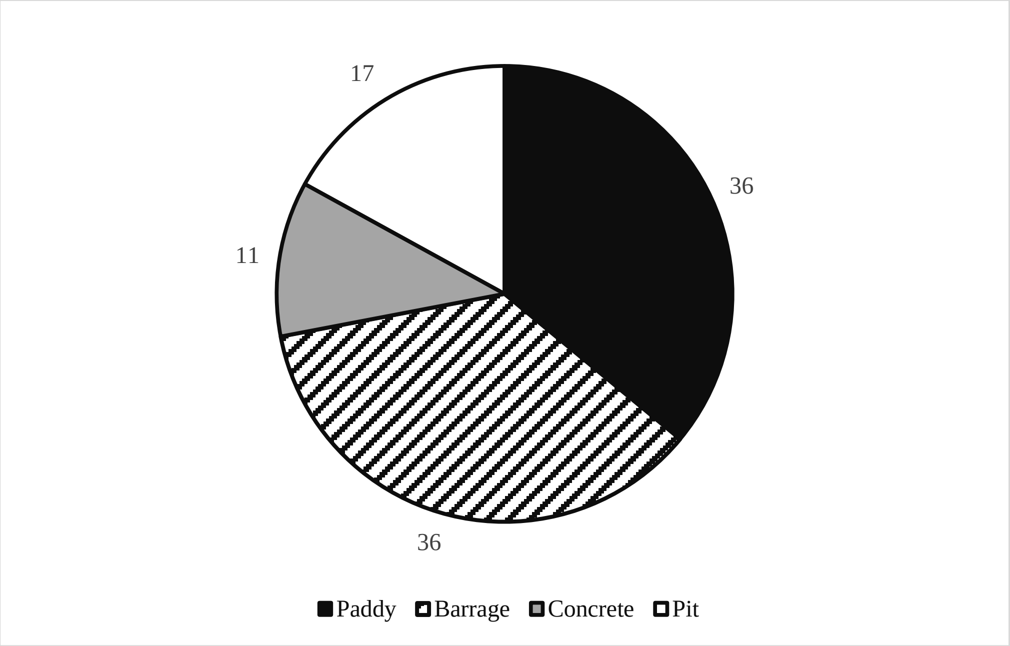

Figure 4.5: Percentage (%) the total area of the various types of ponds in the sampled counties of Liberia. Barrage pond and Pit pond are the most common.

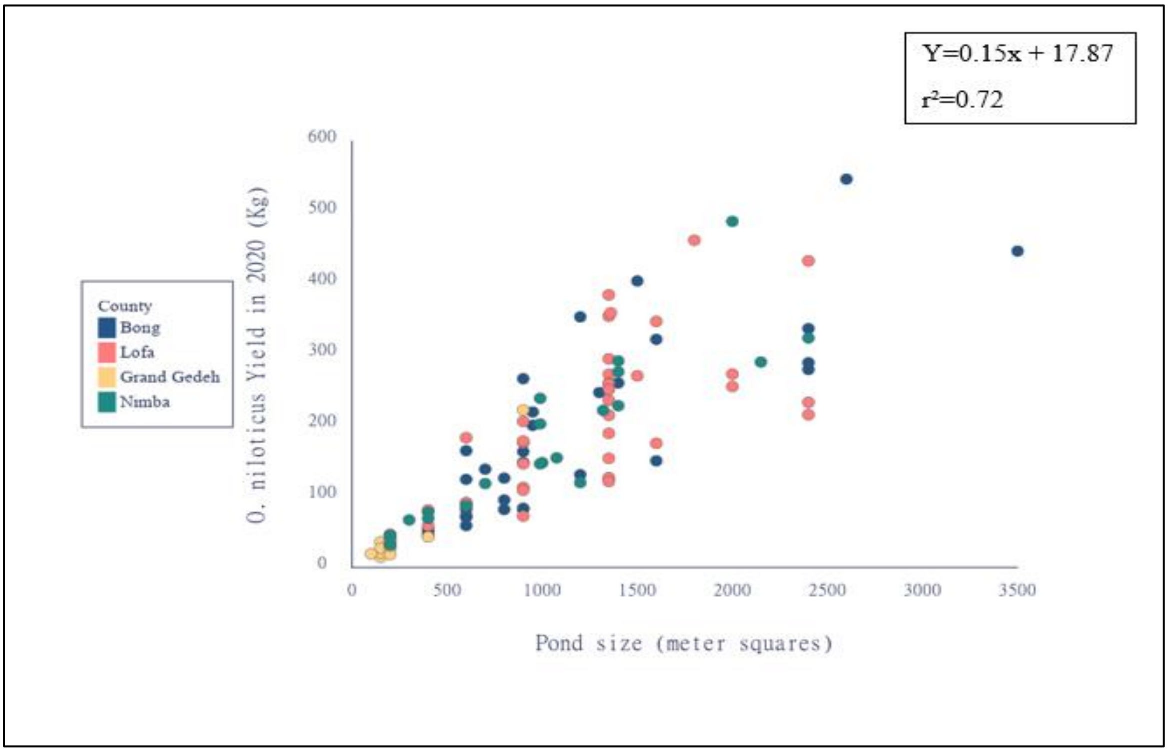

Figure 4.6: Relationship between pond size and the yield of O. niloticus in the study Counties of Liberia

4.1.3 Types of Fish reared in the studied counties

There were also other types of fish species reared by the farmers apart from *O. niloticus.* The other species of fish identified during this study were *Tilapia mossambicus* (21.1%), *Tilapia Zilli* (26.7%), *Heterotis niloticus* (45.6%), and catfish (*Clarias gariepinus*) (6.7%).

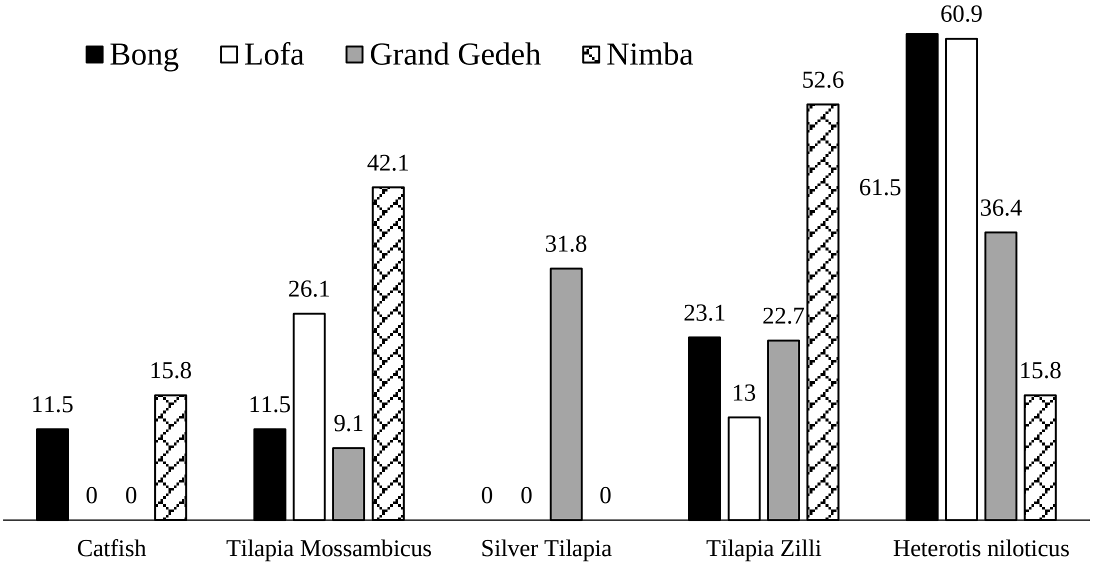

Figure 4.7: The percentage proportions of fish species reared by the farmers in the selected counties of Liberia. This is with the exception of *O. niloticus*.

The graph above (Figure 4.7) shows the other types of fish that are reared in each county. *Tilapia mossambicus*, *Tilapia zilli,* and *Heterotis niloticus* are reared in all the counties under study. Catfish is only reared in Bong and Nimba counties while silver tilapia is only reared in Grand Gedeh. *Heterotis niloticus* is the other most popular type of fish apart from *O. niloticus.*

4.1.4 Types of feeds used by the *O. niloticus* farmers

Generally, locally-made fish feeds are primarily utilized by 67.2% of the fish farmers, with 32.8% of the farmers using blends of commercial feeds and their own-made fish feeds.

However the type of feeds varies among the counties. Locally manufactured feeds were used majorly in Bong County. Figure 4.8 below displays a more detailed information on the responses by the farmers. It is only in Lofa County where the household left overs formed the main part of the fish feeds. In Grand Gedeh County, most of the farmers use imported commercial feeds. Similar to Bong' county, locally made feeds were the main types of feed in Nimba County.

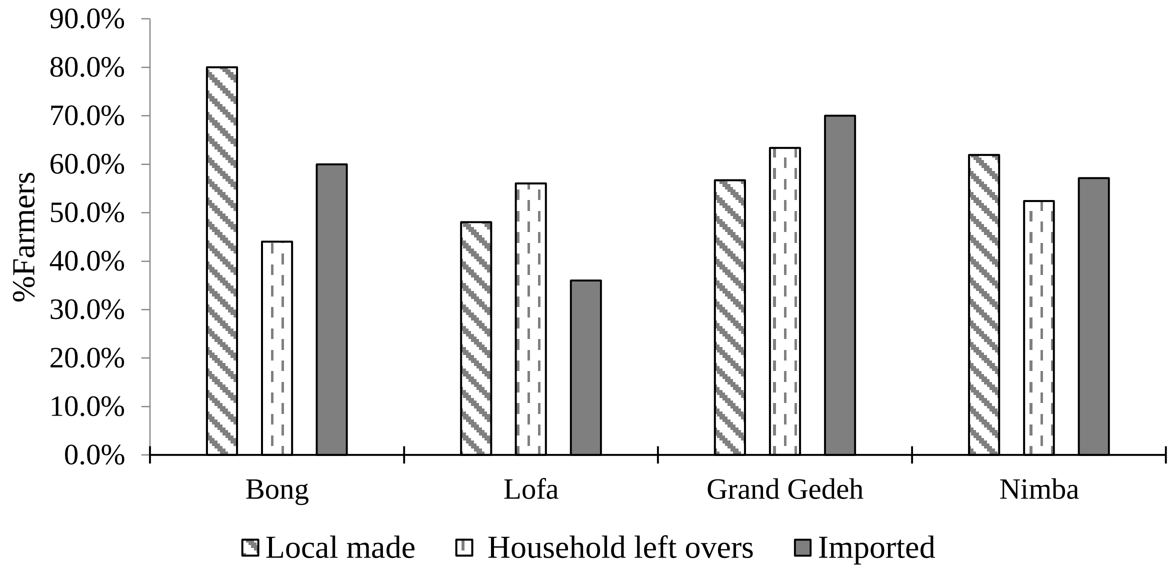

Figure 4.8: Percentage proportions of types of the fish feeds used in the four counties selected for this study.

Farmers from Grand Gedeh County use more commercial feeds more than any the local feeds. Lofa on the other hand, majorly utilize the household waste as feeds.

From the study, it was established that farmers use agro-industry-based by-products as their main source of local feeds. The feeds are either fed to fish as a single ingredient or used as an ingredient in own formulated feeds. The commonly used agro-industry based wastes included; rice bran, palm kernel, wheat bran, corn, fishmeal, and associated blends.

Table 4.3: Amounts of crude proteins in the commonly used agro-industry feeds in Liberia

Feed type	Ingredient	Nimba	Bong	G.G	Lofa
Single-ingredient feeds	Rice bran	3.7±0.03	4.0±0.01	2.9±0.04	2.3±0.07
	Wheat bran	16.4±1.5	18.1±2.1	17.0±2.3	-
	Corn	6.3±0.1	6.2±0.2	5.1±0.09	4.9±0.04
	Palm kernel cake	14.8±1.4	-	13.2±1.6	18.4±2.3
	Fish meal	63.85±1.3	52.65±3.2	62.68±4.4	49.61±3.6
Blended feeds	Ricebran + soybean	8.26±0.4	8.81±0.5	7.65±0.2	9.2±0.1
	Ricebran + Cowpea	9.45±0.9	9.33±0.2	-	10.2±0.8
	Ricebran + Corn	6.99±2.6	5.24±0.7	5.86±0.1	7.12±0.5
	Ricebran + Fishmeal	15.27±1.6	14.87±1.8	15.69±1.5	18.54±1.2
	Ricebran + Palm kernel cake + Fishmeal	19.34±7.8	-	20.01±7.5	17.65±6.2

Key: G.G Grand-Gedeh

The amount of crude protein varied significantly (P = 0.03) in both single and blended feeds in all of counties under study (Table 4.3). For instance, rice bran, an extensively utilized fish feed ingredient in all the counties under investigation, was found to have an average crude protein content of 3.7%, 4.0%, 2.9%, and 2.3%in Nimba, Bong, Grand Gedeh, and Lofa, respectively. The range in the quantity of protein in the feeds was magnified in the blended feeds. Results from the single ingredient feeds, wheat bran showed highest range with the lowest quantity recorded as 14% and the highest as 18.1% a difference of about 4%. On the other hand, blended feeds comprising rice bran and fishmeal had the lowest crude protein percentage as low as 5.1% and the highest as 32.2%. This is a marked difference of 27%.

4.1.5 Proximate analysis of feeds

Proximate composition of the five tests feeds is presented in table 4.4. Among the important dietary nutrients that varied across the diets include percent crude protein (%CP), crude fiber, ash content and lipids. The farm-made feeds (F1 and F2) had low percent crude protein of less than 15% compared to research (30.3%) and commercially formulated diets (Table 4.2). Similarly, crude lipids were high in researcher and commercially formulated feeds, while those from the farmer-made feeds were incredibly low. In contrast to crude protein and lipids, farmer formulated feeds recorded high contents of crude fiber and ash content. However, the research feeds also showed very high amounts of the ash content and ranked second in the current experiment just behind farmer-made feed 1 (F1).

Table 4.4: Proximate composition of fish diets selected for O. niloticus growth study

Feed type	Crude Protein (%)	Moisture content	Dry matter	Crude fiber	Ash content	Lipids
RF	30.7	6.3	93.6	9.1	34.3	14.2
C1	31.9	9.2	90.8	11.1	4.9	17.1
C2	29.7	9.7	90.2	14.6	12.0	11.4
F 1	12.0	5.7	94.2	22.3	39.6	2.1
F2	9.0	2.9	97.1	16.0	22.0	3.9
P	**0.00**	**0.00**	**0.82**	**0.00**	**0.00**	**0.00**

Commercial Feed 1 (C1) had the lowest amount of the ash content at 4.9%. The difference in the amount of ash content range from from a low of 4.9 to a high of 34.31. Research Feeds (RF) had the lowest amount of crude fiber (9.09) while the F1 had the highest amount at 22.35. Among all the nutrients tested in the current proximate analysis, dry matter did not show great variation among the different feed types. The commercial feeds, however, recorded the lowest of all (C1: 90.8, C2: 90.22) while the highest value was recorded from F2 at 97.09. Commercial feeds had the highest moisture content, the only characteristic where these feed types top. On the other hand the F2 had the lowest moisture content, the only other feature to record the lowest amount apart from the crude protein content.

