BIOLOGICAL AND ECONOMIC PERFORMANCE OF PEANUT-BASED MEALS AS ALTERNATIVES TO DIETARY FISHMEAL IN POND CULTURED NILE TILAPIA (*Oreochromis niloticus L.*) IN UGANDA

BY

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DECLARATION

Declaration by candidate:

I declare that this thesis is my original work and that it has not been presented for any academic award in another University or Institution of higher learning.

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I dedicate the study to my late father Mr. C. Musita who provided the foundation for my further studies.

ABSTRACT

Increasing price of dietary fishmeal is offsetting the excellent growth and yield induced in farmed Nile tilapia subsequently reducing the corresponding cost-effectiveness. Replacement of the dietary ingredient with better or comparable substitutes has become necessary in many countries including Uganda. In light of the phenomenon, a study was conducted in Busoga sub-region of Eastern Uganda to evaluate the biological and economic performance of pondcultured Nile tilapia (Oreochromis *niloticus L*.) fed on peanut-based meals as alternative to dietary fishmeal. Sample surveys supplemented by field experiments attained all the specific objectives of the study from January 2016 to March 2017. The specific objectives of the study related the following performance indicators in Nile tilapia fed on the test diets; biomass production (g/pond), Feed Conversion Ratios, Relative Growth Rates (%), Net Fish Yields (g/pond), Survival Rates (%), Economic Conversion Ratios and Profit Indices. The surveys that valuated the test feeds and fish products occurred in sampling units in local commodity markets in Iganga municipality and along the main roads network respectively. The fish pond input and output valuations (USD/Kg) were conducted directly and indirectly respectively. The field experiments aimed at measuring targeted responses induced by test diets in Nile tilapia. Each of the two experimental sites at Busoga University farmland consisted of rectangular shaped earthen ponds. Two experimental sites A and B were stocked in the dry and wet seasons respectively. The replication of Site A at Site B aimed at mitigating the effect of weather on fish production. Forty-eight mono-sex fish fingerlings were stocked in sixteen pond units of uniform size (3.0 x 4.0 x 1.0 cubic meters) at each site. Among the stocked ponds, one acted as a fish reserve pond for mitigating the risk of fish loss in the earthen ponds. Mean body weights at stocking were 22.2 and 21.7 grams for the sites A and B respectively. Test diets were Iso-caloric throughout the experiments (5.3627 Kcal/g) and iso-nitrogenous; 30% and 25% Crude Protein for the first twelve and latter weeks respectively. Dietary treatments included the fishmeal-based diet (control) and two peanut-based diets; peanut meal and mixed plant meal-based diets. The locally available commercial feed for grow-out Nile tilapia containing 25% Crude Protein was the control diet throughout the feeding trials. The results indicated that only unionized ammonia affected fish biomass production negatively. Survival Rates in Nile tilapia were the only performance indicators that were insignificantly different (p□0.05) across all the dietary treatment groups. Other Insignificant differences (p□0.05) among other indicators of performance were restricted were restricted the fishmeal and mixed plant-based diets. With exception to the Survival Rates, the peanut-based diet exhibited significantly poorer (p□0.05) results than the fishmeal-based diet. The lack of significant differences ($p>0.05$) across all tested biological and economic performance indicators implied that the mixed plant meal based and fishmeal-based diets exhibited comparable performances. Therefore, among the peanut-based meals, only the mixed plant-meal should completely substitute the conventional fishmeal-based diet in the pond cultured Nile tilapia in Uganda.

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ABBREVIATIONS AND ACRONYMNS

ANFs	Anti-nutritional factors
APD	Agricultural Planning Department
ANOVA	Analysis of Variance
C	Correction factor
CP	Crude Protein
CRD	Completely Randomized Design
DFE	Degrees of Freedom-Error
DFG	Degrees of Freedom- Group
DFR	Daily Feeding Ration
DO	Dissolved Oxygen
F	F-value
FM	fish meal
FAO	Food and Agricultural Organization
HSD	Tukey"s Honestly Significant Difference
k	Number of treatment groups
Kg	Kilograms
L.	Linnaeus
MSE	Mean Square-Error
MSG	Mean Square-Group
MPM	mixed plant meal
PI	Profit Index
PNM	peanut meal
q	Studentized range statistic
SR	Survival Rate
SRS	Simple Random Sampling
SSE	Sum of Squares-Error
SSG	Sum of Squares-Group
SST	Sum of Squares-Total
USAID	United States Agency for International Development

WORKING DEFINITIONS

Biological performance: Expressed physiological responses induced by test diets in the experimental fish.

Commodity markets: Local trading centers for feed ingredients during the sample surveys. **Dry Season Stock:** Experimental fish stocked at the beginning of dry season but production cycle not limited to duration of the season.

Economic performance: Expressed economic variables during the feeding trial in the experimental fish.

Experimental sites: Independent field locations where the fish feeding trials were conducted. **Farm-gate price:** Sale price (USD) for one kilogram of harvested fish from each of the dietary treatment groups that was indirectly determined from local markets. **Fish biomass:** Summation of the entire weight of fish stock in the pond units.

Fishmeal: Greyish and powdery floor prepared from dried grounded whole fish particularly the wild species referred to as "mukene".

Fish Reserve ponds: Stocked pond units that mitigated possible losses of fish in the corresponding dietary treatment groups.

Peanut-based diets: Test diets formulated wholly or partially from peanut particularly the peanut meal and mixed plant meal respectively.

Performance indicators: Tools that measured levels for targeted the variables.

Product Value: Monetary equivalent of the experimental fish sold from the different dietary treatment groups.

Soybean Meal: Dry, partially heated and grounded soybean flour without oil extraction. **Water Reserve ponds:** Non-stocked pond units that mitigated possible losses of water in corresponding groups of pond units of a treatment group.

Wet Season Stock: Experimental fish stocked at the beginning of wet season but production cycle not limited to duration of the season.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Fish feeds play a vital role in biomass production (Jimoah 2013; Makwina & Kapute, 2015), consequently becoming the most important input in fish production. Bostock *et al*. (2010) revealed that aqua feed is arguably the most critical issue in the advancement of aquaculture in Africa. The challenges of artificial diets in fish production have been varying with time. Initially, low access to feed was limiting aquaculture production (De-Silva & Hassan, 2007). Specifically, Oirere (2019) concluded that inaccessibility to appropriate feeds has hampered efforts to transform aquaculture in sub-Saharan Africa.

The global increase in use of fish feeds (De-silva & Hassan, 2007) has not been matched with fish production. The decline in feed quality that coupled the intensification of fish feeding (FAO, 2012) led to poor growth and yield in farmed species. High quality aqua feeds remain prohibitively expensive (Ragasa *et al*., 2022). The situation has forced farmers to resort to poor quality alternative feeds particularly under semi-intensive production systems. The limit on fish production by poor quality feeds (Hardy, 2010) results into increased production cost and lowered profit margins. Among the ingredients, protein supplements are obligatory in fish feed formulations (Rust *et al*., 2012). Twenty per cent or more of Crude Protein characterizes the protein supplements (Gosh & Mandall, 2015). Since protein constitutes 70% of the dry weight of fish muscle (Robinson *et al*., 2001), dietary protein sources are primarily involved in fish biomass synthesis. The compulsory inclusion of protein supplements in aqua feed formulations (Schmittou & Zhang, (2004) reflects their critical role in fish production.

Protein supplements largely determine the levels of expression of desirable characters in farmed fish such as growth rate (Tiamiyu *et al*., 2013) size at harvest and net yield (Aqua-Techna, 2011; Saidyleigh, 2018) and survival rates (Amoah, 2011). Although dietary proteins have shown excellent performance in terms of fish biomass production (Gabriel *et al*., 2007; The Fish Site, 2010; Rust *et al*. 2012), the corresponding cost has become a challenge to aqua feed formulation. The influences on both biological production and cost production imply that protein supplements largely influence the cost-effectiveness of any artificial fish feed.

Fishmeal is the commonly applied protein source in aqua feeds (Nordahl & Pickering, 2004).