4.2 Impact of the various types of Feeds on the growth performance of *O. niloticus*

4.2.1 Impact of the various types of Feeds on Weights of Fish

Growth performance indicators assessed were weight gain, specific growth rate (SGR), and food conversion ratio (FCR). From the study, the best weight gain was 163.1 g obtained from the fish feed with Research Feeds (RF) (table 4.5). Commercial Feed 1 (C1) was the second best with a weight gain of 159.2 g. These two types of feeds were significantly different (P = 0.02) from the rest. The lowest weight gain was recorded from (F2), which was 72.0 g. Generally, the farmers’ feeds had the lowest performance on fish growth.

Table 4.5: Growth parameters of O. niloticus under 5 treatments for 6 months. Values represent the means of the replicates ± SD

	Treatments					
Growth Parameters	**C1**	**C2**	**F1**	**F2**	**RF**	***P***
Initial mean weight (g)	13.2±1.3	14.6±1.5	11.4±1.1	12.6±1.3	12.2±1.2	0.63
Final mean weight (g)	172.3±8.6[a]	108.9±5.4[b]	94.6±4.7[c]	84.7±5.6[c]	175.3±9.7[a]	0.00
Mean weight gain (g)	159.2±7.3[a]	94.2±5.1[b]	83.1±5.3[bc]	72.0±4.6[c]	163.1±6.8[a]	0.00
Average daily weight gain	0.9±0.04[a]	0.6±0.03[b]	0.5±0.02[c]	0.4±0.01[c]	0.9±0.03[a]	0.00
Average SGR	1.0±0.4[a]	0.6±0.2[b]	0.5±0.2[b]	0.5±0.2[b]	1.0±0.4[a]	0.01
Average FCR	1.9±0.01[a]	3.1±0.3[b]	2.7±0.2[b]	3.8±0.3[b]	1.9±0.02[c]	0.00

Key: C: Commercial Feeds, F: Farmer Feeds, RF : Research Feed SGR: Specific Growth Rate, FCR: Food Conversion Ratio.

Based on weight, C1 and RF were the best performing. Farmers' feeds were the feeds in terms of growth. The commercial diet 2 (C2) performed better than the farmers' feeds.

Assessment of the Specific growth rate of the fish. The best performance was from the RF and C1. Fish fed with RF attained an average daily weight gain of 0.97 g/d while those fed with C1 attained 0.95 g/d. The C2 diet resulted in weight gain at 0.56 g/d while F1 and F2 attained a mean daily weight gain of 0.49 g and 0.43 g, respectively.

Initially, all the feeds did not appear to have any differences in the weight gained by the fish (*p*=0.63). However, at 14 days there was a marked the point of departure for the farmers feeds as the performance deviated sharply from the rest of the feeds. Up to the 28th day the feed performance of C1, C2, and RF were not significantly different. Fish fed with the C2 diet had the best response. However, as the growth performance of the fish fed with C1 and RF were beginning to peak, the ones fed with C2 feed began to drop at this point. A very early peak in the weight gain was recorded between 28th and 56th days for the RF feed. The highest peak in the weight gain was 27 g recorded on the 42nd day of the RF feed. The weight gain by the fish fed with commercial feed 1 peaked later between 42nd and the 70th day. For C1 feed, the highest peak occurred on the 56th day at 24 g. After the peaks observed for the C1 and RF, there was a steady drop in the weight gain.

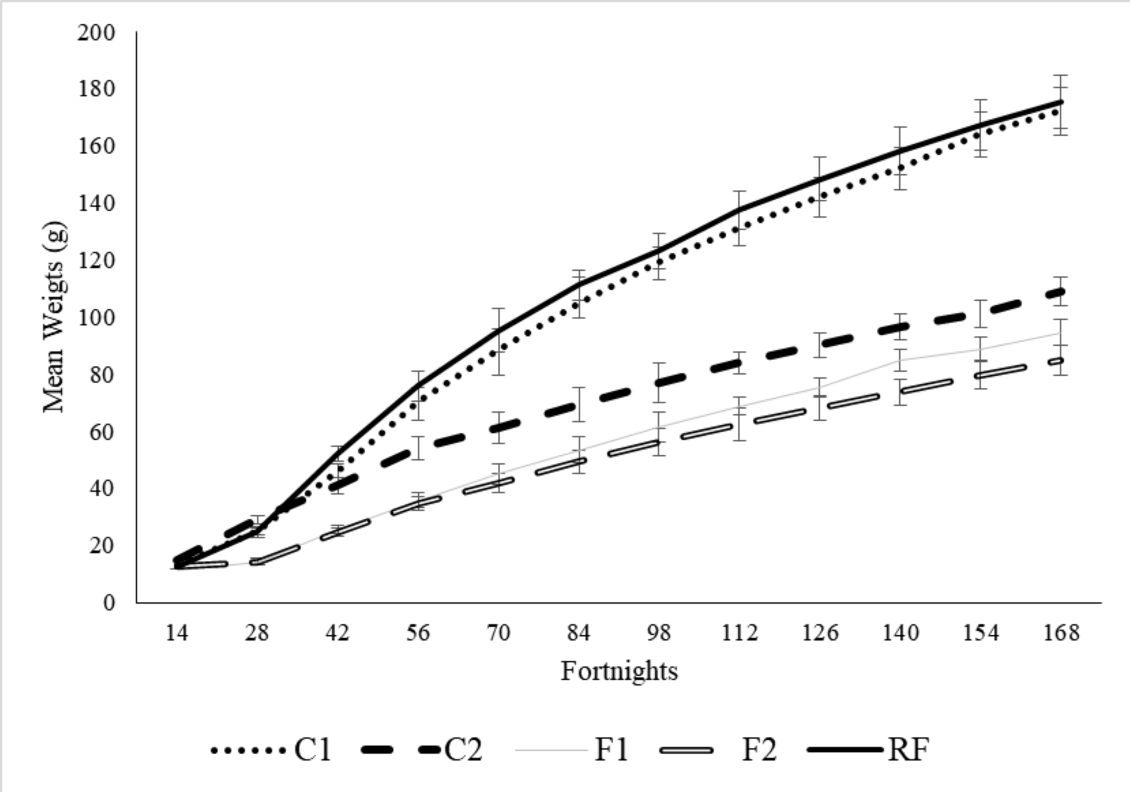

Figure 4.9: Growth of the fish fed with the five treatments for 168 days. Each plotted point represent the mean weight of the fish recorded on that fortnight

Figure 4.9 shows that the best feeds were Commercial Feed 1 (CF1) and the Research Feeds (RF1 and RF2) followed by Commercial feed 2(CF2) and finally the farm-made feeds (F1 and F2). As evidenced in Figure 4.9, farmers' feeds first departed from the rest of the feeds very early after the second week. C2 departed from C1 and RF in the 6^{th} week. From this point, the growth performance of the RF and C1 did not significantly differ and the same was true for both the farmers' feeds. What can also be clearly gathered from the graph (Figure 4.9) is that highest weights had not yet been attained by all the fish regardless of the treatment by the time the experiment was terminated.

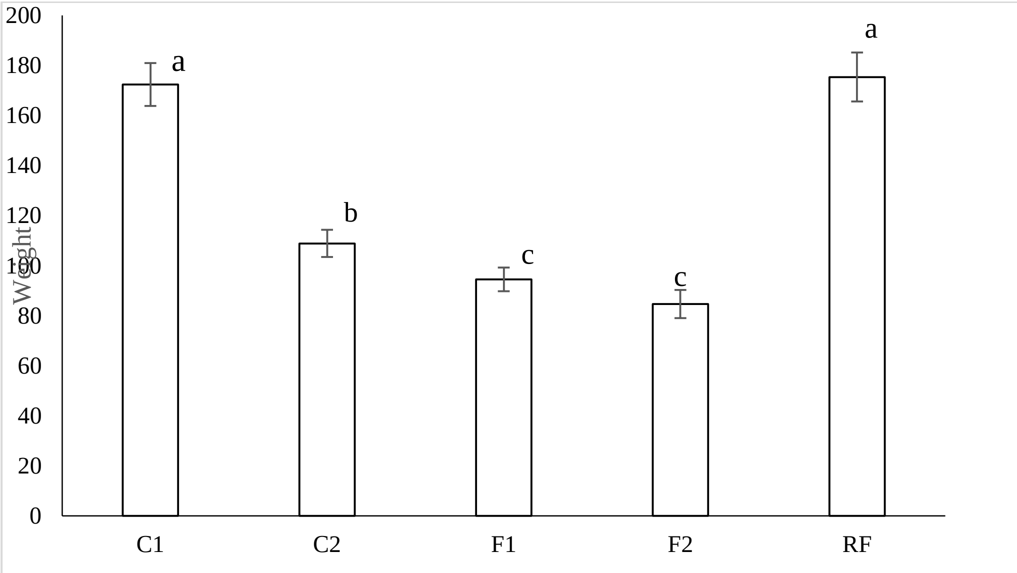

Figure 4.10: Final Mean weights of fish fed on different diets. Each bar represent the average value of all the replicates from each of the treatments. The bars with the same letters represent values that are not significantly different (P < 0.05). (n = 15)

At the end of the experiment, the fish fed with RF reached the highest mean weight of 175 g followed very closely by C1 at 172 g (Figure 4.10). These two feeds showed were significantly different from the rest of the feeds ($P = 7\times10^{-5}$). The fish fed with C2 had an average weight of 108g. Farm-made feeds resulted in lowest average weights at 84 g and 94 g for F2 and F1 respectively and had no significant difference among them.

4.2.2 Impact of the various types of feeds on the specific growth rate (SGR)

The highest SGR recorded was 1.955 g recorded from RF on the 42nd day (Figure 4.11), followed by C1 at 1.934 g on the same day. The lowest SGR was recorded on the 168th day as 0.3g from the Commercial Feed 2.

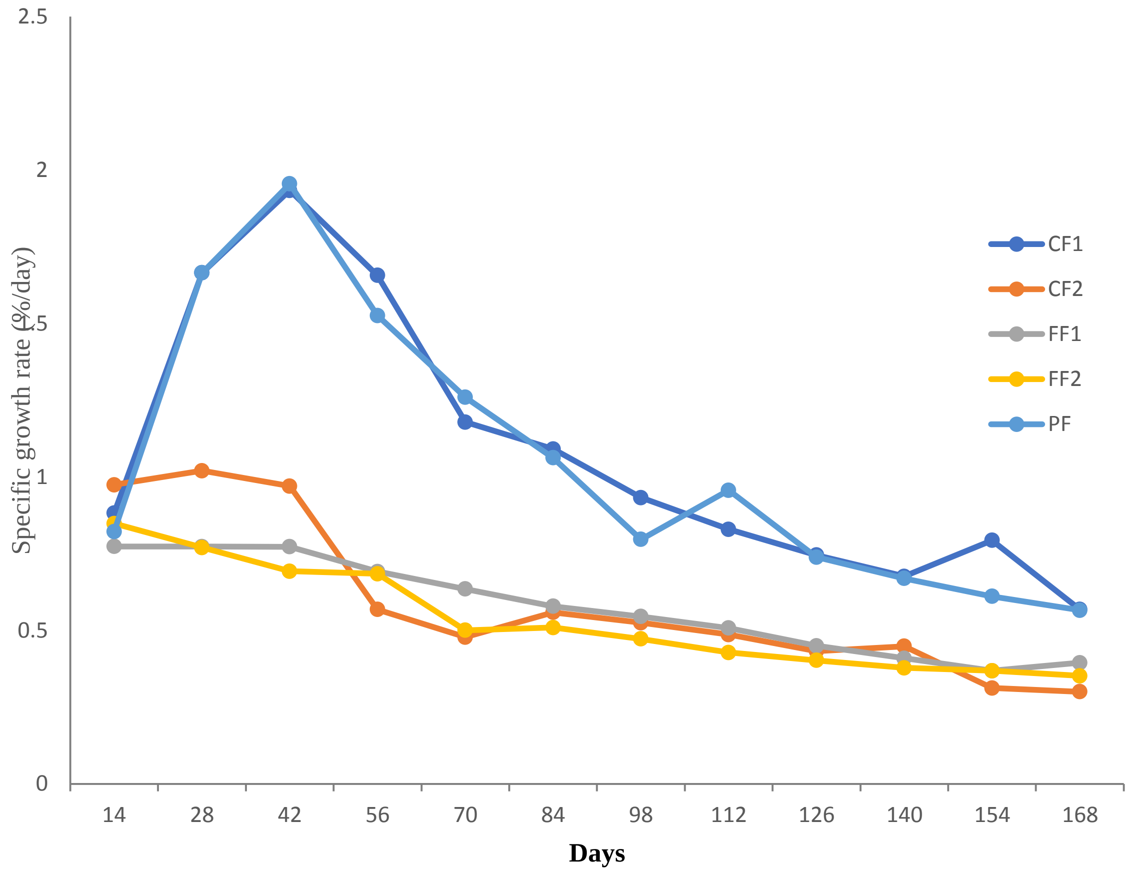

Figure 4.11: Specific Growth Rate of the fish fed with the five types of feeds. Key, C1: Commercial feed 1, 2 (C2): Commercial Feed 2, F1: Farmers' Feed 1, F2: Farmers' Feed 2, RF: Research Feeds.

The highest ranges are 1.39 from RF and 1.37 from C1while the lowest values are 0.58 from F1 and 0.66 from C2, which is evident from the mean specific growth rate ced from figure 4.11 below. The greater the range the greater the positive impact on the growth of the fish.

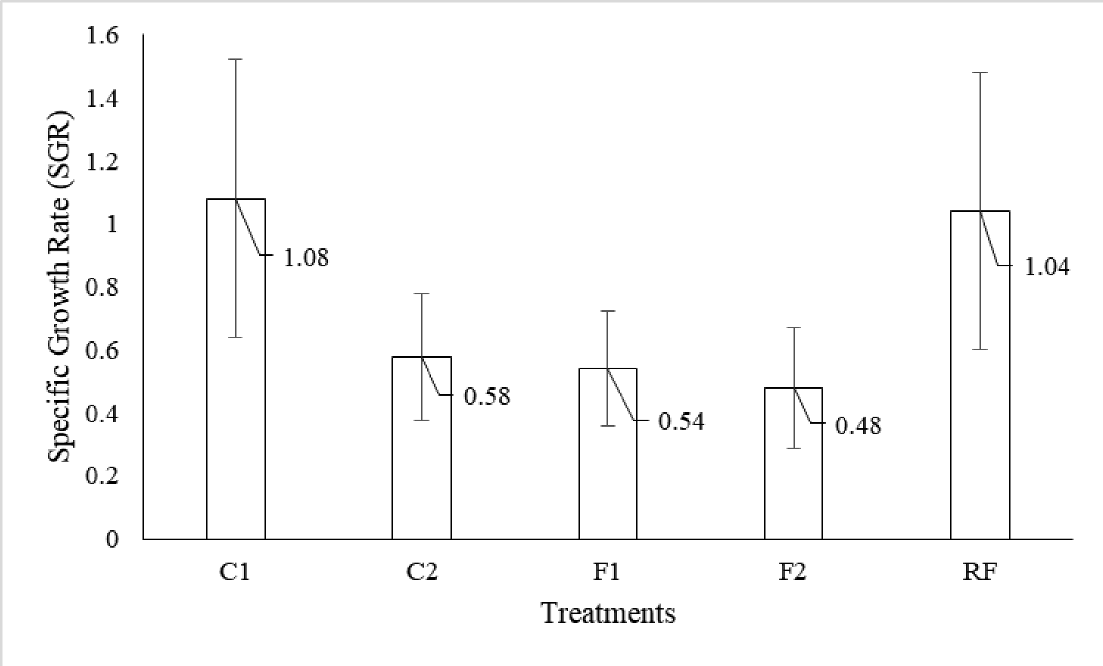

Figure 4.12: Mean specific growth rate (SGR) of the five treatments in the present study. The bars represent the means while the error bars show the standard deviations.

Overall, the SGR was highest in C1 with a mean of 1.08 closely followed by RF with a mean of at 1.04. These two (C1 and RF) were significantly different from the rest of the treatments.

4.2.3 Feed Conversion Ratio

In the present study, the feed conversion ratio (FCR) ranged from 1.03 in C 1 to 3.99 in C 2. Commercial Feed 1 and the Research Feed generally had the lowest values of FCR compared to the rest of the feeds. Both had similar trend looking at the superimposition of the line trend.

Figure 4.13 below shows the average values for the FCR of all the treatments. The performances of the feeds based on FCR differed significantly (P = 0.03). The lowest

Feed Conversion Ratio mean value was obtained from C1 (1.93). The smallest value obtained from C1 was 1.03 on the 28th day while the highest mean value of FCR was 3.99 from F2. With a very minimal deviation, RF had the second smallest FCR mean of 3.3.

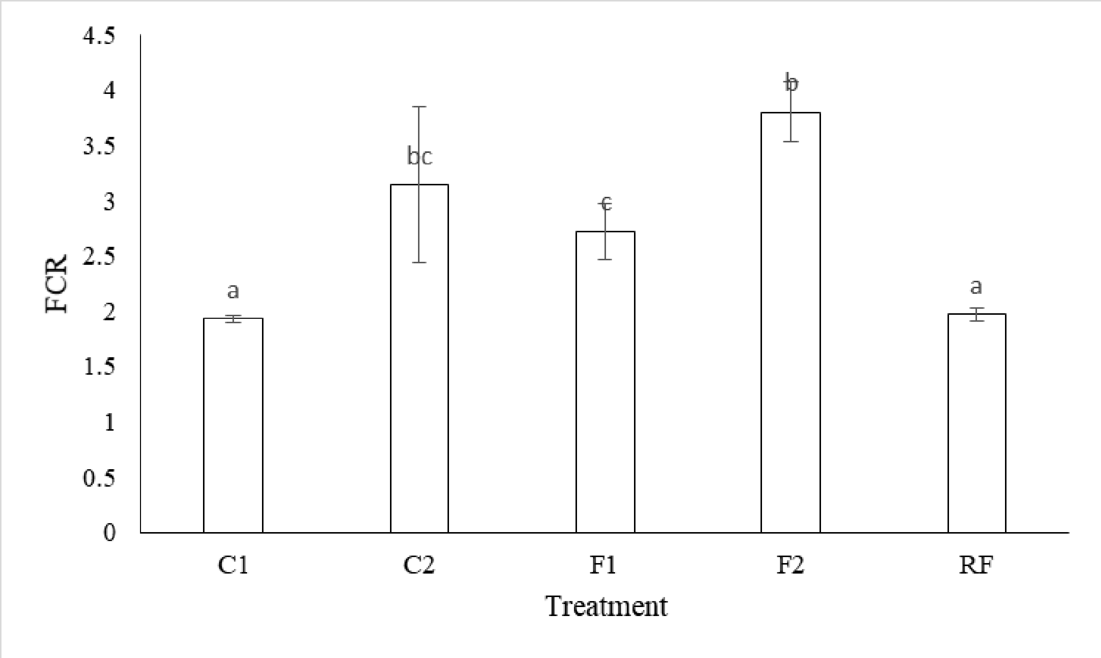

Figure 4.13: Average Feed Conversion Ratios (FCR) of the fish fed with the five types of feeds. The bars followed by the same letters represent FCR values that did not have a significant difference ($p<0.05$)

4.3 Impact of the Feeds on the Water Quality

Analysis for effect of feeds on water quality conducted at the Central Agriculture Research Institute during the study period indicated that feeds did not influence these parameters (Table 4.4). Temperature ranged from a mean of 27.8 ˚C (RF) to 28.9 (C2). Dissolved oxygen ranged from 4.21 mg/L (C2) to 4.66 mg/L (F1). Saturation level of the ponds ranged from 51.1% (RF) to 53.2% (F1). The level of pH ranged from 6.5 (F2) to 7.0 (RF) (Appendix I).

Table 4.6: Values reflecting the water quality parameters recorded from the ponds.

	C1	C2	F1	F2	RF	*P*
Temperature (˚C)	28.70±1.3	28.94±1.8	28.62±1.5	28.6±1.1	27.81±1.2	0.784
D.O(mg/L)	4.52±0.4	4.21±0.3	4.66±0.5	4.46±0.2	4.49±0.3	0.925
Saturation%	51.58±5.6	52.4±4.9	53.16±5.2	52.66±4.3	51.14±4.8	0.698
pH	6.67±0.2	6.73±0.4	6.5±0.3	6.5±0.2	6.95±0.5	0.985

Values represent means ± Standard deviation

4.4 Economic Analysis

Simple economic analysis was done to determine the feed performance. Every cost incurred while rearing *O. niloticus* was the same for all the feeds, the difference only being the cost of the individual feed (Appendices 2 – 6). Therefore, the initial cost remains the same for all the feeds while the operating cost differ from one feed to another.

The best performing feed was found to be C1 registering a fish produce with a profit of USD 259.5 during the entire period (Table 4.5). Another fairly performing feed was the RF where a profit of USD 257.1 can be realized.

Table 4.7: Economic performance of each of the feeds during the experiment

	C1	C2	F1	F2	RF
Profit ($)	259.5	-4.5	-27.25	-69.5	257.1
RoRI (%)	56.41	-0.98	-5.9	-15.12	55.89
RoRO (%)	68.2	-1.2	-7.6	-19.44	64.45

RoRI: Rate of Return on Initial Investment.

RoRO: Rate of Return on Operating Cost.

C1 and RF are the only two profitable feeds in this study at 259.5 and 257.1 respectively (Table 4.5; Figure 4.14). The two diets also resulted in positive returns on investment and operating costs compared to one commercial feed (C2), and both famer feeds (F1 and F2) which retuned negative results (Figure 4.15).

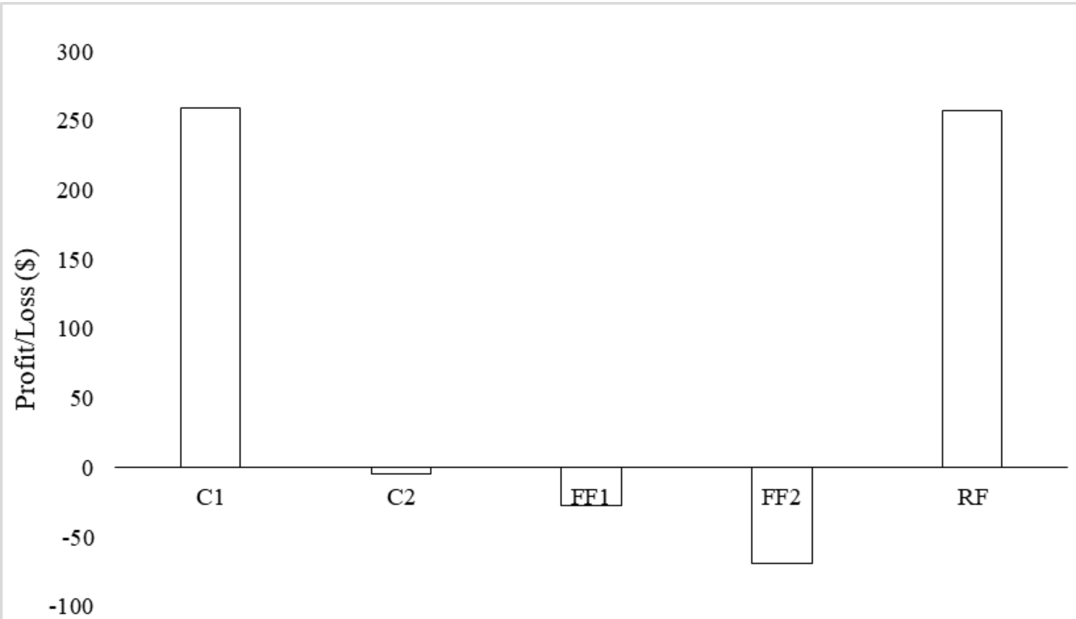

Figure 4.14: Profit and loss graph obtained from the performances of the different feeds.

Rate of return on the initial investment was found to be 56.4% for C1 and 55.9% for RF (Table 4.5). In this regard, C1 and RF are broadly similar in economic performance. However, there was a greater margin in terms of rate of return on operating cost with C1 being 68% and RF Being 64%. Cost of feeds being an operation cost, it was inevitable that C1 was to have a higher rate of return on the operating cost since it was much cheaper than RF.

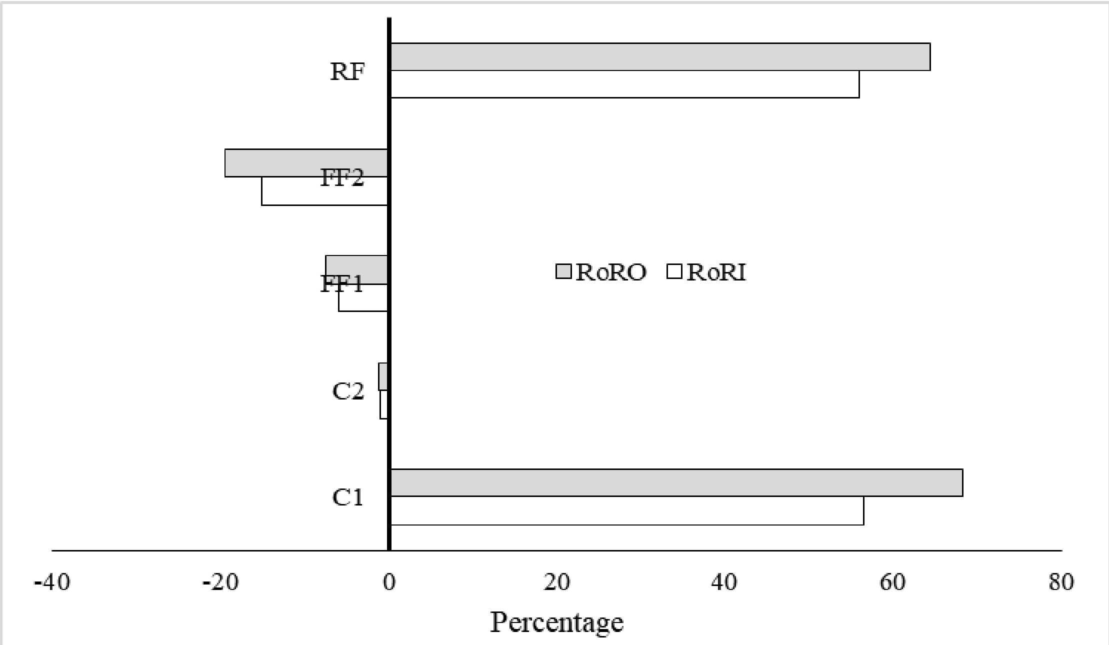

Figure 4.15: A presentation of the Rates of Return on Operating cost (RoRO) and Rates of return on Initial investment.

For the feeds F2, F1, and C2, the feeds have negative rates of return since a farmer runs into losses when using any of these feeds. The magnitude of the losses portrayed by the negative rates of return corresponds to the severity of the losses accrued.

CHAPTER FIVE

DISCUSSION

5.1 Demographic Profile of Fish Farmers

5.1.1 Age of the farmers

The demographic data from the study reveals that a substantial proportion of fish farmers constituting 81.6%, are above the age of 35. Farming in Liberia is majorly dominated by older generation due to the changing life trends where young people prefer white collar jobs in the cities (Dorley, 2022). This finding suggests that aquaculture in Liberia is predominantly driven by experienced individuals who have likely been engaged in fish farming for several years.

The youth (people below the age of 35 years) are known to have negative attitude towards agriculture (Ninson & Brobbey, 2023). Apart from negative perception, youth are faced with inadequate capital, lack of access to land and inadequate technical skills. The high representation of older farmers indicates the existence of a long-standing tradition of fish farming in the region. This critical finding brings to bear two possible consequences to any initiatives aimed at improving aquaculture in Liberia. First due to the apparent long-standing tradition, such traditional knowledge can be leveraged as a valuable resource for sustainable management practices and should be integrated into capacity-building initiatives to benefit the younger generation of fish farmers. On the other hand older farmers have always faced some difficulty in adopting newer technologies (Muzari *et al*., 2012).

The aging trend in the aquaculture workforce also raises concerns about succession planning and the possible potential decline of aquaculture activities in the future. To ensure continuity and growth of the sector, policymakers and stakeholders should encourage and support the involvement of younger individuals in aquaculture through training programs, access to credit, and the relevant technological innovations (Ninson & Brobbey, 2023).

5.1.2 Gender representation

Gender disparities in the aquaculture sector are evident from the study findings, with men dominating the field, while representing 75.7% of all fish farmers. This study concurs with findings obtained from other forms of agriculture like rice farming (Ahn *et al.*, 2020). However, this percentage varies significantly across the sampled counties, suggesting that gender roles in aquaculture are influenced by local socio-economic and cultural factors.

In Bong and Lofa counties, men constitute the majority of fish farmers, with 82.7% and 75.9%, respectively. This could be attributed to prevailing cultural norms that assign fishing and farming roles to men. In contrast, the proportion of male fish farmers is notably lower in Grand Gedeh, where women seem to be more involved, accounting for 53.3% of fish farmers. This trend is influenced by availability of alternative livelihood options and historical involvement of women in fish trading and processing (Thorarensen, 2010). Grand Gedeh is known for other economic activities such as lumbering and mining.

The high proportion of male fish farmers in Nimba, 92.6%, is striking and requires further investigation. Factors such as access to resources, ownership of land, and social norms might play a significant role in determining gender roles in Nimba's aquaculture sector. Policymakers and stakeholders should address gender disparities in aquaculture through targeted interventions that promote women's participation in aquaculture, such as providing training, access to credit, and support for women's cooperatives.

5.1.3 Education levels of fish farmers

Education is a critical factor influencing the adoption of modern and sustainable aquaculture practices. The study findings reveal a diverse educational landscape among fish farmers in the sampled counties. A substantial percentage of fish farmers have no formal education, with Bong (31%) and Grand Gedeh (16.9%) having higher proportions in this category. This finding corroborates that of (Dorley *et al*., 2022) where farmers were found to have at least primary level of formal education. The limited access to formal education in these regions could hinder the adoption of advanced aquaculture technologies and best practices (Adesina & Baidu-Forson, 1995). Addressing this gap requires a multifaceted approach, including the establishment of adult education programs, promoting vocational training centers, and integrating literacy and numeracy education into aquaculture extension services.

Primary education appears to be the most common level of education among fish farmers, with Lofa (41.7%) and Grand Gedeh (46.7%) exhibiting the highest proportions in this category. Bong (37.9%) and Nimba (44.4%) also have significant percentages of fish farmers with primary education. While primary education provides a foundation for learning, it may not be sufficient to address the complexities of modern aquaculture practices (Uaiene, 2011). Policymakers and stakeholders should prioritize enhancing the quality of primary education while offering continuous training and capacity-building programs to bridge the knowledge gap.