The feed ingredient is derivative of wild fish found in natural water bodies. In many countries, *Rastrineobola argentea*, locally referred to as "Mukene" in Uganda (Base Line Survey, 2015) is the primary source of fishmeal (Hua *et al*., 2019). The wild fish is largely captured in the following lakes in the country; Victoria Kioga and Nabugabo (Mukiibi, 2001). According to Wandera (2005), Lake Victoria recorded the highest catches of *R. argentea* compared to other water bodies. As alternatives to Mukene such as bones and trimmings contribute to only 20% of the global fishmeal supply (Hua *et al*., 2019), the former remains the primary source of fishmeal production. As a result, a steady supply of the off-farm resource has become critical for the sustainability of the conventional dietary ingredient on fish farms in Uganda.

Although production peaked at 30.2 million tons in 1994 rendering it a commercial species on Lake Victoria (Wandera, 2005), the trend gradually reversed. Mukene catches from natural waters have been declining in East Africa and other parts of the world. There was a worldwide drop in Mukene output by 42% between 2000 and 2012 (FAO, 2012). Although competition among consumers and commercial fishing rendered Mukene inaccessible (Tacon *et al*., 2010), other influences particularly biological factors have come into play. The further decline of the wild species in L. Victoria can be attributed to predation by Nile perch (*Lates niloticus*) (Sharpe *et al.,* 2012). The reduction in Mukene supply has emerged as a major threat to aquaculture in countries surrounding L. Victoria.

Mukene is increasingly formulating various types of animal feeds. According to Tacon *et al***.** (2010), the significant inclusion of Mukene in feeds largely accounted for the reduced supply of *R. Argentea*. The continued use of fishmeal as a major protein source in animal feeds (Gatlin *et al.,* 2007) has increased the demand for Mukene on fish farms. The continued expansion of animal farming systems implied increased utilization of the *R. argentea* (El-Sayed & Gaber, 2003; Liti *et al*., 2006; Gatlin *et al*., 2007; Hardy, 2010). Notably, Hashim (2006) reported that 34% of the world fishmeal production was converted into animal feed in 2002.

When compared to other animal ventures, aquaculture has shown exceptional growth in the consumption of fishmeal. According to Tacon *et al*. (2010), aqua feed accounted for 68.4% of the fishmeal intended for animal feeds. The relatively higher demand for aquaculture products emphasized the importance of fishmeal in the farmed species. The compulsory inclusion of fishmeal in aqua feed as highlighted by Rust et al. (2012) emphasizes aquaculture‟s dependency on the Mukene fishery. Ultimately, it has become evident that the species supply is unlikely to match the fast-growing aquaculture demand. Hyuha *et al*. (2010) concluded that if aquaculture sustains the annual growth rate of 10%, it would overfish the Mukene stock by 2020.

Fishmeal is essential in feed formulations (Hassan, 2001; Muhoozi, 2001; Wu-chang *et al*., 2004; Coyle *et al*., 2004; Olfasen, 2006). The dietary component stimulates fish production largely due to its highly digestible and perfect balance of nutrients (The Fish Site, 2010; FAO, 2005; Bainempaka, 2006). According to Miles & Chapman (2006), dietary fishmeal induced optimal growth and yield in cultured Nile tilapia (*Oreochromis niloticus L.)*. Despite the excellent production performance, reliance on the fishmeal as feed ingredient is increasingly becoming uneconomical. For example, one kilogram of the fishmeal derived commercial feed rose from 0.272 USD in 2010 (Iganga Fisheries Technical Report, 2010) to 0.314 USD by 2015 (Fish farm Base-line Survey, 2015).

The rising fishmeal prices are likely to constrain the growth of aquaculture (Calvelle *et al.*, 2013) due to the inevitable elevation in fish production cost. Increased production cost on fish farms justifies the fishmeal elimination in aqua feeds (Mmanda, 2020; Hardy, 2010; Bob-manuel & Erondu, 2010) with more cost-effective alternatives. The majority of investigations are insisting on application of farm made feed (Al-thobaiti *et al*., 2017). The preference aims at eliminating the extra costs associated with off-farm alternatives. Prioritization of plantproteins in fish diets has intensified due to the demerit of fishmeal (Goda *et al.,* 2007). The diverse flora in sub-Saharan Africa (Moehl & Hawart, 2005) implies that a wide range of alternatives to dietary fishmeal exist in the region. Authors including Goda *et al*. (2007) indicated that local availability had become a relative advantage of plant products in fish feed formulations subsequently accounting for the increased preference of vegetable products in artificial diets in many countries. Among the cultured species, trials on plant- derived feeds have largely targeted farmed Nile tilapia (Nordahl & Pickering, 2004; El-Sayed, 2006; Agbo, 2011; FAO, 2013; Al-thobaiti *et al*., 2017). The herbivorous nature of Nile tilapia accounts for the dietary preferences. El-Sayed (2006), Aanyu (2009) and Fitzsimmons (2009) indicated that adults in Nile tilapia were herbivorous and largely suitable for the plant-derived diets.

The availability of plant-derived components on fish farms often results in a lower cost compared to dietary fishmeal (Bob-manuel & Erondu, 2010). Because of this comparative advantage, plant-based feeds are an appealing alternative for aquaculture. However, Gatlin *et al*. (2007) point out that limited production restricts the inclusion plant-based feeds in cultured fish. The use of plant-derived diets in aquaculture frequently results in lower fish productivity due to a variety of causes. Anti-nutrients found in plant ingredients, as well as shortages in critical amino acids, have been linked to poor fish development and overall performance (Yildrim *et al*., 2014). Furthermore, as indicated by David *et al*. (2003), large quantities of non- digestible components in plant-based meals can impede efficient nutrient use by the farmed species.

The poor fish growth offsets the relative advantage of low cost among the dietary plant proteins (Obirikoranga *et al*., 2016; Chakraborly *et al*., 2019) consequently reducing cost-effectiveness. The phenomenon largely accounts for the stagnated progress towards the complete inclusion of plant-derivatives in artificial diets. That accounts for the partial inclusion plant-based ingredients in artificial diets of farmed species in many countries. Although plant feedstuffs are the future for aquaculture development (Gatlin *et al*., 2007), the practical application of „all plant‟ diets on fish farms is yet to succeed.

Soybean meal (SBM) as one of the plant proteins has been recognized as a potential substitute for dietary fishmeal in fish production (Nordahl & Pickering, 2004; Uga-chick, 2014). According to the Agricultural Planning Department (2010), the scarcity of fishmeal has made SBM a competitive alternative. Despite its potential, SBM did not acquire sustained popularity in Uganda. For example, Naylor (2009) reported that high price precluded the extensive use of soybean meal in aqua feeds. This price barrier made it difficult for SBM to compete with dietary fishmeal in terms of cost-effectiveness. As a consequence, the costly fishmeal has persisted in the Nile tilapia diet. Since high cost of feed poses a significant threat to the profitability of aquaculture operations (Sogabesan & Bashir, 2018), the continued use of fishmeal derived diets is a risk to the profitability of Nile tilapia farming. Local farms in Uganda have witnessed a high production of peanuts, which is a relative advantage for utilizing the crop as an ingredient in artificial fish feeds (Agricultural Planning Department, 2010). In addition, inherent nutritional factors such as excellent palatability, high protein and phosphorus contents can improve the suitability of peanut-derivatives for aqua feeds (Peanut Institute, 2003).

The intensification of peanut production links to the National Agricultural Advisory Services that promoted the following varieties; Red Beauty (Kabonge), Serenati II and Serenati III (NAADS National Review, 2009). Despite the consistent omission of peanut products in fish feed formulations, Chakraborly *et al*. (2019) revealed that peanut meal exhibits a high possibility for future incorporation in aqua feed. Aflatoxin contamination has been a significant factor for the exclusion of peanut derivatives in aquaculture feeds (Tuan *et al*., 2002). However, conflicting findings emerged among researchers in relation to the limitation. Meteljan (2001) revealed that aflatoxins were not specific to peanut products while Russa & Yanong (2002) indicated higher resistance to the pathogens in Nile tilapia relative to other farmed species. Despite the lifted restriction, peanut- derivatives particularly peanut meal (PNM) achieved only partial substitution of the dietary fishmeal (Agbo, 2008; Agbo *et al*.; 2011; Liu *et al*. 2011; Yieldrim *et al*., 2014) implying that complete inclusion was unattainable. The partial substitutions or low inclusions characteristic to dietary PNM in Nile tilapia were reflections of poor performances at higher inclusion levels. Following the limited success, Borgeson (2000), recommended further research on the utilization of peanut products in fish feeds.