Secondary education levels vary among the counties, with Lofa (44.8%) having the highest proportion of fish farmers with this level of education. Bong (27.6%), Grand Gedeh (36.7%), and Nimba (25.9%) also show some representation of fish farmers with secondary education. The presence of fish farmers with secondary education is encouraging, as individuals with this level of education are more likely to adapt to new technologies and market trends easily (Uaiene, 2011).

Vocational training appears to be scarce among fish farmers, with Bong (3.4%) being the only county with a notable percentage in this category. The absence of vocational training opportunities in Lofa, Grand Gedeh, and Nimba raises concerns about the potential limitations faced by farmers in adopting modern aquaculture techniques. Vocational training programs tailored to the specific needs of fish farmers, such as fish health management, feed formulation, and pond management, could greatly enhance the sector's productivity and sustainability.

Notably, only Nimba had a small percentage (3.7%) of fish farmers with university-level education. The other counties had no representation of farmers with this level of education. This finding highlights the need for enhanced access to higher education and specialized training for fish farmers across Liberia to drive innovation and sustainable growth in the aquaculture sector. Universities and research institutions should collaborate with the government and private sector to design targeted training programs, conduct research on aquaculture challenges, and develop locally relevant solutions.

5.1.4 Types of aquaculture

The assessment of aquaculture practices among fish farmers in the sampled counties of Bong, Lofa, Grand Gedeh, and Nimba provides valuable insights into the prevailing aquaculture methods and their distribution across different regions in Liberia. The study found that the majority of farmers practice subsistence aquaculture (79.2%), with the rest engaging in semi-commercial fish farming. This is particularly so for a country where a larger population prefer sea fish compared to fresh water fish (Wuor & Mabon, 2022). Therefore majority of tilapia farmers practice it for subsistence causes. Additionally, the study highlights the dominance of pond culture, with a small proportion of farmers practicing cage culture and tank culture. Dominance of pond culture also mirrors many parts of sub-Saharan Africa (Ragasa *et al*., 2022).

The high prevalence of subsistence aquaculture among the farmers shows that fish farming in Liberia is primarily driven by the need for household consumption and local markets. As earlier mentioned, Liberians prefer sea fish as compared to fish from inland waters. Subsistence aquaculture provides an important source of protein and income for rural households, contributing to food security and livelihoods (Kinkela *et al*., 2019). However, this finding also raises questions about the potential limitation for scaling up aquaculture production to meet broader market demands and contribute to the national economy.

The small proportion of farmers engaged in semi-commercial fish farming indicates some level of commercialization of aquaculture in Liberia. Semi-commercial fish farming typically involves a higher level of investment, technology adoption, and engagement in the market (Mapfumo, 2022). Encouraging more farmers to transition from subsistence to semi-commercial fish farming could boost production, create employment opportunities, and contribute to economic growth in the country (Subasinghe, 2017). Policymakers should explore ways to support and incentivize farmers to adopt more commercial-oriented practices, such as providing access to credit, technical assistance, and market linkages. This was done in Zambia with success (Kaminski *et al*., 2018).

5.1.4.1 Predominance of pond culture

The study reveals that the vast majority of fish farmers (98%) practice their fish farming in ponds. Pond culture is a common and traditional method of aquaculture in Liberia that allows for controlled and efficient fish rearing (Kassam & Dorward, 2017). Ponds provide a stable environment for fish growth and can be managed with relatively simple technology, making them accessible to a wide range of farmers (Ragasa *et al*., 2022).

The prevalence of pond culture aligns with the findings from other developing countries, where ponds remain the most common form of aquaculture due to their low investment costs and adaptability to local conditions (Ewoukem *et al*., 2017). However, the marked differences in the types of ponds among the counties (paddy pond, barrage pond, concrete pond, and pit pond) suggest variations in available resources, landscape, and local practices.

Paddy ponds are the most common type in Bong, Lofa, and Nimba counties, accounting for 31.1%, 33.3%, and 33.3% of the ponds, respectively. Paddy ponds are often created within rice fields, using the rice paddies for fish farming during the non-cropping season. The three counties are some of the Liberia’s food basket engaging mainly in rice farming (Dorley *et al*., 2023). This integration of fish and rice farming, known as civiliculture farming, can provide additional income and enhance overall farm productivity (Vongvichith *et al*., 2018). The widespread adoption of paddy ponds in these counties may indicate the potential for promoting integrated farming systems to improve food and income security.

Barrage ponds are more prevalent in Nimba (40%) and Bong (35%) counties. These ponds are typically constructed by impounding water, often using embankments or weirs, and are well-suited for water storage and fish culture (Kool *et al*., 2018). The presence and prevalence of barrage ponds may be linked to local topography and water availability, making them a practical choice for certain regions (Fitzgerald, 2017).

Concrete ponds are more common in Grand Gedeh (47.6%) and less so in Bong (23.8%) and Lofa (14.3%) counties. Concrete ponds are often used for intensive fish culture and can provide greater control over water quality and stocking density (Oladimeji *et al.*, 2017). The higher prevalence of concrete ponds in Grand Gedeh may is due to factors such as available resources, technical knowledge, and proximity to potential markets for premium fish products (Alariefi, 2019).

Pit ponds are the least prevalent among the counties, with the highest percentage found in Grand Gedeh (65.5%) and the lowest in Nimba (3.5%). Pit ponds are typically excavated in the ground and may be more suitable for certain landscapes or areas with limited access to water bodies (Wu *et al*., 2021). The predominance of pit ponds in Grand Gedeh may indicate the importance of such ponds for local fish farming practices in this region.

5.1.5 Types of Fish Reared by Farmers in the selected areas of Liberia

The diversity of fish species reared by farmers in the sampled counties of Bong, Lofa, Grand Gedeh, and Nimba highlights the potential for varied and sustainable aquaculture practices in Liberia. While the present study focused on aquaculture of *O. niloticus* (Nile tilapia), the inclusion of other fish types in the analysis provides valuable insights into the local fish farming landscape and the suitability of different fish species in different pond types.

The study found that catfish rearing was relatively limited, with only Bong (11.5%) and Nimba (15.8%) having some presence of this species. The absence of catfish farming in Lofa and Grand Gedeh is due to local preferences, market demand, and unavailability of fingerlings (Ndome & IU, 2018). Catfish is a popular and fast-growing species with good market potential (Fregene, 2021). Promoting catfish farming in regions where it is not currently practiced could diversify fish production and improve income opportunities for farmers.

Tilapia mossambicus showed a significant presence in Lofa (26.1%) and Nimba (42.1%), with smaller percentages in Bong (11.5%) and Grand Gedeh (9.1%). *Tilapia mossambicus* is a hardy and fast-growing species, well-suited for pond culture (Reddy, 2017). Its prevalence in Lofa and Nimba is attributed to favorable environmental conditions and a history of successful tilapia farming in these regions (Addo *et al*., 2021). Encouraging tilapia mossambicus culture in other counties could lead to increased fish production and further enhance food and nutrition security.

Silver tilapia was predominantly reared in Grand Gedeh (31.8%), indicating its suitability for aquaculture in this region (Dabbadie *et al*., 2019; Mansaray & Simpson, n.d.). The absence of silver tilapia farming in Bong, Lofa, and Nimba indicates that farmers in these counties might not be as familiar with this species or that it may not be as well-adapted to the prevailing environmental conditions (Nguyen & Nguyen, 2019). Providing training and technical support to farmers on the potential benefits of silver tilapia farming could expand its adoption and diversify fish production.

Tilapia zilli demonstrated a strong presence in Nimba (52.6%) and Bong (23.1%), with significant representation in Grand Gedeh (22.7%) as well. This species' adaptability to diverse environmental conditions may explain its widespread cultivation across the sampled counties (Chukwuka *et al*., 2019). *Tilapia zilli* is known for its resilience and ability to tolerate a wide range of water quality parameters, making it an attractive choice for farmers with varying pond types (Abdelsalam *et al*., 2017).

Heterotis niloticus, commonly known as the African butter catfish or the African lungfish, was particularly prevalent in Bong (61.5%) and Lofa (60.9%). This species' high representation in these counties shows its cultural and economic significance to the communities. *Heterotis niloticus* is valued for its high nutritional content and can survive in water bodies with low oxygen levels, making it suitable for pond culture in regions where oxygen availability may be limited (Ashour *et al.*, 2018).

5.1.5.1 Relationship between fish species and pond types

The types of fish species reared by farmers appear to be influenced by the prevailing pond types in each county. For instance, the presence of paddy ponds in Bong, Lofa, and Nimba may have contributed to the higher representation of *Tilapia zilli* in these regions (Abdelsalam *et al*., 2017). *Tilapia zilli* thrives in shallow, nutrient-rich waters, making it well-suited for rice-fish farming systems in paddy ponds. On the other hand, the absence of silver tilapia in Bong, Lofa, and Nimba, where paddy ponds are prevalent, may be related to its preference for deeper waters found in concrete or barrage ponds (Dabbadie *et al*., 2019).

The high representation of *Heterotis niloticus* in Bong and Lofa, both known for their agricultural landscapes, may be linked to the species' association with flooded areas during the rainy season. *Heterotis niloticus* is an air-breathing fish capable of surviving in stagnant or oxygen-depleted waters, making it suitable for pit ponds, which might be common in these regions (Ashour *et al*., 2018).

Similarly, the dominance of concrete ponds in Grand Gedeh appears to favor the rearing of silver tilapia, as this species can thrive in a controlled environment with good water quality. Concrete ponds' presence may also explain the relatively lower representation of *Tilapia mossambicus* in this county, as this species prefers earthen ponds or natural water bodies (Addo *et al*., 2021).

5.2 Types of feeds

The investigation into the types of feeds used by fish farmers in the four counties of Bong, Lofa, Grand Gedeh, and Nimba provides critical insights into the feeding practices employed in semi-intensive aquaculture systems in Liberia. The study identified four main types of feeds used by farmers: own-farm-made feeds, kitchen waste, agroindustry-based wastes, and manufactured feeds. This is also reflected the situation in many sub-Saharan countries as reported in a study by (Ssepuuya *et al*., 2017). The analysis revealed variations in feed preferences and the use of locally available feed resources in each county. Additionally, the study examined the crude protein content of the different feeds, shedding light on their nutritional value and potential implications for fish growth and health.

The study found that 67.2% of fish farmers used locally made feeds, demonstrating their preference for self-sufficiency in feed production. Locally made feeds often consist of various ingredients sourced from the farm or nearby market areas, making them cost-effective and readily accessible to farmers (Fialho *et al*., 2021). The widespread use of locally made feeds indicates the reliance on available resources and traditional knowledge in feed formulation. The dynamics of locally made feeds differ markedly across the counties, with Bong having the highest proportion of farmers (80%) using this feed type. This high adoption rate in Bong can be attributed to the county's agricultural landscape, with farmers having access to a variety of agricultural by-products suitable for fish feed formulation (Witinok-Huber *et al*., 2021). On the other hand, Lofa (48%), Grand Gedeh (56%), and Nimba (61.9%) show relatively lower usage of locally made feeds, suggesting possible limitations in feed ingredient availability or knowledge gaps in feed formulation.

Kitchen waste is commonly used as a supplementary feed in semi-intensive aquaculture systems (Mo *et al*., 2018). It consists of organic waste from households, such as vegetable peels, fruit scraps, and leftovers. The use of kitchen waste as fish feed is a sustainable practice that reduces food waste and provides additional nutrients to the fish (Hua *et al*., 2019). The preference for kitchen waste as fish feed in Grand Gedeh is due to to cultural norms and practices, where fish are often fed with organic kitchen waste, enhancing the circularity of resource utilization (Singh & Chaube, 2021). However, the relatively lower adoption in Bong might indicate a potential opportunity for promoting kitchen waste utilization as fish feed through awareness campaigns and educational programs.

Agroindustry-based feeds are formulated using by-products from agricultural industries, such as rice bran, palm kernel cake, corn, and fish meal. These feeds offer a more balanced nutritional profile and are often used to supplement locally made feeds (De Corato *et al*., 2018). The study found that 32.8% of farmers used blends of imported and their own feeds, reflecting a combination of self-sufficiency and the integration of commercial feed resources. The dynamics of agroindustry-based feeds varied across the counties, with Grand Gedeh having the highest proportion of farmers (70%) using imported feeds. The single biggest factor contributing to this is better market access and higher availability of commercial feed resources in Grand Gedeh. On the other hand, Bong and Nimba had a relatively higher proportion of farmers utilizing commercial feeds, possibly due to their proximity to urban centers with better access to commercial feed suppliers.

5.2.1 Crude protein analysis

The analysis of the crude protein content in the different feeds is essential as protein is a vital nutrient for fish growth and development (Hodar *et al*., 2020). Fish meal, derived from fish processing industries, had the highest crude protein content. Fish meal is a highly digestible and rich protein source, making it a valuable component in fish feed formulations (Agboola *et al*., 2021).

Rice bran is a common by-product of rice milling, and while it contains some protein, its nutritional value is relatively low compared to other feed ingredients (Batson *et al*., 2021). Nevertheless, rice bran is often used as a cost-effective energy source in fish feed formulation (Koegelenberg & Chimphango, 2017).

Among the blended feeds, a blend of rice bran, palm kernel cake, and fishmeal exhibited the highest crude protein content (19.34%). This blend represents a more balanced and nutritious feed option, providing essential proteins and energy for fish growth. In contrast, a blend of rice bran and corn had the lowest crude protein content (7%), indicating its limited protein contribution to the overall diet.

The findings of the study regarding the challenges faced by fish farmers in Liberia provide critical insights into the barriers to successful fish farming operations. The study identified three major challenges: the cost of quality feeds, water pollution, and diseases in fish. These challenges are significant as they directly impact the productivity, profitability, and sustainability of the aquaculture sector in the country. Furthermore, these challenges are not unique to Liberia and are commonly faced by fish farmers in the Sub-Saharan region as well (Adeyemi *et al.*, 2020; Ngarava *et al*., 2023).

The cost of quality feeds emerged as the most prominent challenge cited by fish farmers in the study, with feeds accounting for up to 43% of the overall cost of operations. High feed costs can significantly affect fish farmers' profitability, particularly in semi-intensive aquaculture systems that rely heavily on formulated feeds (Muhala *et al*., 2021). Quality feeds are essential for supporting optimal growth, development, and health of the fish (Dorothy et al., 2018).In many Sub-Saharan countries, the availability of affordable and high-quality fish feeds remains a persistent challenge (Zulhisyam *et al*., 2020). The aquaculture industry in the region heavily relies on commercial feeds, making fish farming costly for small-scale farmers. Commercial feeds can be subject to price fluctuations due to international market dynamics, further increasing production costs for farmers (Udo & Dickson, 2017).

Water pollution was identified as a major challenge by the farmers in the study. Water pollution can arise from various sources, including agricultural runoff, industrial discharges, improper waste disposal and even including feeds and feed waste (Manoj *et al*., 2022). Polluted water adversely affects fish health, growth, and reproduction, and can lead to increased mortality rates and decreased productivity (Boyd & Tucker, 2012). Sub-Saharan Africa faces various environmental challenges, including deforestation, soil erosion, and improper waste management, contributing to water pollution in many regions (Magwaza *et al*., 2017). These environmental issues are not only detrimental to fish farming but also impact the overall ecosystem and biodiversity.

The study found that 18% of fish farmers identified diseases in fish as a major constraint. Disease outbreaks can lead to significant economic losses, reduced fish production, and increased operating costs due to disease management measures and treatments (Wanja *et al*., 2020). Common fish diseases in the region include bacterial infections, parasitic infestations, and viral outbreaks (Tossavi *et al*., 2014). Fish disease management is a complex issue, influenced by various factors such as water quality, nutrition, stocking density, and biosecurity measures (Faye *et al*., 2020). Sub-Saharan African countries share similar disease challenges due to the movement of fish, trade, and the introduction of non-native species (Tossavi *et al*., 2014).

5.3 Effects of feeds on the growth performance of fish

The experiment assessed the fish fed different types of feeds, namely commercial feed 1 (C1), commercial feed 2 (C2), farmers' feed 1 (F1), farmers' feed 2 (F2), and research feed (RF).

The weight gain performance of fish is a crucial indicator of the feed's ability to provide adequate nutrients for growth (Teles *et al*., 2020). The study showed that RF performed exceptionally well, with fish fed RF achieving a weight gain of 163.12g. This significant weight gain points to the fact that the research feed provided the optimal balance of essential nutrients for promoting efficient growth in fish. Further, C1 exhibited relatively good weight gain performances (159.17g) implying that it also contains the necessary nutrients to support fish growth. However, C2's performance was notably lower, suggesting that this specific commercial feed formulation may be lacking essential nutrients or might not be well-suited for *O. niloticus,* species used in the current study. The lowest weight gain performances were observed in fish fed F1 (83.12 g) and F2 (72.03 g). These results highlight the limitations of the farmers' feeds in providing adequate nutrition for optimal fish growth. Indeed, this is a common problem with many farmers’ own formulated feeds in most of sub-Saharan Africa (Das & Mandal, 2022). The inferior performance of F1 and F2 could be attributed to the lack of balanced nutrition or the use of suboptimal feed ingredients in their formulations.

Specific growth rate is a crucial parameter that provides insights into the rate of fish growth over time (Ragasa *et al*., 2018). The study demonstrated that fish fed RF and C1 had the highest SGR values. This indicates that RF and C1 provided the ideal nutritional profile, enabling the fish to achieve maximum growth during this period. In contrast, fish fed F1 and F2 had extremely low SGR values. These low SGR values further emphasize the inadequate nutritional quality of the farmers' feeds (Obiero *et al*., 2019). The poor performance of F1 and F2 in promoting fish growth may be attributed to imbalances in essential nutrients or deficiencies in critical growth-promoting factors (Nestor *et al*., 2023). The occurrence of the peak SGR in C1 and RF around the same period (days 28 to 56) suggests that both commercial feeds may have similar nutritional value during this growth phase. However, the significant difference in SGR values between C1 and C2 indicates that subtle variations in feed formulations can have profound effects on fish growth performance (Obwanga *et a*l., 2020).

The feed conversion ratio is a critical parameter that reflects the efficiency with which fish convert feed into body mass (Munguti *et al*., 2021). A lower FCR value indicates better feed utilization and higher feed efficiency (Soma *et al*., 2023). The study found that C1 had the lowest FCR value and RF had the second lowest) on the 28th day. These results indicate that C1 and RF were the most efficient feeds in terms of feed conversion and utilization during this period. In contrast, C2 exhibited the highest FCR value, indicating poor feed efficiency and a higher feed requirement for fish growth. This can be undesirable as it increases production costs and may indicate inefficiencies in the feeding process. The exceptionally high FCR value for C2 suggests that this commercial feed formulation may be lacking some essential nutrients or may not be suited for *O. niloticus.* Poor-quality feeds with insufficient nutrients, improper formulation, or inadequate digestibility can lead to suboptimal growth and high FCRs. If the feed lacks essential nutrients, the fish may not grow efficiently, leading to increased feed consumption for the same output (Brugere *et al*., 2021). This can be plausible explanation for the difference in performance, that is, the poor performing feeds lack some essential nutrients or are poorly formulated. This is particularly so since the other factors that may cause poor performance have been kept uniform for all the treatments.

The FCR values obtained in this study were much higher than the values expected from feeds of good quality. Even the lowest FCR values obtained were significantly larger than the required threshold. For many commonly farmed fish species, such as tilapia, catfish, and salmon, an FCR of around 1.0 to 1.5 is considered good (Limbu, 2020).These findings emphasize the importance of optimizing feed formulations to enhance feed efficiency and minimize feed wastage in fish farming operations. However other environmental conditions during the study may have contributed to the very high FCR values obtained here. These factors are discussed in the following pages.

5.4 Water quality

The investigation of the effects of different fish feeds on water quality is a critical aspect of aquaculture research. Water quality parameters, such as temperature, dissolved oxygen (D.O), saturation percentage, and pH, play a crucial role in supporting fish health, growth, and overall aquaculture system stability (Benjamin *et al*., 2022). Understanding the impact of different feeds on water quality is essential for sustainable fish farming practices. The findings of this study reveal that none of the tested feeds had adverse effects on water quality, as all the measured parameters remained within acceptable ranges. The water quality parameters assessed were temperature, dissolved oxygen, saturation percentage, .

Temperature is a critical environmental factor that influences fish metabolism, growth, and overall physiological functions (Limbu, 2020). The observed temperature range of 27.8 °C to 28.9 °C falls within the optimal temperature range for the fish species under consideration (Hlordzi *et al*., 2020). The absence of significant fluctuations in water temperature indicates stable pond conditions, which are conducive to fish growth and health. Maintaining suitable water temperature is essential for ensuring optimal feed utilization and nutrient assimilation by fish (Leal *et al*., 2018). Fluctuations or extremes in water temperature can stress fish and affect their feeding behavior, leading to reduced growth rates and potential health issues.

Dissolved oxygen is a critical parameter that directly affects fish respiration and aerobic metabolism. The observed D.O range of 4.2 to 4.6 mg/L indicates sufficient oxygen availability in the water, which is essential for supporting fish survival and growth. Adequate dissolved oxygen levels are vital for promoting fish activity, immune function, and resistance to diseases (Spiliotopoulou *et al*., 2018). Insufficient dissolved oxygen in the water, known as hypoxia, can lead to stress or even mortality in fish. On the other hand, high levels of dissolved oxygen, known as hyperoxia, can also be detrimental to fish health.

Saturation percentage is a measure of the relative concentration of dissolved gases in the water compared to the maximum amount that the water can hold at a given temperature and pressure. The observed saturation percentage range of 51.1% to 53.2% indicates that the water was relatively well-saturated with gases, including oxygen. Maintaining appropriate gas saturation levels is crucial for supporting fish metabolism and overall pond ecosystem health. Under-saturation can lead to reduced oxygen availability, while supersaturation can result in gas bubble disease, which can be harmful to fish. The study's results suggest that the feeds tested did not negatively impact gas saturation levels, ensuring a stable and oxygen-rich aquatic environment.

The pH is a measure of the acidity or alkalinity of the water and is an essential factor influencing fish physiology and the availability of nutrients. The observed pH range of 6.5 to 7.0 falls within the acceptable pH range (6.5-9.0) for the fish species under study. The pH levels within this range support efficient nutrient absorption and enzyme activity in fish. Extreme pH values can have adverse effects on fish, affecting their ion regulation and nutrient utilization (Wang *et al*., 2018). Acidic conditions can lead to increased stress and reduced growth, while alkaline conditions can affect ammonia toxicity and hinder nutrient absorption. The study's findings suggest that the feeds tested did not cause significant shifts in water pH, maintaining a stable and suitable pH range for fish farming. Fish feeds can significantly impact pH levels in aquaculture ponds (Kosemani *et al*., 2014). When fish consume feeds, particularly protein-rich ones, metabolic byproducts like ammonia are released into the water, leading to pH increases as ammonium ions form. Additionally, fish respiration releases carbon dioxide, which can form carbonic acid, lowering pH. Feed particle size and distribution can affect organic matter decomposition and pH variations. The pond's alkalinity and buffering capacity play vital roles in stabilizing pH. Monitoring water quality is crucial, and corrective actions like adjusting feed quantities, enhancing aeration, water exchange, or using pH stabilizers may be needed to maintain optimal pH levels. Understanding these relationships is essential for successful aquaculture management and the health of the fish population.

5.5 Economic analysis

The economic analysis conducted to determine the economic viability of using different fish feeds provides valuable insights into the financial suitability of various feed options for fish farming (Temesgen *et al*., 2019). The analysis considered the cost of production, fish yield, and overall profit generated by each feed. The study revealed that (C1) and (RF) were the most economically profitable choices, leading to positive net profits. On the other hand, Commercial Feed 2 (C2) and both Farmers' Feeds (F1 and F2) resulted in losses, with F2 yielding the greatest loss due to its low fish yield.

The study's results indicate that C1 and RF are the most economically viable feed options for fish farming. The profitability of C1 and RF can be attributed to their superior performance in terms of fish growth, feed conversion efficiency, and overall feed utilization. High feed conversion efficiency and optimal growth rates observed in fish fed C1 and RF translate into higher fish yields, contributing to increased revenue for fish farmers. The relatively lower costs of these feeds and the profits generated further enhance their economic attractiveness. The positive economic performance of C1 and RF supports their continued utilization in fish farming operations.

In contrast to C1 and RF, C2 and both Farmers' Feeds (F1 and F2) resulted in losses during the study period. The study identified F2 as the most financially uneconomical feed choice, primarily due to its low fish yield. The poor performance of F2 in terms of fish growth and conversion efficiency translated into lower fish output, leading to reduced revenue and, ultimately, losses for farmers. Similarly, C2's negative economic performance can be attributed to its suboptimal fish growth and poor feed utilization. The poor feed conversion efficiency observed in fish fed C2 meant that higher quantities of feed were required to achieve the same level of fish growth, increasing the overall cost of production and reducing profitability.

The economic analysis underscores the critical role of feed performance in determining the financial success of fish farming operations. Feeds with superior nutritional composition and balanced formulation, such as C1 and RF, facilitate optimal fish growth and conversion rates. This, in turn, leads to increased fish yield, higher revenue, and improved profitability for farmers. On the other hand, feeds with subpar nutritional content and inadequate formulation, such as C2 and F2, hamper fish growth and efficiency in feed utilization (Wachira *et al*., 2021). The resultant low fish yield and higher feed costs contribute to financial losses for farmers. These findings emphasize the importance of selecting feeds based not only on their cost but also on their ability to support optimal fish growth and economic outcomes.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Fish farming in Liberia is largely a male driven sector. The main aquaculture systems used are barrages, paddies, pits, earthen and concrete ponds with most farmers making their own feeds from locally available ingredients. Nile tilapia (*O. niloticus*) is the species of choice for most farmers. The best growth was in fish fed with the research feeds, attributed to high crude protein levels. The feeds were found to have no effect on water quality. The research and commercial feeds were most profitable feeds for production of *O. niloticus.*

6.2 Recommendations

1. There is need to increase the representation of women and youth in the aquaculture in Liberia.

2. Create awareness on the importance for farmers to use properly formulated feeds that have adequate amounts of protein for production of *O. niloticus* which is the most common fish for aquaculture.

3. Regular monitoring of water quality parameters should be conducted in fish farming facilities to prevent negative impacts on fish.

4. Train farmers on farm record keeping for increased profitability and improved livelihoods.

REFFERENCES

Abdelsalam, M., Elgendy, M. Y., Shaalan, M., Moustafa, M., & Fujino, M. (2017). Rapid identification of pathogenic streptococci isolated from moribund red tilapia (Oreochromis spp.). Acta Veterinaria Hungarica, 65(1), 50–59.

ACTION, I. (2020). World Fisheries and Aquaculture.

Addo, S., Mullah, S., Ofori-Danson, P., Amponsah, S., & Nyarko, J. (2021). Prevalence of parasitic infections on cultured Nile tilapia, Oreochromis niloticus (Linnaeus, 1758) In Bong County, Liberia. Ghana Journal of Science, 62(1), 13–25.

Adeleke, E., & Omafuvbe, B. (2011). Antibiotic resistance of aerobic mesophilic bacteria isolated from poultry faeces. Research Journal of Microbiology, 6(4), 356.

Adesina, A. A., & Baidu-Forson, J. (1995). Farmers' perceptions and adoption of new agricultural technology: Evidence from analysis in Burkina Faso and Guinea, West Africa. Agricultural Economics, 13(1), 1–9.

Adéyèmi, A. D., Kayodé, A. P. P., Chabi, I. B., Odouaro, O. B. O., Nout, M. J., & Linnemann, A. R. (2020). Screening local feed ingredients of Benin, West Africa, for fish feed formulation. Aquaculture Reports, 17, 100386.

Agboola, J. O., Øverland, M., Skrede, A., & Hansen, J. Ø. (2021). Yeast as major protein- rich ingredient in aquafeeds: A review of the implications for aquaculture production. Reviews in Aquaculture, 13(2), 949–970.

Ahn, J., Briers, G., Kibriya, S., & Price, E. (2020). Case studies of female-headed farms and households in Liberia: A comparative analysis of Grand Bassa, Lofa, and Nimba counties. The Journal of Agricultural Education and Extension, 26(1), 19–35.

Akian, D. D., Yao, K., Parmentier, E., Joassard, L., Clota, F., Baroiller, J.-F., Lozano, P., Chatain, B., & Bégout, M.-L. (2020). Acoustic signals produced by Nile tilapia Oreochromis niloticus and black-chinned tilapia Sarotherodon melanotheron during intra-and interspecific pairings. Zoology, 143, 125831.

Aklilu, Y., Little, P. D., Mahmoud, H., & McPeak, J. (2013). Market access and trade issues affecting the drylands in the Horn of Africa. *Brief prepared by a Technical Consortium hosted by CGIAR in partnership with the FAO Investment Centre. Technical Consortium Brief*, *2*.

Alariefi, M. N. (2019). Liberia-AFRICA-P146827-Liberia Youth Opportunities Project-Procurement Plan.

AMA, O. A. G. (2019). EFFECTS OF DOMINANCE HIERARCHIES WITHIN GROUPS ON NILE.

Anani, F. A. (2015). Evaluation of Farm-Made and Commercial Fish Diets for Hapa Culture of Nile Tilapia (Oreochromis Niloticus L.) in Ghana Francis Assogba Anani.

Anetekhai, M. A., Akin-Oriola, G., Aderinola, O., & Akintola, S. (2004). Steps ahead for aquaculture development in Sub-Saharan Africa—The case of Nigeria. Aquaculture, 239(1–4), 237–248.

Arlinghaus, R., Aas, Ø., Alós, J., Arismendi, I., Bower, S., Carle, S., Czarkowski, T., Freire, K. M., Hu, J., & Hunt, L. M. (2021). Global participation in and public attitudes toward recreational fishing: International perspectives and developments. Reviews in Fisheries Science & Aquaculture, 29(1), 58–95.

Ashour, M., Abo-Taleb, H., Abou-Mahmoud, M., & El-Feky, M. (2018). Effect of the integration between plankton natural productivity and environmental assessment of irrigation water, El-Mahmoudia Canal, on aquaculture potential of Oreochromis niloticus. Turkish Journal of Fisheries and Aquatic Sciences, 18(10), 1163–1175.