The limitations on the performance of dietary PNM in farmed species were largely due the following; firstly, the sole protein was deficient in theamino acid essential for growth referred to as lysine (Yieldrim *et al*., 2014). Certain investigations mitigated the above limitation via perfect blending of dietary peanut meal with other plant-derived proteins. According to Cost *et al*. (2001) and Gosh & Mandal (2015), improved performance was possible following the mixing of peanut meal with other oil-seed meals. The combination attained significant promotions (p□0.05) in fish growth rates; Kaushik & Seliez (2010), Gonzalex-Felix *et al*. (2010) and Dernebasi & Karayuce (2017) due to mutual supplementation by the constituent oil seed meals. Shukula *et al*. (2018) revealed that Blotch (*Heteropneutes fossilis*) performed significantly better (p□0.05) when a mixture of PNM and soybean meal (SBM) in a 50:50 ratio replaced dietary fishmeal.

Secondly, the attempts to eliminate dietary fishmeal using peanut derived products in cultured fish concentrated on growth rates (Mbahinzireki, *et al*., 2001; Goda, 2007; Mensah, 2013; Obirikorange *et al*., 2016). Despite the simplicity of fish growth responses (Soltan *et al*.,(2008), they are restricted to gains in fish biomass (Soltan *et al*., 2008) without regard to possible fish losses particularly under the semi-intensive production systems. Authors largely omitted comprehensive alternatives such as net yield that consider both loss and gain in fish biomass (Mukwanja & Kapute, 2015; Limbu *et al*., 2016; Phiri *et al*., 2018; Limbu, 2020). The exclusiveness of fish growth trials renders them unreliable under susceptible production systems such as earthen ponds.

Thirdly, the evaluation of fishmeal replacers in the Nile tilapia diet took biological views with limited economic studies (El-Sayed, 2006; Ogello *et al*., 2014) yet the corresponding cost of production is increasingly influencing the viability of farmed species. The phenomenon accounts for the repeated application of the following parameters in farmed fish; fish growth (Tiamiyu *et al*., 2013; Menghe & Penelope, 2017) feed conversion efficiencies (Rust *et al*, 2011; Divu *et al*., 2013) and yield (Mengistu *et al*. (2019). According to Mmanda (2020), economic analyses are supposed to justify the inclusion of non-conventional ingredients in fish feeds. Consequently, comprehensive evaluation of performance is the requirement for the attainment of a valid and sustainable replacement of dietary FM in cultured species.

Ultimately, the initial tests on the peanut meal as alternative to dietary fishmeal equated to under-evaluation. Since potential ingredients as alternatives to fishmeal in fish feeds require thorough evaluation (Glencross et al., 2007), there is need for an adjusted approach to the substitution of dietary ingredient in farmed fish. Therefore, the current study aimed at evaluating biological and economic performances in pond cultured Nile tilapia fed on peanutbased meals as alternatives to dietary fishmeal.

1.2 Statement of the problem

The rising price of dietary fishmeal is increasingly offsetting the rapid growth stimulated in Nile tilapia (Aanyu & Graber, 2010; Hyuha, 2011) consequently leading to lowered cost-effectiveness of the conventional feed ingredient. Attempts on complete substitution of dietary fishmeal by low-cost plant-based alternatives were largely unsuccessful due to poor fish growth (Agbo *et al*., 2011; Khan *et al*., 2011; Bamba *et al*., 2014). Only soybean meal was comparable to the fishmeal in the Nile tilapia diet (Nordahl & Pickering, 2004) albeit temporarily. The high demand for soybean coupled with low production in Uganda (Uga-chick, 2014) led to the unsustainability of the vegetable product in aqua feed formulations. Subsequently, dietary fishmeal has persisted in the farmed Nile tilapia.

The local and intensive production of peanut in Uganda (Agricultural Planning Department, 2010) coupled with its high protein (Gosh & Mandala 2015) render the crop product a possible substitute to fishmeal in aqua feeds. Although the retardation in Nile tilapia growth fed on peanut products (Fapohunda, 2008; Gosh & Mandal, 2015; Yieldrim *et al*. 2014) discouraged further investigations, the potentiality remains high. The previous trials on dietary peanut meal in farmed Nile tilapia were exclusive and ultimately under-evaluated; based on sole proteins (Agbo *et al.*, 2011), largely targeting growth rates (Mbahinzireki, *et al*., 2001; Goda, 2007; Mensah, 2013) with no regard to the production economics (El-Sayed, 2006; Ogello *et al*., 2014). Potential ingredients as alternatives to fishmeal in fish feeds require thorough evaluation (Glencross *et al*., 2007) contrary to the previous investigations. The phenomenon accounts for the current study on biological and economic performances in pond cultured Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

1.3 Significance of the study

Since the selection of a suitable alternative based on both biological and economic performances, the current study is likely to result into production of a cost-effective dietary alternative to the dietary fishmeal in Nile tilapia. The possible recommendation of a peanut-based meal as dietary fishmeal alternative will conserve the Mukene fishery in Uganda via reduced fishing pressure on the species in Lake Victoria and L. Kioga. The exclusion of fishmeal in the Nile tilapia diet will preserve the feed component for other farmed animals particularly poultry and pigs. The resultant dietary demand in Nile tilapia will increase the local production of peanut and soybean cropping in Uganda. Further still, the integration of traditional farming systems with nitrogen fixers (peanut and soybean crops) will improve on soil fertility and productivity of farmlands. The use of earthen ponds to mimic the most common and local fish production system in Uganda will render the results more applicable than the largely artificial production systems. The application of fish reserve ponds to mitigate possible losses of fish is likely to improve on the popularity of earthen ponds among investigators. The use of multiple responses during the study will improve on the validity of the current results. Amidst the continued loss of plant biomass due to human activities, use of blended proteins is becoming the viable method for generating the variation for research on ingredient adjustments in fish diets.

1.4 Objectives

1.4.1 General objective

The overall objective was to study the biological and economic performances of peanut-based meals as alternatives to dietary fishmeal in pond cultured Nile tilapia (*Oreochromis niloticus L.*).

1.4.2 Specific objectives

The specific objectives of the study were to relate;

1. Selected water quality and fish biomass production in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.
2. Feed Conversion Ratios in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.
3. Relative Growth Rates in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.
4. Net Fish yields in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.
5. Survival Rates in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

6. Economic Conversion Ratios in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.
7. Profit Indices in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

1.5 Hypotheses

The null hypotheses of the study tested whether:

H_{01} No significant correlation existed between the selected pond water parameters and fish biomass production in Nile tilapia fed on peanut meal as alternatives to dietary fishmeal H_{02} No significant difference existed among Feed Conversion Ratios in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

H_{03} No significant difference existed among Relative Growth Rates in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

H_{04} No significant difference exists among Net Fish Yields in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

H_{05} No significant difference existed among Survival Rates in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

H_{06} No significant difference existed among Economic Conversion Ratios in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

H_{07} No significant difference existed among Profit Indices in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal.

1.6 Assumptions of the study

The current study based on the following assumptions;

a) The annual alternation of dry and wet seasons in Uganda is capable of varying the biological production and corresponding cost in farmed fish

b) The cost of fish feeding during the study reflected prices of feed ingredients in local markets.

c) Comprehensive evaluation of alternative diets required more than the fish production performance.

d) Valuations of inputs and outputs of the feeding trails based on the local Ugandan Shilling would limit the applicability of the current findings.