Atalah, J., & Sanchez-Jerez, P. (2020). Global assessment of ecological risks associated with farmed fish escapes. Global Ecology and Conservation, 21, e00842.

Authman, M. M., Abbas, W. T., & Gaafar, A. Y. (2012). Metals concentrations in Nile tilapia Oreochromis niloticus () from illegal fish farm in Al-Minufiya Province, Egypt, and their effects on some tissues structures. Ecotoxicology and Environmental Safety, 84, 163–172.

Barman, D. (2020). Bioremediation of Waste Waters and Application in Aquaculture-A Mini Review. Research Biotica, 2(1), 20–25.

Bartlett, M. S. (1954). A note on the multiplying factors for various χ 2 approximations. Journal of the Royal Statistical Society. Series B (Methodological), 296–298.

Batson, K. L., Calderón, H. I., Tokach, M. D., Woodworth, J. C., Goodband, R. D., Dritz, S. S., & DeRouchey, J. M. (2021). Effects of feeding diets containing low crude protein and coarse wheat bran as alternatives to zinc oxide in nursery pig diets. Journal of Animal Science, 99(5), skab090.

Behera, B., Pradhan, P., Swaminathan, T., Sood, N., Paria, P., Das, A., Verma, D., Kumar, R., Yadav, M., & Dev, A. (2018). Emergence of tilapia lake virus associated with mortalities of farmed Nile tilapia Oreochromis niloticus (Linnaeus 1758) in India. Aquaculture, 484, 168–174.

Beletew, M., Getahun, A., & Vanhove, M. P. (2016). First report of monogenean flatworms from Lake Tana, Ethiopia: Gill parasites of the commercially important Clarias gariepinus (Teleostei: Clariidae) and Oreochromis niloticus tana (Teleostei: Cichlidae). Parasites & Vectors, 9(1), 1–7.

Belton, B., & Thilsted, S. H. (2014). Fisheries in transition: Food and nutrition security implications for the global South. Global Food Security, 3(1), 59–66.

Benjamin, E. O., Ola, O., & Buchenrieder, G. R. (2022). Feasibility study of a small-scale recirculating aquaculture system for sustainable (Peri-) urban farming in Sub-Saharan Africa: A Nigerian Perspective. Land, 11(11), 2063.

Berge, J. W. (1974). Geology, geochemistry, and origin of the Nimba itabirite and associated rocks, Nimba County, Liberia. *Economic Geology*, *69*(1), 80-92.

Bhateria, R., & Jain, D. (2016). Water quality assessment of lake water: A review. Sustainable Water Resources Management, 2(2), 161–173.

Bills, T. D., Boogaard, M. A., Johnson, D. A., Brege, D. C., Scholefield, R. J., Westman, R. W., & Stephens, B. E. (2003). Development of a pH/alkalinity treatment model for applications of the lampricide TFM to streams tributary to the Great Lakes. *Journal of Great Lakes Research*, *29*, 510-520.

Blasco, F. R., Taylor, E. W., Leite, C. A., Monteiro, D. A., Rantin, F. T., & McKenzie, D. J. (2022). Tolerance of an acute warming challenge declines with body mass in Nile tilapia: Evidence of a link to capacity for oxygen uptake. Journal of Experimental Biology, 225(16), jeb244287.

Boyd, C. E., & Tucker, C. S. (2012). Pond aquaculture water quality management. Springer Science & Business Media.

Brugere, C., Padmakumar, K. P., Leschen, W., & Tocher, D. R. (2021). What influences the intention to adopt aquaculture innovations? Concepts and empirical assessment of fish farmers’ perceptions and beliefs about aquafeed containing non-conventional ingredients. Aquaculture Economics & Management, 25(3), 339–366.

Butt, C. R. M., & Bristow, A. P. J. (2013). Relief inversion in the geomorphological evolution of sub-Saharan West Africa. *Geomorphology*, *185*, 16-26.

Cai, J., Quagrainie, K., & Hishamunda, N. (2017). Social and economic performance of tilapia farming in Africa. FAO Fisheries and Aquaculture Circular, C1130.

Carbonara, P., Dioguardi, M., Cammarata, M., Zupa, W., Vazzana, M., Spedicato, M. T., & Lembo, G. (2019). Basic knowledge of social hierarchies and physiological profile of reared sea bass Dicentrarchus labrax (L.). PloS One, 14(1), e0208688.

Chavan, B. (2015). Tilapia as food fish: Enhancement of ω-3 polyunsaturated fatty acids in tilapia (Oreochromis spp.). International Journal of Agriculture Sciences, ISSN, 0975–3710.

Chowdhury, M. K., Bureau, D. P., Bose, M. L., & Dey, M. (2007). Relevance of a rapid appraisal approach to identify locally available feed ingredients to small-scale Nile tilapia (Oreochromis niloticus L.) aquaculture. Aquaculture Economics & Management, 11(2), 151–169.

Chukwuka, A., Ogbeide, O., & Uhunamure, G. (2019). Gonad pathology and intersex severity in pelagic (Tilapia zilli) and benthic (Neochanna diversus and Clarias gariepinus) species from a pesticide-impacted agrarian catchment, south-south Nigeria. Chemosphere, 225, 535–547.

Dabbadie, L., Stankus, A., Yuan, D., & Halwart, M. (2019). Report of the special session on advancing integrated agriculture-aquaculture through agroecology, Montpellier, France, 25 August 2018.

Dabrowska, H., Meyer-Burgdorff, K., & Günther, K.-D. (1989). Interaction between dietary protein and magnesium level in tilapia (Oreochromis niloticus). Aquaculture, 76(3–4), 277–291.

Das, S., & Mandal, A. (2022). Diversification in aquaculture resources and practices for smallholder farmers. In Agriculture, Livestock Production and Aquaculture: Advances for Smallholder Farming Systems Volume 1 (pp. 263–286). Springer.

De Corato, U., De Bari, I., Viola, E., & Pugliese, M. (2018). Assessing the main opportunities of integrated biorefining from agro-bioenergy co/by-products and agroindustrial residues into high-value added products associated to some emerging markets: A review. Renewable and Sustainable Energy Reviews, 88, 326–346.

Delincé, G. (2013). The ecology of the fish pond ecosystem: With special reference to Africa (Vol. 72). Springer Science & Business Media.

Dipasquale, V., Cucinotta, U., & Romano, C. (2020). Acute malnutrition in children: pathophysiology, clinical effects and treatment. *Nutrients*, *12*(8), 2413.

Dorley, O. S., Ochuodho, J. O., Auma, E. O., Were, J. O., & Mutio, J. M. (2022). Rice: Seed Systems, Production Characteristics, and Fungal Infections of Stored Grains in Major Production Zones of Liberia. Asian Journal of Agriculture and Rural Development, 12(4), 297–305.

Dorley, O. S., Were, J. O., Ochuodho, J. O., & Auma, E. O. (2023). Fungal Pathogens Affecting the Quality of Rice (Oryza sativa L.) Seed in Selected Agro-ecological Zones of Liberia. World, 11(1), 8–15.

Dorothy, M., Raman, S., Nautiyal, V., Singh, K., Yogananda, T., & Kamei, M. (2018). Use of potential plant leaves as ingredient in fish feed-a review. Int. J. Curr. Microbiol. Appl. Sci, 7(7), 112–125.

Dunbar, A., Mungai, D., & Muthee, J. K. (2021). Factors influencing the sustainable utilization of artisanal fisheries: A case of west point, Liberia. *Int J Fish Aquat Stud*, *9*, 52-9.

Edwards, P., & Allan, G. (2004). Fish feeds and feeding in countries of the Lower Mekong Basin. World Aquaculture.

Efole Ewoukem, T., Mikolasek, O., Aubin, J., Tomedi Eyango, M., Pouomogne, V., & Ombredane, D. (2017). Sustainability of fish pond culture in rural farming systems of Central and Western Cameroon. International Journal of Agricultural Sustainability, 15(2), 208–222.

El-Sayed, A.-F. M. (2006). Tilapia culture in salt water: Environmental requirements, nutritional implications and economic potentials. Avances En Nutricion Acuicola.

Fagbemi, M. N., Oloukoule, R., Lederoun, D., Baglo, I. S., Melard, C., Laleye, P. A., & Rougeot, C. (2021). Comparative study of the breeding performances of five populations of Nile tilapia (Oreochromis niloticus)(F1) in an experimental ongrowing system in Benin (West Africa). Journal of Applied Aquaculture, 1–17.

FAO, E. (2018). Meeting the sustainable development goals. The State of World Fisheries and Aquaculture 2018.

FAO, I. (2022). The state of world fisheries and aquaculture 2016. Contributing to Food Security and Nutrition for All, 200.

Faye, R., Diouf, N. D., LY, M. A., & Ayih-Akakpo, J. A. (2020). Biosecurity Practices Applied in Aquacultural Farms in Northern Senegal, West Africa. *European Scientific Journal*, *16*(6), 287-299.

Fialho, N. S., Valenti, W. C., David, F. S., Godoy, E. M., Proença, D. C., Roubach, R., & Bueno, G. W. (2021). Environmental sustainability of Nile tilapia net-cage culture in a neotropical region. Ecological Indicators, 129, 108008.

Finkbeiner, E. M., Bennett, N. J., Frawley, T. H., Mason, J. G., Briscoe, D. K., Brooks, C. M., ... & Crowder, L. B. (2017). Reconstructing overfishing: moving beyond Malthus for effective and equitable solutions. *Fish and Fisheries*, *18*(6), 1180-1191.

Fitzgerald, M. A. (2017). Modeling Habitat Suitability for Pan troglodytes verus in Montane Rainforests.

Fitzsimmons, K., Martinez-Garcia, R., & Gonzalez-Alanis, P. (2011). Why tilapia is becoming the most important food fish on the planet. Better Science, Better Fish, Better Life, 8.

Fregene, B. (2021). AfDB_Technologies for African Agricultural Transformation (TAAT) _Quarterly Project Performance Reporting Q3_ July–September 2021.

Gabriel, U., Akinrotimi, O., Bekibele, D., Onunkwo, D., & Anyanwu, P. (2007). Locally produced fish feed: Potentials for aquaculture development in sub-Saharan Africa. African Journal of Agricultural Research, 2(7), 287–295.

Gaillard, J., Thomas, M., Lazartigues, A., Bonnefille, B., Pallez, C., Dauchy, X., Feidt, C., & Banas, D. (2016). Potential of barrage fish ponds for the mitigation of pesticide pollution in streams. Environmental Science and Pollution Research, 23(1), 23–35.

Gonçalves-de-Freitas, E., Bolognesi, M. C., Gauy, A. C. dos S., Brandão, M. L., Giaquinto, P. C., & Fernandes-Castilho, M. (2019). Social behavior and welfare in Nile tilapia. Fishes, 4(2), 23.

Gui, J.-F., Tang, Q., Li, Z., Liu, J., & De Silva, S. S. (2018). Aquaculture in China: Success stories and modern trends. John Wiley & Sons.

Halwart, M. (2020). Fish farming high on the global food system agenda in 2020. FAO Aquaculture Newsletter, 61, II–III.

Hendrick, E. (2008). Forests and the UNFCCC process-an overview. In *Forests, Carbon and Climate Change-Local and International Perspectives. Proceedings of the COFORD conference held at the* (p. 1).

Hlordzi, V., Kuebutornye, F. K., Afriyie, G., Abarike, E. D., Lu, Y., Chi, S., & Anokyewaa, M. A. (2020). The use of Bacillus species in maintenance of water quality in aquaculture: A review. Aquaculture Reports, 18, 100503.

Hodar, A., Vasava, R., Mahavadiya, D., & Joshi, N. (2020). Fish meal and fish oil replacement for aqua feed formulation by using alternative sources: A review. Journal of Experimental Zoology India, 23(1).

Honfoga, B. G., Tognon, I. A., & Chikou, A. (2017). Profitability and sustainability of modern fish farming in Benin: An on-farm experimental appraisal of two production systems of Clarias gariepinus. Journal of Development and Agricultural Economics, 9(9), 243–249.

Hossain, M. A., Sarker, A. K., Amin, M. N., Hossain, M. M., & Miah, M. S. (2016). Development and performance evaluation of sludge remover for intensive aquaculture. Aquacultural Engineering, 74, 62–69.

Hua, K., Cobcroft, J. M., Cole, A., Condon, K., Jerry, D. R., Mangott, A., Praeger, C., Vucko, M. J., Zeng, C., & Zenger, K. (2019). The future of aquatic protein: Implications for protein sources in aquaculture diets. One Earth, 1(3), 316–329.

IMF, O., & UNCTAD, W. (2011). Price volatility in food and agricultural markets: Policy responses. FAO: Roma, Italy.

Jauncey, K. (2000). Nutritional requirements–In: Tilapias: Biology and exploitation (Eds) MCM Beveridge, BJ McAndrew.

Jueseah, A. S., Knutsson, O., Kristofersson, D. M., & Tómasson, T. (2020). Seasonal flows of economic benefits in small-scale fisheries in Liberia: A value chain analysis. Marine Policy, 119, 104042

Kaleem, O., & Sabi, A.-F. B. S. (2021). Overview of aquaculture systems in Egypt and Nigeria, prospects, potentials, and constraints. Aquaculture and Fisheries, 6(6), 535–547.

Kaminski, A. M., Genschick, S., Kefi, A. S., & Kruijssen, F. (2018). Commercialization and upgrading in the aquaculture value chain in Zambia. Aquaculture, 493, 355–364.

Kassam, L., & Dorward, A. (2017). A comparative assessment of the poverty impacts of pond and cage aquaculture in Ghana. Aquaculture, 470, 110–122.

Koegelenberg, D., & Chimphango, A. F. (2017). Effects of wheat-bran arabinoxylan as partial flour replacer on bread properties. Food Chemistry, 221, 1606–1613.

Kone, M., Sylla, I., Djirieoulou, C. K., Burducea, M., & Miron, D.-L. (2022). Effects of the parasite Argulus ambloplites (Wilson, 1920) on welfare and mouthbreeding eggs capacity of Oreochromis niloticus (Linnaeus, 1758) females. International Journal of Biological and Chemical Sciences, 16(2), 515–526.

Kool, M., van Steenbergen, F., Mehari Haile, A., Abbas, Y. M., & Hagos, E. (2018). The promise of flood-based farming systems in arid and semi-arid areas. Rainwater-Smart Agriculture in Arid and Semi-Arid Areas: Fostering the Use of Rainwater for Food Security, Poverty Alleviation, Landscape Restoration and Climate Resilience, 77–94.

Kosemani, S., Adewole, H., Olaleye, V., Azeez, Y., Saanu, C., & Kosemani, E. (2017). Assessment of effect of fish feeding practices on the water quality of some fish ponds in Ekiti State Fish Farm, Ado Ekiti, Nigeria. *Int J Fish Aquat Stud*, *5*, 357-364.

Kouadio, K. I., Clement, P., Bolongei, J., Tamba, A., Gasasira, A. N., Warsame, A., ... & Nshimirimana, D. (2015). Epidemiological and surveillance response to Ebola virus disease outbreak in Lofa County, Liberia (March-September, 2014); lessons learned. *PLoS currents*, *7*.

Labasque, T., Chaumery, C., Aminot, A., & Kergoat, G. (2004). Spectrophotometric Winkler determination of dissolved oxygen: re-examination of critical factors and reliability. *Marine Chemistry*, *88*(1-2), 53-60.

Leal, J. F., Neves, M. G. P., Santos, E. B., & Esteves, V. I. (2018). Use of formalin in intensive aquaculture: Properties, application and effects on fish and water quality. Reviews in Aquaculture, 10(2), 281–295.

Leroy, J. L., & Frongillo, E. A. (2007). Can interventions to promote animal production ameliorate undernutrition? The Journal of Nutrition, 137(10), 2311–2316.

Limbu, S. M. (2020). The effects of on-farm produced feeds on growth, survival, yield and feed cost of juvenile African sharptooth catfish (Clarias gariepinus). Aquaculture and Fisheries, 5(1), 58–64.

Lunnan, A., & Sandberg, E. (1983). Economic evaluation of a district heating plant in Trysil.[Norway].

Lutterodt, J. B. (2018). Evaluation of Nile Tilapia (Oreochromis Niloticus, Linnaeus 1758) Fingerling Production at the Aquaculture Demonstration Centre-Ashaiman, Ghana.

Mafwila Kinkela, P., Kambashi Mutiaka, B., Dochain, D., Rollin, X., Mafwila, J., & Bindelle, J. (2019). Smallholders' Practices of Integrated Agriculture Aquaculture System in Peri-urban and Rural Areas in Sub Saharan Africa. Tropicultura.

Magwaza, N. M., Nxumalo, E. N., Mamba, B. B., & Msagati, T. A. (2017). The occurrence and diversity of waterborne fungi in African aquatic systems: Their impact on water quality and human health. International Journal of Environmental Research and Public Health, 14(5), 546.

Majiwa, E. B. O. (2017). Productivity and efficiency of the agricultural sector: Africa with a special focus on rice farming and processing in Kenya.

Manoj, M., Dhilip Kumar, V., Arif, M., Bulai, E. R., Bulai, P., & Geman, O. (2022). State of the art techniques for water quality monitoring systems for fish ponds using iot and underwater sensors: A review. *Sensors*, *22*(6), 2088.

Mansaray, M., & Simpson, P. L. (n.d.). MONTHLY SERIES.

Mapfumo, B. (2022). Regional review on status and trends in aquaculture development in sub-Saharan Africa–2020.

Mathiesen, Á. M. (2015). The state of world fisheries and aquaculture 2012.

Mmanda, F. P., Mulokozi, D. P., Lindberg, J. E., Norman Haldén, A., Mtolera, M., Kitula, R., & Lundh, T. (2020). Fish farming in Tanzania: The availability and nutritive value of local feed ingredients. Journal of Applied Aquaculture, 32(4), 341–360.

Mo, W. Y., Man, Y. B., & Wong, M. H. (2018). Use of food waste, fish waste and food processing waste for China's aquaculture industry: Needs and challenge. Science of the Total Environment, 613, 635–643.

Monticini, P. (2019). Breeding Marine Aquarium Fishes: Opportunity or Threat for the Local Fishing Community? Infofish International, 2019, 32–36.

Muhala, V., Rumieque, A., & Hasimuna, O. J. (2021). Aquaculture production in Mozambique: Approaches and practices by farmers in Gaza Province. The Egyptian Journal of Aquatic Research, 47(1), 87–92.

Munguti, J., Odame, H., Kirimi, J., Obiero, K., Ogello, E., & Liti, D. (2021). Fish feeds and feed management practices in the Kenyan aquaculture sector: Challenges and opportunities. Aquatic Ecosystem Health & Management, 24(1), 82–89.

Muzari, W., Gatsi, W., & Muvhunzi, S. (2012). The Impacts of Technology Adoption on Smallholder Agricultural Productivity in Sub-Saharan Africa: A Review. Journal of Sustainable Development, 5(8), p69. https://doi.org/10.5539/jsd.v5n8p69

Ndome, C., & IU, U. (2018). Food, feeding habit and condition factor of Silver Catfish (Chrysichthys nigrodigitatus)(Geoffrey Saint Hilaire, 1808) from Cross River estuary, Nigeria. Journal of Fisheries and Life Science, 3(2), 14–18.

Nestor, K. B., Abdoulaye, K., Emmanuel, G., Célestin, A. B., & Nahoua, O. I. (2023). ANALYSIS OF CÔTE D'IVOIRE FISH FARM-MADE FEEDS: RAW MATERIALS, PRODUCTION AND PROXIMATE COMPOSITION. Journal of Global Biosciences Vol, 12(4), 9747–9759.

Ngarava, S., Zhou, L., Nyambo, P., Chari, M. M., & Bhungeni, O. (2023). Aquaculture production, GHG emission and economic growth in Sub-Sahara Africa. Environmental Challenges, 100737.

Nguyen, A. T., & Nguyen, M. N. (2019). Straw phytolith for less hazardous open burning of paddy straw. Scientific Reports, 9(1), 1–6.

Ninson, J., & Brobbey, M. K. (2023). Review on engaging the youth in agribusiness. Cogent Social Sciences, 9(1), 2193480.

Obiero, K. O., Waidbacher, H., Nyawanda, B. O., Munguti, J. M., Manyala, J. O., & Kaunda-Arara, B. (2019). Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. Aquaculture International, 27, 1689–1707.

Obwanga, B., Soma, K., Ayuya, O. I., Rurangwa, E., van Wonderen, D., Beekman, G., & Kilelu, C. (2020). Exploring enabling factors for commercializing the aquaculture sector in Kenya. Centre for Development Innovation.

Okeke-Ogbuafor, N., Stead, S., & Gray, T. (2021). Is inland aquaculture the panacea for Sierra Leone's decline in marine fish stocks?. *Marine Policy*, *132*, 104663.

Oladimeji, Y., Abdulsalam, Z., Mani jr, J., & Galadima, S. (2017). Profit efficiency of concrete and earthen pond systems in Kwara State, Nigeria: A path towards protein self-sufficiency in fish farming. Nigerian Journal of Fisheries and Aquaculture, 5(2), 103–113.

Pauly, D., & Zeller, D. (2019). Agreeing with FAO: Comments on SOFIA 2018. *Marine Policy*, *100*, 332-333.

Prabhu, M., Abdullah, N. N., & Madan Mohan, G. (2019). An Empirical Study on the Satisfaction Level of National and International Tourists towards Natural Attractions in Kurdistan. African Journal of Hospitality, Tourism and Leisure, 8(2), 1–8.

Ragasa, C., Agyakwah, S. K., Asmah, R., Mensah, E. T.-D., Amewu, S., & Oyih, M. (2022). Accelerating pond aquaculture development and resilience beyond COVID: Ensuring food and jobs in Ghana. Aquaculture, 547, 737476.

Ragasa, C., Andam, K. S., Kufoalor, D. S., & Amewu, S. (2018). A blue revolution in sub-Saharan Africa? Evidence from Ghana’s tilapia value chain (Vol. 49). Intl Food Policy Res Inst.

Rahaman, M., Sarkar, S., & Rahman, M. (2011). Bigger ponds favour Nile tilapia production. Aquaculture Europe, 36, 28–30.

Reddy, P. (2017). Evaluation of malathion induced oxidative stress in Tilapia mossambica. Sci J, 6(3), 2319–4758.

Seto, Katherine, and Kathryn J. Fiorella. "From sea to plate: the role of fish in a sustainable diet." *Frontiers in Marine Science* 4 (2017): 74.

Shechonge, A., Ngatunga, B. P., Bradbeer, S. J., Day, J. J., Freer, J. J., Ford, A. G., Kihedu, J., Richmond, T., Mzighani, S., & Smith, A. M. (2019). Widespread colonisation of Tanzanian catchments by introduced Oreochromis tilapia fishes: The legacy from decades of deliberate introduction. Hydrobiologia, 832(1), 235–253.

Shieh, G., & Jan, S. L. (2004). The effectiveness of randomized complete block design. *Statistica Neerlandica*, *58*(1), 111-124.

Singh, D., & Chaube, R. (2021). Recycling of sewage in Aquaculture: An overview. IJBI, 3(2).

Singini, W., Msiska, O., Kapute, F., Kasulo, V., Kang'ombe, J., Wilson Jere, W., Nyasulu, T., Mzengereza, K., & Kamangira, A. (2014). Development of quality and affordable fish feed for small scale fish farmers in Malawi. 407–413.

Soma, K., Vernooij, A., Barbosa, M., Opiyo, M., Kals, J., Cubero, R., Komleh, S. P., Rurangwa, E., Ndambi, O., & Schrijver, R. (2023). The protein transition.: How to operationalise use of black soldier fly larvae (BSFL) and spirulina as feed ingrediencies in Kenya and Uganda? Wageningen Economic Research.

Spiegel, P. (1998). The Relief-Reconstruction-Development Dynamic: A New Approach to the Concept of Linking Relief, Reconstruction, and Development. *Refuge: Canada's Journal on Refugees/Refuge: Revue canadienne sur les réfugiés*, *17*(4), 33-37.

Spiliotopoulou, A., Rojas-Tirado, P., Chhetri, R. K., Kaarsholm, K. M., Martin, R., Pedersen, P. B., Pedersen, L.-F., & Andersen, H. R. (2018). Ozonation control and effects of ozone on water quality in recirculating aquaculture systems. Water Research, 133, 289–298.

Ssepuuya, G., Namulawa, V., Mbabazi, D., Mugerwa, S., Fuuna, P., Nampijja, Z., Ekesi, S., Fiaboe, K., & Nakimbugwe, D. (2017). Use of insects for fish and poultry compound feed in sub-Saharan Africa–a systematic review. Journal of Insects as Food and Feed, 3(4), 289–302.

Stauffer, J. R., Chirwa, E., Jere, W., Konings, A. F., Tweddle, D., & Weyl, O. (2022). Nile Tilapia, Oreochromis niloticus (Teleostei: Cichlidae): A threat to native fishes of Lake Malawi? Biological Invasions, 1–13.

Subasinghe, R. (2017). World aquaculture 2015: A brief overview. FAO Fisheries and Aquaculture Report, 1140.

Sultana, N. (2020). Effect of short time temperature alteration on two key reproduction hormone levels of Nile tilapia (Oreochromis niloticus).

Swar, N. M. S. (2016). Incorporation of dietary palm date pits in all-male Nile tilapia (Oreochromis niloticus) diets.

Tacon, A. G., & Metian, M. (2013). Fish matters: Importance of aquatic foods in human nutrition and global food supply. Reviews in Fisheries Science, 21(1), 22–38.

Tatemoto, P., & Serra, M. (2021). Low Luminosity Reduces Agonistic Behaviour of Nile Tilapia. Journal of Applied Animal Welfare Science, 24(4), 434–441.

Teles, A. O., Couto, A., Enes, P., & Peres, H. (2020). Dietary protein requirements of fish–a meta- analysis. Reviews in Aquaculture, 12(3), 1445–1477.

Temesgen, M., Getahun, A., & Lemma, B. (2019). Livelihood functions of capture fisheries in Sub-Saharan Africa: Food security, nutritional, and economic implications. Reviews in Fisheries Science & Aquaculture, 27(2), 215–225.

Thilsted, S. H. (2013). Fish diversity and fish consumption in Bangladesh. Diversifying Food and Diets: Using Agricultural Biodiversity to Improve Nutrition and Health, 270.

Thomas, M. F. (1995). Models for landform development on passive margins. Some implications for relief development in glaciated areas. *Geomorphology, 12*(1), 3-15.

Thorarensen, H. (2010.). THE POTENTIAL OF AQUACULTURE IN LIBERIA.

Tiamiyu, L. O., Okomoda, V. T., & AENDE, A. A. (2016). Growth performance of Oreochromis niloticus fingerlings fed Moringa oleifera leaf as replacement for soybean meal. Journal of Aquaculture Engineering and Fisheries Research, 2(2), 61–66.

Tossavi, N. D., Gbankoto, A., Adité, A., Ibikounlé, M., Grunau, C., & Sakiti, G. N. (2014). Metazoan parasite communities of catfishes (Teleostei: Siluridae) in Benin (West Africa).

Uaiene, R. N. (2011). Determinants of agricultural technology adoption in Mozambique. 10th African Crop Science Conference Proceedings, Maputo, Mozambique, 10-13 October 2011.

Udo, I., & Dickson, B. (2017). The Nigerian aqua-feed industry: Potentials for commercial feed production. Nigerian Journal of Fisheries and Aquaculture, 5(2), 86–95.

UNESCO, N. (2006). Double burden of malnutrition—A common agenda. Proceedings of the 33rd Annual Session of the Standing Committee on Nutrition, Geneva, Switzerland, 13–17.

Vajargah, M. (2021). A review of the physiology and biology of Nile tilapia (Oreochromis niloticus). J Aquac Mar Biol, 10(5), 244–246.

Van der Knaap, M. (2017). Is Aquaculture a Logical Choice for Youth Employment? Lessons Learnt from a Project in Liberia. *FAO Aquaculture Newsletter*, (56), 33.

Vannuccini, S., Kavallari, A., Bellù, L. G., Müller, M., & Wisser, D. (2019). Understanding the impacts of climate change for fisheries and aquaculture: Global and regional supply and demand trends and prospects. Impacts of Climate Change on Fisheries and Aquaculture, 41.

Vongvichith, B., Morioka, S., Kawamura, K., & Mori, A. (2018). Factors influencing fish productivity in rice paddy aquaculture: A case study in Vientiane province, central Laos. Japan Agricultural Research Quarterly: JARQ, 52(4), 359–366.

Wachira, M. N., Osuga, I. M., Munguti, J. M., Ambula, M. K., Subramanian, S., & Tanga, C. M. (2021). Efficiency and improved profitability of insect-based aquafeeds for farming Nile tilapia fish (Oreochromis niloticus L.). Animals, 11(9), 2599.

Wang, R., Zhang, Y., Xia, W., Qu, X., Xin, W., Guo, C., Bowker, J., & Chen, Y. (2018). Effects of aquaculture on lakes in the Central Yangtze River Basin, China, I. water quality. North American Journal of Aquaculture, 80(3), 322–333.

Wanja, D. W., Mbuthia, P. G., Waruiru, R. M., Mwadime, J. M., Bebora, L. C., Nyaga, P. N., & Ngowi, H. A. (2020). Fish husbandry practices and water quality in central Kenya: Potential risk factors for fish mortality and infectious diseases. Veterinary Medicine International, 2020.

Witinok-Huber, R., Radil, S., Sarathchandra, D., & Nyaplue-Daywhea, C. (2021). Gender, place, and agricultural extension: A mixed-methods approach to understand farmer needs in Liberia. The Journal of Agricultural Education and Extension, 1–20.

Wu, Z., Lin, C., Shao, H., Feng, X., Chen, X., & Wang, S. (2021). Ecological risk assessment and difference analysis of pit ponds under different ecological service functions-A case study of Jianghuai ecological Economic Zone. Ecological Indicators, 129, 107860.

Wuor, M., & Mabon, L. (2022). Development of Liberia’s fisheries sectors: Current status and future needs. Marine Policy, 146, 105325.

Wuyep, S. Z., & Rampedi, I. T. (2018). Urban fish farming in Jos, Nigeria: Contributions towards employment opportunities, income generation, and poverty alleviation for improved livelihoods. Agriculture, 8(7), 110.