1.7 Ethical considerations

The current study adhered to the conventional guidelines and standards regarding the use of animals in scientific research following European Union (2010) and Metacafe (2011) as follows; capture of specimens using pond seine nets caused no physical harm to the experimental fish and the continuous water column during fish size measurements promoted a suitable environment for the fish specimens.

The research promoted secrecy of respondents‟ information during sample surveys in the commodity markets

CHAPTER TWO

LITERATURE REVIEW

2.1 Trends in local, regional and global production of farmed fish

The increasing human population in Uganda accounts for the elevated demand for fish (Kasozi *et al*., 2017). The population growth in Uganda estimated at 3 % per year has been important in promoting the market for fish products (Aanyu *et al*., (2010). Consequently, the higher annual per capita consumption of fish in Uganda estimated at 12.5 relative to the Africa"s average of 10.1 (Adeleke *et al*., 2020) reflects a rapidly growing human population. Fish products represent significant percentages in terms of both quantity and quality relative to alternative protein sources. Adeleke *et al***.** (2020) indicated that fish represent approximately 63% of the dietary protein in Uganda while Amoah (2011) concluded that quality is higher for fish relative to other animal proteins.

Uganda"s annual demand for fish products is projected at 1,700,000 by 2025 (Aanyu *et al*., (2020). The rising demand accounts for fish scarcity under the capture fisheries. Fish catches have declined since 2006 due to over exploitation of its water bodies (Kjaer *et al*., 2012). As a result, aquaculture has faced significant challenges in mitigating the declining fish supply from the capture fisheries. Although the decreased fish supply coupled with elevated demand are opportunities for aquaculture development in Uganda (Kasozi *et al*., 2017), the former has become more important in the country.

Since capture fisheries in Uganda are dwindling aquaculture is the undisputed alternative for the fish supply (Lulijwa *et al*., 2017). The overfished natural waters in the country have rendered aquaculture important as a source of commercial species (Mukiibi, 2001). According to Sserembala (2017), aquaculture contributed 20% of the fish production in Uganda. Aquaculture production in the country is reported to have increased from 31 metric tons in 1984 through 117,590 metric tons in 2015 (kasozi *et al*., 2017) to 120,000 metric tons by 2018 (Aanyu *et al*., 2020). The sustained growth in production will depend on level of profitability of farmed fish relative to other enterprises.

High cost of conventional feed ingredients such as fishmeal in Uganda has increased the production cost of farmed fish (Walakira *et al*., 2014). Authors including Adeleke *et al*. (2020) reported higher feed cost in Uganda relative to the corresponding fish sale price. The phenomenon has forced fish farmers to resort to accessible and poor-quality alternative feeds. According to Ondhoro *et al*. (2021), farmers opted for low priced grain brans and vegetable residues. Subsequently, lack of affordable and good quality feed has become one of the challenges of aquaculture in Uganda (Aanyu *et al*., 2020).

Production of cultured fish is highly integrated with the traditional farming enterprises in Uganda. Nile tilapia, catfish (*Clarias gariepinus*) and common carp (*Cyprinus carpio*) are the farmed species in Uganda (Lulijwa *et al*., 2017). Although catfish and Nile tilapia are increasingly produced under mixed fish farming (Sserwambala, 2017), the majority of farms in Uganda prefer Nile tilapia According to FAO Fish Stat (2016), the total productions for Nile tilapia and catfish by 2012 in Uganda were 52,303 and 43,586 tons respectively. The preference for Nile tilapia is largely based on the following; high demand due to good taste, easy breeding and tolerance to on-farm vegetable feed (Namatovu *et al*., 2018). The initial Nile tilapia based on mixed stocks became unpopular due to overbreeding coupled with stunted growth. Consequently, modern breeding particularly production of mono sex stock was introduced to enhance the growth of Nile tilapia (Ahmed *et al*., 2015).

Earthen ponds are the commonest culturing system for Nile tilapia in Uganda (Adekele *et al*., 2020). According to Sserwambala (2017), there were about 14,000 fish farmers and over 30,000 earthen ponds in the country. The earthen ponds have largely succeeded in most parts of Uganda due to the water retentive loam and clay soils. Small and medium farms prefer the cheap earthen ponds for fish rearing (Mengistu *et al*., 2020). The estimated production of farmed fish in ponds is 70% of the global production (Kabir, 2019). Despite the significant contribution to the production of farmed species particularly Nile tilapia, earthen ponds are prone to deterioration in water quality (Ondhoro *et al*., 2021), and predators (Mengistu *et al*., 2020) and competitors such as wild fish. Despite the popularity, the limitations have rendered the culturing system less profitable in many countries including Uganda.

Generally, East and Central regions of Africa dominate the African production of farmed fish. Countries such as Egypt, Uganda, Ghana, Tunisia, Kenya, Zambia, Madagascar, Malawi and South Africa are largely involved in aquaculture production (Wachira, 2021). Production from the African continent is responsible for only 2.67% of the world production (Adeleke, 2020) implying an insignificant contribution. Nile tilapia and catfish (*Clarias gariepinus*) are often combine in production ponds in many countries (Ragasa *et al*., 2022), but the production of the former has been growing at 15 % annually particularly in sub-Saharan Africa. The growth rate is likely to render the species unparalleled in terms of contribution to total production in the region. According to Wachira (2021), the estimated Nile tilapia production is over 80% of the aquaculture production in sub-Saharan Africa.

Despite the mild contribution, Bolton (2017) revealed that there is a growing need and opportunity to develop aquaculture in response to the depleted fisheries in Africa. The fresh and diverse aquatic resources on the continent imply a high potential for culturing a wide range of fish species. There is no doubt that development in aquaculture production in many parts of

Africa is still in progress. Despite the consistent exploitation of earthen ponds and cages for fish farming (Adeleke *et al*., 2020), other potentials such as streams, dams and flooded rice fields remain unexploited.

The 11% worldwide growth rendered aquaculture the fastest expanding farming system by 2000 (Machena *et al*., 2001). Under-utilization of natural resources has largely restricted it in sub-Saharan Africa. Although the natural environment has been important in aquaculture production in the region, other inherent relative advantages are increasingly becoming visible. Further attempts to enhance the production system should exploit the favourable tropical climate for fish growth and high demand for fish protein (Adeleke *et al*., 2020). Despite the potentials for the farming system, Machena *et al*. (2001) concluded that aquaculture development in Africa was to follow a long and bumpy road.

Uneven production of cultured fish exists worldwide. Asia alone shares 92% of the world production of farmed fish (World Fish Centre, 2009; FAO, 2012). The Asian countries account for 89% of world production of cultured fish. Among the Asian countries, China is the best in terms of fish production (FAO, 2020). The global aquaculture production grew by almost 12 times in the past three decades (FAO, 2012) rendering the increase greater than ever before. According to FAO (2020), global fish production due to aquaculture reached 46% in 2018 up from 25.7% in 2000. None of the traditional farming systems has matched the exponential growth of the culture fisheries.

The hike in fish farming largely aimed at mitigating the dwindled capture fisheries. Despite the current dominance of capture fisheries (Suleiman & Ahmed, 2011), aquaculture industry is showing an upward trend. Growth rates of 9-10% and 1.2% for cultured and wild fisheries respectively (Mbahinzireki, 1999) indicate that supremacy of capture fisheries is unlikely to persist. Subsequently, aquaculture is destined to succeed the capture fisheries as major fish producers. Increased access to aqua feed largely accounts for the rise in aquaculture production. The emphasis of the pivotal role of feeds in the aquaculture development was published.

According to Machena *et al*. (2001), feed remains one of the most prominent barriers to the expansion of aquaculture production.

The elevation in global production of farmed fish from 130.2 million tons to 148 million tons from 2001 to 2010 (FAO, 2012) accounted for the increased application of aqua feeds. On-farm feed supply rose from 19.3 in 2003 to 30.7 million tons by 2013 (De-silva & Hassan,

2007) consequently reducing the reliance on natural fish feed in many countries. Since the expansion in fish farming demanded efficient technologies, industrial aqua feed production became an inevitable progression. Subsequently, fed aquaculture continued outpacing the non-fed counterpart as a preferred approach. This transition from on-farm to large-scale feed processing inevitably modified the fish farming. According to World Fish Centre (2009), the gradual shift from extensive to intensive aquaculture systems reflected the increased feed input.