Xu, J., Liu, Y., Cui, S., & Miao, X. (2006). Behavioral responses of tilapia (Oreochromis niloticus) to acute fluctuations in dissolved oxygen levels as monitored by computer vision. Aquacultural Engineering, 35(3), 207–217.

Zengeya, T. A., Booth, A. J., & Chimimba, C. T. (2015). Broad niche overlap between invasive nile tilapia Oreochromis niloticus and indigenous congenerics in Southern Africa: Should we be concerned? Entropy, 17(7), 4959–4973.

Zulhisyam, A. K., Kabir, M. A., Munir, M. B., & Wei, L. S. (2020). Using of fermented soy pulp as an edible coating material on fish feed pellet in African catfish (Clarias gariepinus) production. Aquaculture, Aquarium, Conservation & Legislation, 13(1), 296–308.

APPENDICES

Appendix I: Table of Correlations showing the relationships among water qualities derived from the different feeds and between water quality and Standard Growth Rate.

Correlations

		SGR	Size	Temperature	pH	Dissolved Oxygen	Saturated %
Pearson Correlation	SGR	1.000	-.944	.385	-.762	-.107	-.501
	Size	-.944	1.000	-.514	.914	.156	.541
	Temperature	.385	-.514	1.000	-.521	-.041	-.732
	pH	-.762	.914	-.521	1.000	.091	.444
	Dissolved Oxygen	-.107	.156	-.041	.091	1.000	.093
	Saturated %	-.501	.541	-.732	.444	.093	1.000
Sig. (1-tailed)	SGR		.000	.121	.003	.377	.058
	Size	.000		.053	.000	.323	.043
	Temperature	.121	.053		.050	.452	.005
	pH	.003	.000	.050		.395	.086
	Dissolved Oxygen	.377	.323	.452	.395		.393
	Saturated %	.058	.043	.005	.086	.393	

Appendix II: Economic Analysis for Commercial Feed 1

1.) Initial Cost				
Items	**Cost $**	**Economic Life**	**Salvage value**	**Annual Depreciation ($)**
Pond Construstion	n/a	n/a		
Happas Nets	200	2		100
Happas sewing	20	2		10
Bird Nets	200	2		100
Ropes	10	2		5
Bamboo Sticks	10	n/a		
Others	20			
Total	**460**			**215**

2) Annual operating Cost			
	Quantity	**Unit Price**	**Total Cost**
a) Variable Items			
Fingerling	500	0.1	50
Commercial feed 1	50	0.6	30
Hired Laborer	1	30	30
Fuel	5	3.1	15.5
Others			30
Sub-Total			**155.5**
b) Fixed Cost			
Depreciation	n/a		215
Maintenance	n/a		10
SubTotal			**225**

Total				**380.5**
3) Income				
	Final weight (g)	**Production (kg)**	**UnitPrice ($)**	**income**
Tilapia	160	80	8	640
4) Indicators				
a. Profit	640-380.5 = 259.5	**259.5**		
b. Rate of return on initial cost	259.5/460	**56.41304348**		
c.Rate of return on operating cost	259.5/380.5	**68.19973719**		

Appendix III: Economic Analysis for Commercial Feed 2

1.) Initial Cost

Items	Cost $	Economic Life	Salvage value	Annual Depreciation ($)
Pond Construstion	n/a	n/a		
Happas Nets	200	2		100
Happas sewing	20	2		10
Bird Nets	200	2		100
Ropes	10	2		5
Bamboo Sticks	10	n/a		
Others	20			
Total	**460**			**215**

2) Annual operating Cost

	Quantity	Unit Price	Total Cost
Variable Items			
Fingerling	500	0.1	50
a. Commercial feed 2	50	0.6	30
Hired Laborer	1	30	30
Fuel	5	3.1	15.5
Others			30
Sub-Total			**155.5**

Fixed Cost

Depreciation	n/a		215
Maintaince	n/a		10
SubTotal			**225**

Total				**380.5**
3) Income				
	Final weight (g)	**Production (kg)**	**UnitPrice ($)**	**income**
Tilapia	94	47	8	376
4) Indicators				
a. Profit	376-380.5 = 259.5	-4.5		
b. Rate of return on initial cost	-0.009782609	-0.98%		
c.Rate of return on operating cost	-0.011826544	-1.2%		

Appendix IV: Economic Analysis for Farmers' Feed 1

1.) Initial Cost				
Items	**Cost $**	**Economic Life**	**Salvage value**	**Annual Depreciation ($)**
Pond Construstion	n/a	n/a		
Happas Nets	200	2		100
Happas sewing	20	2		10
Bird Nets	200	2		100
Ropes	10	2		5
Bamboo Sticks	10	n/a		
Others	20			
Total	**460**			**215**

2) Annual operating Cost			
	Quantity	**Unit Price**	**Total Cost**
Variable Items			
Fingerling	500	0.1	50
Farmers' Feed 1	50	0.175	8.75
Hired Laborer	1	30	30
Fuel	5	3.1	15.5
Others			30
Sub-Total			**134.25**

Fixed Cost		
Depreciation	n/a	215
Maintaince	n/a	10
SubTotal		**225**
Total		**359.25**

3) Income				
	Final weight (g)	**Production (kg)**	**UnitPrice ($)**	**income**
Tilapia	83	41.5	8	**332**
4) Indicators				
a. Profit ($)	332-359.25 = -27.25	-27.25		
b. Rate of return on initial cost	-0.05923913	-5.9%		
c.Rate of return on operating cost	-0.07585247	-7.6%		

Appendix V: Economic Analysis for Commercial Feed 2

1.) Initial Cost

Items	Cost $	Economic Life	Salvage value	Annual Depreciation ($)
Pond Construstion	n/a	n/a		
Happas Nets	200	2		100
Happas sewing	20	2		10
Bird Nets	200	2		100
Ropes	10	2		5
Bamboo Sticks	10	n/a		
Others	20			
Total	**460**			**215**

2) Annual operating Cost

	Quantity	Unit Price	Total Cost
Variable Items			
Fingerling	500	0.1	50
Farmers' Feed 2	50	0.14	7
Hired Laborer	1	30	30
Fuel	5	3.1	15.5
Others			30
Sub-Total			**132.5**

Fixed Cost			
Depreciation	n/a		215
Maintaince	n/a		10
SubTotal			**225**

Total				**357.5**

3) Income

	Final weight (g)	Production (kg)	UnitPrice ($)	income
Tilapia	72	36	8	288

4) Indicators

a. Profit	288-359.25 = -69.5	**-69.5**
b. Rate of return on initial cost	-0.151086957	**-15.10%**
c.Rate of return on operating cost	-0.194405594	**-19.44%**

Appendix VI: Economic Analysis for Commercial Research Feeds

1.) Initial Cost				
Items	**Cost $**	**Economic Life**	**Salvage value**	**Annual Depreciation ($)**
Pond Construstion	n/a	n/a		
Happas Nets	200	2		100
Happas sewing	20	2		10
Bird Nets	200	2		100
Ropes	10	2		5
Bamboo Sticks	10	n/a		
Others	20			
Total	**460**			**215**

2) Annual operating Cost			
	Quantity	**Unit Price**	**Total Cost**
Variable Items			
Fingerling	500	0.1	50
Research Feeds	50	0.968	48.4
Hired Laborer	1	30	30
Fuel	5	3.1	15.5
Others			30
Sub-Total			**173.9**

Fixed Cost			
Depreciation	n/a		215
Maintenance	n/a		10
SubTotal			**225**

Total				**398.9**
3) Income				
	Final weight (g)	**Production (kg)**	**Unit Price ($)**	**income**
Tilapia	164	82	8	656
4) Indicators				
a. Profit	656-359.25 = 257.1	**257.1**		
b. Rate of return on initial cost	0.558913043	**55.90%**		
c.Rate of return on operating cost	0.644522437	**64.45%**		

Appendix VII: Objective One Questionnaire

Evaluation of fish farming and document the impact of different types of feed on Nile Tilapia farming in Liberia

Greetings,

My name is……………………………. {Name of the enumerator, and I am grateful for your warm welcoming. Am here to collect data on your fish farming activities, particularly on feeding, feed types and challenges on production of Nile Tilapia. The data is meant to provide a highlight into a research on "Nile Tilapia fish formulation and use" by a PhD student who is undertaking his studies in University of Eldoret, Kenya. Your participation (fully or partially) is voluntarily. The collected data will be treated with utmost confidentiality and will only be used for stated purpose and creation of awareness that might help in developing supportive policies towards more efficient fish farming in Liberia. Upon consent to participate, the survey also assumes that (1) You (herein denoted as respondent) are not under influence of any substance, person/s or brain related illness that can interfere with the authenticity of the information you are expected to provide. (2) The responses that you will provide will be consciously made and accurate. Where you find difficult answering a question kindly request for further explanations. I hereby request you to participate in the survey. The interview might take 1 hour. **WELCOME**

Consent given Yes ☐ No☐ (Tick according to respondents answer)

{If the respondent declines on consent, record the questionnaire number, thank them and move to another farmer as per the provided list}

Section 1: Farmers information

1. Farmer code……………………………………(to be provided by enumerator).
2. GPS
3. Northing………………………………………………………………

   Easting…………………………………………………………………

   County of the respondent (Select where applicable)

   i. Bong ◯
   ii. Lofa ◯
   iii. Nimba ◯
   iv. Gbapolu ◯
   v. River Gee ◯
   vi. Grande Gedeh ◯

   3.1 Sub-county of the respondent………………………………………

4. Sex of the respondent (Owner of the fish farm) (Select where applicable)

   i. Male ◯
   ii. Female ◯
   iii. Prefer not to say ◯

5. Age of the respondent (Select where applicable)

   (a) Below 35 years ◯ (b) Above 35 years ◯

6. Highest level of education attained (Select where applicable)

   i. No education ◯
   ii. Primary ◯
   iii. Secondary ◯

iv. Vocational ◯

v. University/College ◯

Section 2: General fish farming information

1. How long have you been practicing fish farming?…… (indicate the answer in years)

2. What motivated your ambition to start fish farming? (Tick all that applies)

i. Source of income ☐

ii. Create employment ☐

iii. Market availability ☐

iv. Diversify investment ☐

v. Availability of government/NGO support ☐

vi. Past experience ☐

vii. Any other ☐

State any other factor that motivated you to join fish farming

…………………...………………………………………………………

Total pond size owned…………………………………………………… (meter squares)

3. Name fish species you actively farm (Tick all that applies)

i. Nile Tilapia ☐

ii. Silver Tilapia ☐

iii. Tilapia Zilli ☐

iv. Tilapia Mossambicus ☐

v. Heterotis niloticus ☐

vi. Catfish ☐

State any other species farmed…………………………………………

(b) What are the advantage of farming Nile Tilapia over other species?

i. Short maturation period ☐

ii. Efficient feed conversion ☐

iii. Can feed on any type of feed ☐

iv. Can survive under diverse range of environmental conditions ☐

v. Has ready market ☐

vi. Any other ☐

State any other Nile Tilapia advantages……………………………………

(c) What are the disadvantages of farming Nile tilapia over other species?

i. Feed requirement ☐

ii. Over population ☐

iii. Lack of market ☐

iv. High competition from other species ☐

v. Poor adaptation to Liberian climate ☐

(d) What was your total harvest of Nile Tilapia in

2020……………………(convert to kgs)

(e) Rate the productivity of Nile Tilapia over other farmed species

i. Very poor ○

ii. Poor ○

iii. Average ○

iv. Good ○

v. Excellent ○

Section 4: Fish feeding

1.0 What type of feed do you use to feed your fish?

i. Farmer formulated ☐

ii. Local commercial feeds ☐

iii. Imported commercial feeds ☐

iv. Kitchen remains ☐

2.0 Are feeds used in {Section 4, (1)} continuously available for production period?

Yes ☐ ☐ No

3.0 (a) If you use farmer formulated fish feeds, do you prepare the feeds?

Yes ☐ ☐ No

(b) If Yes, which ingredient do you use and their combination ratio?...

....

....

....

....

(C) Where do you source your feed ingredients?

i. On farm ingredients (crops, grains etc) ☐

ii. From food processors (millers, etc) ☐

iii. Any other?

Specify other sources for your feed ingredient

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

(d) if you don't produce your own feeds, where do you source farmer formulated feeds?

i. Other fish farmers ☐
ii. Local feed vendor ☐
iii. Local market ☐
iv. Any other ☐

Specify any other…………………………………………………………

(e) How much do you pay per Kilograms of farmer formulated feeds……………….(state amount in USD)

…………………………………………………………………………………

…………………………………………………………………………………

………………………………………………………………………………….

(g) If you use commercial feeds, where do you source them? (Tick all that apply)

i. Local Agro-dealers ☐
ii. Local markets ☐
iii. Government ☐
iv. Non-governmental organizations' ☐
v. Import ☐

vi. Other ☐

(h) What challenges do you face in accessing commercial feeds?

i. Expensive ☐

ii. Not available locally ☐

iii. Poor quality ☐

iv. Others ☐

Specify other challenges

…………………………………………………………………………….

4.0 How do you administer the feed to the fish?

i. Manual broadcasting ◯

ii. Automated feeding ◯

iii. Other ◯

Specify any other feeding mechanism used………………………………

5.0 (a) Do you keep records on the impact of feed to the growth of the fish?

Yes ☐ No ☐

(b) If Yes, what are the growth aspects are monitored? (Tick all that apply)

i. Fish weight ☐

ii. Fish length ☐

iii. Fish yield ☐

iv. Survival rate ☐

6.0 (a) Have you received training on how to formulate feed for the farmed fish species?

Yes ☐ No ☐

(b) If **YES,** what aspect of feed formulation were you trained in? (Tick all that apply)

i. Feed ratio ☐
ii. Feed ingredients ☐
iii. Feed types ☐
iv. Feeding different fish species ☐

(c) Who provided the training? (Tick all that apply)

i. Government extension officers ◯
ii. Non-Governmental organizations ◯
iii. Research institutions (Universities, agriculture organizations etc) ◯
iv. Fellow farmers ◯
v. Any Other ◯

Specify any other place/organization you received training

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

7.0 What are some of challenges you face in feeding your fish?

i. Poor quality ☐

ii. ………………………………………………………………………………

iii. ………………………………………………………………………………

iv. Other

Specify any other challenges

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

8.0 What management practice do you adopt to ensure that the fish are in the best of condition?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

9.0 What are your recommendation on improving aquaculture in the country

i. Increased government support in terms of inputs ☐

ii. Improved extension services ☐

iii. Improved access to quality feed ☐

iv. Other

Specify any other suggestion;

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

Thank you for your participation

Appendix VIII: Similarity Report

University of Eldoret

Certificate of Plagiarism Check for Dissertation

Author Name	MANDELA KLON-YAN HINNEH (SNAT/FAS/P/004/19)
Course of Study	Type here...
Name of Guide	Type here...
Department	Type here...
Acceptable Maximum Limit	Type here...
Submitted By	titustoo@uoeld.ac.ke
Paper Title	EVALUATION OF FARM-MADE AND COMMERCIAL FEEDS ON GROWTH AND ECONOMIC PERFORMANCE OF NILE TILAPIA (Oreochromis niloticus LINNAEUS, 1758) IN LIBERIA
Similarity	12%
Paper ID	1542007
Submission Date	2024-03-18 10:27:45

Signature of Student

Signature of Guide

Head of the Department

University Librarian

Director of Post Graduate Studies

* This report has been generated by DrillBit Anti-Plagiarism Software