Since fish production correlates directly with aqua feed supply, the latter governs the economics of the farmer more than any other farm input. In developing countries such as Uganda, cost of feed is the most pressing challenge in fish farming (Lulijwa, *et al*., 2017). The economics of production in cultured fish is largely governed by feed input. Feed remains prohibitively expensive for small-scale farmers (Ragasa *et al.,* 2022). Both the access and nutritional content of fish feed are critical issues in the production of cultured fish. According to Machena *et al*. (2001), both quality and quantity are limiting the production of farmed fish.

2.2 Feeding trials and water quality in farmed fish

Knowledge on fish feeding is limited and varies among the cultured species. Investigations conducted in the late 20th century focused on amino acids, proteins, lipids and vitamins requirements of fish (Hardy, 2003). Despite the increased aquaculture production, studies on fish feeding narrowed to specific areas. The focus was on nutrient demands for selected species namely rainbow trout (*Onchorhynchus mykis*) and channel catfish (*Ictalurus punctatus*) (Lall,1991). In the tropics, nutritionists targeted indigenous fish probably due to their high demand. Trials especially in sub-Saharan Africa involved highly marketable species particularly Nile tilapia (Suleiman & Ahmed, 2011).

Scientific research on specific nutrient requirements of fish has grown considerably along with the development of aquaculture (FAO, 2013). Most research on fish nutrition has aimed at acquiring knowledge on production of suitable feeds for the various cultured species. The advances in fish nutrition have included the development of balanced diets (Crags & Helfrich) that promote optimal growth and health in cultured fish. Subsequently, there has been a growing trend towards improving the quantity and quality of compounded aqua feeds.

Field-based feeding trials are increasingly becoming popular among farmed fish. Although information on nutritional requirements of fish has largely been generated through controlled trials (Mbahinzireki *et al*., 2001; Marty, 2003; Akinawole & Faturori, 2007; Makwinja & Kapute, 2016; Davidson & Summerfelt, 2016), customization to local farm conditions became difficult. That explains why Liti *et al*. (2006) repeated the artificial experiment of Jauncey & Ross (1982) on Cotton Seed Meal as fishmeal substitute in the Nile tilapia fed under semi-artificial fishponds. According to Ogello *et al*. (2014), conditions close to the natural environment are fit for long-term evaluation of alternatives to dietary fishmeal in farmed fish.

In order to promote applicability, feeding trials are increasingly customizing to farm field conditions.

Fishponds remain the commonest farming systems for Nile tilapia in many countries including Uganda (Ondhoro *et al*., 2021). Despite the complicated feed management in fish raised under earthen ponds (FAO, 2013), the cheaper initial investment accounts for the popularity of the production system. The limited control over water quality, fish stock and other external variables render feeding trials under the earthen pond systems risky compared to alternative systems.

Poor feeding practices contaminate water in the earthen fishponds consequently leading to fluctuations in productivity and profitability in the farmed species (Phiri, 2018; Ahmed, 2015). That explains why pond productivity among small and medium scale Nile tilapia farms varies considerably Mengistu *et al*. (2020) despite the application of recommended management systems. The unfavorable environment created by water pollution negatively affects profitability via loss of fish biomass and corresponding lowered product value. Reduction in stock densities due to fish mortality (Bolivar *et al*., 2011) remains the greatest limitation facing fish feeding experiments in earthen ponds.

Fish feeding has the potential to have significant effect on key water characteristics such as dissolved oxygen, temperature, unionized ammonia, nitrite, and pH. These parameters are susceptible to alteration due to the fish feeding techniques employed. (Makori *et al*., 2017). Deviation from optimum levels of specific water parameters (Table 2.1) due to feed contamination often triggers stressful conditions in cultured fish.

Robinson (2015) stated that feed conversion is more efficient in fish raised under optimum than unfavorable conditions. Consequently, optimum fish productivity is dependent on maintenance of appropriate water parameter levels. Poor water quality can lead to reduced fish yield (Makori *et al.*, 2017) and other negative effects on fish production. According to Mengistu *et al*. (2019), contamination of fish cultures due to improper feeding culminated into fish mortality. Baccarin & Carmago (2005) revealed that impaired production and profitability in Nile tilapia culture was partly due to poor water quality. Ultimately, water quality, productivity and profitability correlate positively in farmed fish.

Table 2.1: Ranges for water quality parameters in Nile tilapia cultured in fresh water

Water quality parameter	Acceptable ranges	References
Water temperature	25-29 □ C	(FAO, 2012), (Gray, 2001)
Dissolved Oxygen	4.0-6.0 mg/l	(Marty, 2003)
Ammonia nitrogen Nitrite	0.025-0.05 mg/l	(Popmat & Masser, 1999) (Stone *et al*., 2005)
Nitrogen Water pH	1.5-2.0 mg/l	(Stone *et al*., 2005)
	6.5-9.5	

*mg=milligrams, l=litre, C=centigrade

The effect on water quality varies depending on type of feed component. Among the feed ingredients, protein sources account for the state of water quality (Torres-Beristain *et al.*, 2004). Consequently, poor water conditions in fish culturing systems are largely due to dietary protein. Production of the toxic unionized ammonia and alteration of pH in water bodies due to dietary protein (Onada *et al.*, 2016) are the major water quality concerns in fish farming. Since poor water quality negatively affects growth rate, yield and survival in farmed fish (Abou *et al*., 2012; Onada *et al*., 2015), feeding trials should maintain optimum water conditions for the targeted species. Poor water quality due to fish diets can affect the outcome in a trial. According to Goda *et al*. (2007), conflicting results that followed the dietary fishmeal replacements with alternative ingredients in farmed fish attributed to variation in culture conditions.

Ecological factors are increasingly influencing the substitution of dietary fishmeal in cultured species. Although high cost of the fishmeal-based diet has been a major concern for aqua culturists (Turchini *et al*., 2019), the corresponding negative effect on water quality is equally important. Subsequently, the role on water quality has amplified the efforts aimed at complete elimination of fishmeal in fish diets. The negative effect on fish survival due to poor water quality (Abou *et al*., 2012; Onada *et al*., 2015) counteracts the high fish productivity due to dietary fishmeal (Miles & Chapman, 2006).

2.3 Classification and production of farmed Nile tilapia

Production is higher for Nile tilapia than African catfish (*C. gariepinus*) and other farmed species in Uganda (Namatovu *et al*., 2018). The species dominates major water bodies in Uganda and other countries. Nile tilapia represents more than 75% of tilapias worldwide and is next to carps (*Cyprinus*) as the most widely farmed fish (FAO, 2009). Although the genus *Oreochromis* where Nile tilapia belongs (Gray, 2001) is endemic in eastern and southern Africa (Picker & Griffiths, 2011), it invaded other tropical countries outside the region.

Repeated adjustments in the naming of Nile tilapia reflect the intensive research on the species taxonomy. The previous *Tilapia nilotica* became *Sarotherodon nilotica* and ultimately *Oreochromis niloticus L*. (Meschkat, 2003). The several sub-species existing imply high speciation in Nile tilapia: *Oreochromis. niloticus niloticus, O. niloticus eduadianus, O. niloticus vulcani, O. niloticus baringaensis, O. niloticus sugatae, O. niloticus tana* (Luna & Torres, 2005). The speciation in Nile tilapia links to both genetic and environmental factors. Although genetic variants from the original stock largely accounted for the high diversity in

Nile tilapia (Mwanja, 2000), the impact of varied aquatic environments became important. Subsequently, local habitats partially determined the speciation in Nile tilapia. For example, the emergences of *Oreochromis n. eduadianus* and *Oreochromis n. baringoensis* attributed to their localities; Lake Edward and L. Baringo respectively (Luna & Torres, 2005).

Nile tilapia is capable of surviving under conditions at contrasting extremes; deep, fast flowing waters (Picker & Griffiths, 2011), shallow and still waters Nyakuni (2008). Despite the exploitation of varied aquatic conditions by the species, specific habitats have proved to be more productive. Generally, Nile tilapia prefers shallow and sheltered waters (Onada *et al*., 2015). According to Luna & Torres (2005), high yields in Nile tilapia occurred under flooded crop fields. The dominant pond culture of Nile tilapia in Uganda (National Aquaculture Sector Review, 2013) reflects the species preference for shallow waters. Despite the popularity among farmers in many countries, production of fish under earthen ponds is risky. Pond-raised fish were negatively affected by uncontrolled breeding, stunted growth (FAO, 2006) and high mortality (Mengistu *et al*. 2019).

The unequal worldwide distribution of Nile tilapia links to variations in water temperature. The warm water characteristic to the tropics largely accounts for the intensive production of the species. The favourable temperature range of 28-30 °C for Nile tilapia induces fast growth andincreased biomass production (Onada et al., 2015). In addition, the parameter exhibits other effects in the fish. Meschkat (2003) revealed that warm water temperatures accelerate breeding in Nile tilapia. According to FAO (2006), warm aquatic environments facilitate the economical production in Nile tilapia. Ultimately, the potential for profitable production of the species is higher for sub-Saharan Africa relative to other regions.

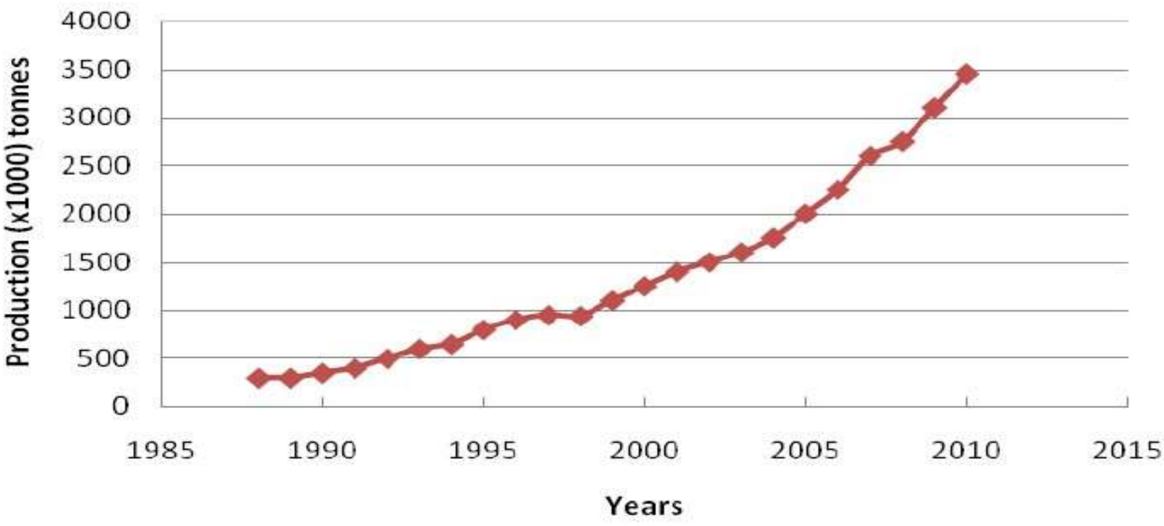


Figure 2. 1 Trend of global production of farmed Nile tilapia in a period of 30 years.

Source: FAO (2006)

Nile tilapia production systems are subsistence, semi-intensive or intensive (Mengistu *et al*., 2020). Categorization of the production systems links to level of input use. The increased fish farming is likely to mitigate the over harvesting of Nile tilapia in natural waters. Between 1990 and 2010, growth in the production of Nile tilapia experienced exponential growth globally (Figure 2.1). Subsequently, the cultured species has become a top priority in many countries. Nile tilapia became commercially important due to its high demand (Liti *et al*., 2006). Despite the relative advantage, Hyuha *et al*. (2010) reported uneven production in Nile tilapia worldwide. According to El-Sayed (2006), prominent contributors to the production of farmed Nile tilapia include; China (50%), Egypt (12%), Philippines (9%), Indonesia (8%), Thailand (7%), Taiwan (6%), Brazil (3%), Laos (2%), Colombia (2%) and Malaysia (1%). China that has consistently accounted for not less than half of the global supply of farmed Nile tilapia (FAO, 2013) is likely to retain the supremacy throughout the first half of 21st century.

2.4 Tested plant-based products in the Nile tilapia diet

Soybean meal and fishmeal exhibited comparable performances in terms of fish growth rates in feeding trials (Soliman, 2006). Subsequently, Zhenhva *et al*., (2019) indicated that the ingredient appropriate for the fishmeal replacement in aqua feeds. Despite the success, fish feeds did not sustain soybean meal due to economic factors.

Table 2.2: Leading countries in global production of soybean by 2012

Country	MT
• United States	91.39
• Brazil	86.7
• Argentina	53.4
• China	11.95
• India	9.5
• Paraguay	8.2
• Canada	5.4

*MT= metric tons Source: FAO (2016).

Irrespective of the favorable environmental conditions in many countries, (Agbo *et al*., 2011), soybean production remained poor in countries including Uganda (Uga-chick, 2014).

Few countries namely United States of America, Brazil, Argentina and China control soybean production worldwide (Table 2.2). The four nations hold nearly 80% of global production of the crop (Nordahl, 2011). Since all the major producers are located outside sub-Saharan Africa, access to soybean in the region has become difficult. The low soybean production led to scarcity and hiking prices for the products including soybean meal in many countries (Azaza *et al*., 2009). The phenomenon accounts for the persistence of dietary fishmeal in many countries including Uganda. According to Turchini (2019), reliance on dietary fishmeal remains an on-going constraint.

Although peanut products belonging to family Leguminosae rank fourth as the largest oil seed suppliers globally (Health & Nutrition research, 2010), they rarely constitute fish feed formulations in many countries. Despite the potential of peanut derivatives such as peanut meal, El-Sayed & Gaber (2003) reported that they rarely constitute the fish feed formulations. The few investigations on peanut meal attained only partial substitution of the dietary fishmeal in farmed Nile tilapia (Yildrim *et al*., 2014).

APD (2010) revealed that production in the eastern districts of Uganda was higher for peanut than other oil seed crops such as cotton, soybean and sunflower. The crop is intensively cultivated in the districts of Kumi, Tororo, Soroti, Iganga, Kamuli, Mbale, Gulu, Kitgum and Nebbi (Busolo-Bulafu & Obong‟o, 2001). The increased production of peanut products in the country links to the National Agricultural Advisory Services. The program encouraged large-scale production of specific peanut varieties in the area particularly Red Beauty (Kabonge), Serenati II and Serenati III (NAADS National Review, 2009).

According to Peanut Institute (2003), the following is the amino acid share in 25 of 100 grams (g) of peanut; tryptophan (0.2445g), thereonine (0.859g), isoleucine (0.882g), leucine (1.62g), lysine (0.901g), methionine (0.308g), cytine (0.322g), phenylanine (1.300g), tyrosine (1.020), valine (1.052g), arginine (3.001 g), histidine (0.634g), alanine (0.997g), aspartic acid (3.060g), glutamic acid (5.24g), glycine (1.512g) proline (1.107g) and serine (1.236g). The short list indicates low availability of methionine and lysine. The deficiencies of the two EAAs account for the growth retardations in Nile tilapia fed on peanut meal (Agbo, 2008; Agbo *et al.,* 2011). Despite this limitation, characteristics such as high palatability (Health & Nutrition research, 2010) coupled with high Crude Protein and phosphorus levels (Peanut Institute, 2003) have promoted the application of peanut products in aqua feed.

The exclusion in aqua feed formulations partly links to pathogenic infection. Suspicion of aflatoxins in peanut meal particularly *Aspergillus flavus* and *A. parasiticus* (Russa & Yanong, 2002; Chakraborly *et al*., 2019) discouraged investigations on its potential as a feed ingredient. Although susceptibility is higher in peanut derivatives, Russa & Yanong (2002) and Bainempaka (2006) revealed that aflatoxins could attack all forms of feed stored under dirty and humid conditions. Since the pathogens are not specific to peanut products, the restriction to explore peanut as a feed ingredient has become invalid.

The application of sole sources of peanut meal for complete replacement of dietary fishmeal was unsuccessful in aqua feed. The reduced growth in fish fed solely on dietary peanut protein was due to lysine and methionine deficiencies (Agbo, 2008; Agbo *et al*., 2011; Yildrim *et al*., 2014; Chakraborly, 2019). The failed attempts imply that the single protein cannot attain complete replacement of fishmeal in diets of cultured species due to poor production performance. Instead, Gosh & Mandalla (2015) indicated that inclusion levels below 50% of ground (peanut) cake did not depress growth in Nile tilapia. Subsequently, investigations on fishmeal substitution in fish diets are inevitably shifting to mixtures of plant-derived proteins. According to Kaushik & Seliez (2010) and Gonzalex-Felix *et al*. (2010), perfect combinations of dietary proteins can improve on feed performance by mimicking the amino acid profile of the targeted fish.

2.5 Economics of inclusion of dietary protein supplements in cultured fish

Expenses on raw ingredients largely constitute the cost of fish feed. The stiff competition for ingredients accounts for the hiking prices of artificial feed (The Fish Site, 2010; Rust *et al*., 2012). Variation in commodity prices exists among fish feed constituents. According to De-Silva & Hassan (2007), protein supplements are the most expensive in fish feed formulations. Although Skiba *et al*. (2015) generalized that economical feeding in farmed fish is highly dependent on ingredient prices; Tiamiyu *et al*. (2016) specified that profitability in aquaculture closely relates to prices of protein feeds. Subsequently, high price of dietary fishmeal (Bob- manuel & Erondu, 2010; Gonzalex-Felix *et al*. 2010) accounts for the lowered profitability in farmed fish.

Authors including Suleiman *et al.* (2011), Borski *et al.* (2012) indicated that dietary fishmeal constituted 40%-70% of the fish feed cost. Consequently, the production economics of cultured species relates to the inclusion level of dietary fishmeal. Climatic hazards that led to hiking prices of crop-derived products (APD, 2010) are reversing the trend of feed costs. Prices have risen faster for feed ingredients derived from terrestrial than aquatic environments. Cost *et al*. (2001) specifically revealed that peanut meal is more expensive than the dietary fishmeal. According to Byrne (2017), price competitiveness is increasingly governing the choice of alternative diets in cultured fish.

Despite the higher biological production of dietary fishmeal in farmed species, other economic factors are offsetting the relative advantage. The global fishmeal supplies reached a plateau (Nune & Vazquez, 2014) and led to scarcity of the feed ingredient. Specifically, Lucy (2015) revealed that overfishing of mukene in natural water bodies accounted for the inaccessibility to fishmeal in Uganda. Subsequently, Chai *et al*. (2020) reported that the high demand for fishmeal resulted into increased fishmeal prices. The rising prices imply that the future for the conventional dietary protein source may become unsustainable. According to Daniel (2018), fishmeal will no longer be a major fish feed protein in the near future. This occurrence can be ascribed to current efforts aimed at completely removing dietary fishmeal from cultivated species.

Efforts to promote affordable fishmeal substitutes are in progress (Gatlin *et al*., 2007). Although use of plant-derived diets is the low-cost option in aquaculture diets (Goda *et al*. (2007), production performance in farmed species remains a major concern. It is no longer solely the cost of fishmeal alternatives in aqua feeds since the challenge is beyond the unilateral variable. Since suitable alternatives to dietary fishmeal should be cheap and capable of sustaining fish growth (Daniel, 2020), the feed cost should be considered with corresponding level of fish production.

Ogello *et al*. (2014) recommended the locally available, cheap and non-conventional ingredients for fishmeal replacement in the Nile tilapia diet. Similarly, Chakarborly & Mallik (2019) revealed that plant proteins are easily available and fetch lower market prices compared to dietary fishmeal. Fish nutritionists should resort to on-farm vegetable products in order to lower the feed cost. According to Rust *et al.* (2012), investigators have promoted the utilization of crop resources in fish diets as a strategy for mitigating the highly priced fishmeal. Despite the intervention, feed cost is still a challenge in fish farming (Kasozi *et al*., 2014) due to the persistence of fishmeal in aqua feed formulations. Subsequently, substitution of dietary fishmeal with the plant-based products is yet to become economical in cultured fish.

Although plant-based feeds are cheap (Al-thobaiti *et al*., 2018; Fall, 2018**;** Chakarborly & Mallik, 2019), they induce poor growth in farmed fish (Gatlin *et al*. 2007; Agbo *et al*., 2011). The trade-off between the cost of plant-derived meals and the potential limitation of fish growth eventually undermines their overall cost-effectiveness. This explains why majority of the recommended plant-based alternatives to dietary fishmeal are limited to partial substitution. Induction of high fish production mitigates the increased price of dietary fishmeal (Miles & Chapman, 2006; Byrne, 2017) consequently rendering the ingredient more cost- effective than the plant-derived counterparts.

According to Turchini *et al*. (2019), it has not been possible for plant-derived alternatives to match the fish production performance elicited by dietary fishmeal. Complete substitution of the dietary ingredient by plant-derived alternatives has been unattainable. Maintenance of the rapid fish growth due to dietary fishmeal in cultured species by plant-based alternatives (Miles & Chapman, 2006) is the major challenge facing the complete elimination of former in aqua feed formulations. Despite the limitation, attempts on complete replacement of dietary fishmeal by plant proteins are still in progress.

According to Goda *et al*. (2007), the abundant supply of crop products on farmsteads makes them economically viable and highly likely to dominate fish feed formulas. The herbivorous character in Nile tilapia (El-Sayed, 2006) accounts for its consistent involvement in plant-based feeding trials. Although wild plants became dominant in fish feeds (Hardy, 2003), depletion of the resource due to intensification of human activities (Moehl & Hawart, 2005) is increasingly reversing the trend. Subsequently, a restricted inclusion of wild vegetation in aqua feeds is likely to manifest. Irrespective of the high demand for crop-derived products (APD 2010), the ingredients are destined for fish feed formulations.

Oil-seed products have dominated the research for possible substitutes to fishmeal in fish feeds (David *et al.*, 2003; FAO, 2013). The focus on the vegetable ingredients in Uganda and other sub-Saharan countries reflects the intensified production of oil seed crops. Some of the tested oil-seed meals in fish diets include soybean meal (Nordahl & Pickering, 2004; Soliman, 2006; cottonseed meal (Mbahinzireki, 1999), sunflower meal (Merica *et al*., 2015) and peanut meal (Yidrim *et al*., 2014).

While high protein and energy contents have historically been considered critical nutritional qualities (Ramasamy, 2002), Azaza *et al*. (2009) highlight that the local availability of feed ingredients in tropical regions provides a relative benefit. Despite the high potential, trials on the oil seed meals published varying results. For example, dietary fishmeal substitution by cottonseed meal in Nile tilapia led to reduced growth rate (Mbahinzireki, 1999) while dietary soybean meal improved the growth performance in the same species (Nordahl & Pickering, 2004).

2.6 Production performance of protein sources in fish diets

Dietary fishmeal stimulates high growth and yield in farmed fish (Miles & Chapman, 2006). The excellent production performance due to fishmeal in aqua feeds links to several factors including desirable amino acid profile, good palatability, availability of essential nutrients in highly digestible forms (Bainempaka, 2006), high level of Crude Protein and minerals particularly phosphorus (Miles & Chapman, 2006). The exceptional performance of the dietary ingredient reflects its unique combination of nutrients. According to Rust et *al*. (2012), fishmeal contains the required nutrients in perfect balance. Ultimately, it has remained the standard for validating the biological performance of alternative proteins in fish diets.

The unrivalled performance of the dietary ingredient largely attributes to the amino acid pattern. The amino acid profile in dietary fishmeal is desirable since it is well-balanced (Yieldrim *et al*., 2014) and comparable to the body protein in farmed fish (Olfasen, 2006; Gonzalex-Felix *et al*., 2010). Suitable dietary proteins must possess balanced Essential Amino Acids in order to meet the requirements of targeted species.

Table 2.3: Comparisons of amino acid patterns for Nile tilapia (*Oreochromis niloticus L.)* and dietary fishmeal

EAA	CP (%)Nile tilapia	Fishmeal	Soybean meal
Arginine	5.04	5.70	7.33
Histidine	2.11	2.41	2.69
Leucine	6.35	7.74	7.71
Isoleucine	3.44	4.74	4.55
Lysine	5.93	7.91	6.36
Methionine	2.7	3.02	1.41
Phenylalanine	3.38	4.12	5.03
Threonine	3.8	4.37	3.89
Tryptophan	1.0	1.18	1.37
Tyrosine	0.24	3.33	3.83

*AA=Amino Acid, CP=Crude Protein

Source: Batal & Dale (2010).

The matching amino acid patterns between the body protein in Nile tilapia and fishmeal accounts for the excellent performance of the latter as a feed ingredient. Similarly, the appropriate amino acid profile is the most important factor accounting for the competitive performances of potential alternatives particularly soybean meal in terms of fish production (Table 2.3).

Soybean meal exhibits a superior blend of amino acids (Garry, 2017) becoming the most balanced amino acid profile among plant proteins (Gatlin, 2003). The amino acid pattern in soybean meal accounts for the higher suitability of ingredient in diets of cultured fish (Zhenhva *et al*., 2019) than other oil-seed meals. The largely similar levels of lysine and methionine accounted for the comparable performances in Nile tilapia fed on the fishmeal and soybean-based diets (Yildrim *et al*., 2014) (Table 2.4).

Table 2.4: Comparison of selected amino acid levels of dietary and body proteins in terms of limiting amino acids

Protein sources	EAA	
	Lys	Met
FM	8.0	2.9
SBM	6.28	1.38
PNM	0.47	0.44
Nt	5.1	2.7

*FM= fishmeal, SBM= soybean meal, PNM= peanut meal, Lys. = lysine, Met. = methionine, EAA= Essential Amino Acid.

Source: Yildrim *et al*. (2014).

Consequently, nature of amino acid largely accounted for the differences in performances among tested oil seed meals. Unlike the animal derived counterparts, Nune & Vazquez-Anum, (2014) revealed that deficient amino acid profiles among plant proteins such as peanut meal restrain protein synthesis. Nordahl & Pickering (2004) stated that the low levels of both lysine and methionine in dietary peanut meal accounted for the retardation in fish growth. The role of lysine in promoting fish growth is not doubtable. According to Gary (2017), lysine deficiency in plant-derived dietary proteins accounts for the poor growth responses in cultured fish.

Modification remains the most viable solution to the poor production performance characteristic to deficient amino acid profiles. Although mixtures of plant-based proteins increase the availability of essential amino acids in fish diets (Gonzalex-Felix *et al.*, 2010), only perfect combinations involving lysine rich proteins improve on biological production in farmed fish. Ultimately, the stimulation of rapid growth and yield in cultured species due to a desirable Amino acid profile EAA is not exceptional to dietary fishmeal.

2.7 Important responses induced by feeding in farmed fish

Feeding trials can induce multiple responses in farmed fish. Type of feed influences the level of induction of the physiological responses. The commonly targeted economically important responses in farmed fish include efficiency of feed conversion (Mengistu, *et al*., 2019), rate of growth (Soltan *et al*., 2008), net yield (Obaroh & Achionye-nzeh, 2011), survival rate (Royes *et al*. (2013), economic conversion of feed (Umaru *et al*., 2016) and profitability of fish feeding (Anani *et al*., 2017).

Performance indicators in feeding trials can be grouped group according to the target. Biological indicators of feed performance measure fish productivity (Farnshell *et al*., 2018). Among them are responses directly related to fish growth; Feed Conversion Ratios (Divu *et al*., 2013) and Relative Growth Rates (Agbo *et al*., 2011; FAO, 2012). In addition, Net yields (Limbu, 2020) and Mortality Rates (Mengistu, 2020) that feature during estimation of output equally indicate biological production in farmed fish. All the above variables largely focus on biomass production contrary to the indicators of economic performance. For instance, Economic Conversion Ratios relate feed input to farm output (Martinenz-Llorens, 2011) while the Profit Indices are involved in valuation of both inputs and outputs in farmed fish (Anani *et al*., 2017).

Although the majority of feeding trials relied on sole responses such as growth rate (FAO, 2012), combinations or diversification with alternative responses is necessary for validation of results. That explains why fish nutritionists are increasingly exploiting multiple responses. For example, the study on feed performance in African catfish (*C. gariepinus*) by Limbu (2020) targeted more than a single response particularly growth rate, size at harvest and net yield.

Levels of induction of responses in farmed fish vary according to type of feed or corresponding nutrient. Dietary protein that is essential for synthesis of body protein (Gabriel *et al*. 2007) yet most expensive in feed formulations (Aanyu & Graber, 2010), influences both the biological and economic responses in farmed fish. The existence of dissimilar protein supplements in nature (Bureau, 2006) may account for varied bio-economic responses in feeding trials. The phenomenon explains why protein sources have become important in feeding trials. Irrespective of high price for protein supplements in fish diets (Aanyu & Graber, 2010), their inclusion in aqua feed is obligatory (Gabriel *et al*., 2007).

According to Divu *et al*. (2013), Feed Conversion Ratio (FCR) refers to the number of kilograms of feed that can produce one kilogram of whole fish. It is the real measure for efficiency of feed conversion into fish biomass. The FCR relates feed mass to the desired farm output. Consequently, FCR compares physical forms of farm inputs and outputs (Mengistu *et al*., 2020) without regard to corresponding market values. Feeding trials reported two types of FCRs namely Biological Feed Conversion Ratio (BFCR) and Economic Feed Conversion Ratio (EFCR). bFCR is applicable under intensive cultures and is sensitive to feed wastage (Techna Group, 2015) contrary to the economic counterpart. According to Engle (2012), eFCR considers all the input including wasted feed. Since FCR generally considers the quantity of feed input, it is economically important in fish feeding trials. According to Mengistu, *et al*. (2019), under-performance in terms of FCR is a major concern in aquaculture as it negatively affects profitability on fish farms.

Since fishes expend less energy for body regulation, they possess lower or more efficient FCRs than terrestrial counterparts. According to Rust *et al*., (2011), the characteristic FCRs in the range of 1.5-2.0 for fishes indicate good feed performance. Exposure to different fish diets is the common cause of variation in FCRs. Consequently, quality of diets influences feed conversion in cultured fish (Rust *et al*., 2011; Divu *et al*., 2013). Apart from the fish feeds, genetic factors account for variations in FCRs among fishes. For example, the inherited high feed conversion in Atlantic salmon accounted for its low FCR equivalent to 1: 1 (Rust *et al.*, 2011).

Growth rate is the obvious response to fish feeding (Agbo *et al*., 2011; FAO, 2012; Tiamiyu *et al*., 2013; Menghe & Penelope, 2017). Relative Growth Rate (RGR) often applies as a measure for fish growth. RGR equates to the division of harvest by initial weights of fish followed by conversion into percentage (Soltan *et al*., 2008). Despite the wide application, growth rates in farmed fish target only biomass gain. Growth trials are insensitive to fish mortality yet Mukwanja & Kapute (2015) indicated that the latter led to reduced fish biomass. Since reliance on growth rate may not accurately determine the output on fish farms, nutritionists are increasingly supplementing the performance indicator with inclusive alternatives.

Unlike growth rate in cultured fish, Altoire-Jacome *et al*. (2012) indicated that yield performance directly relates to fish farm output. Net Fish Yield (NFY) is the difference between total weights at harvest and stocking respectively (Charo-Karisa, 2013). Since NFY focuses on gain and loss in fish biomass in production systems (Aqua-Techna, 2011; Saidyleigh, 2018)), it is more reliable than growth rate in farmed fish. Despite the inclusiveness of yield performance, FAO (2012) revealed that growth rate indirectly influences fish yield. Subsequently, differences in yields on farms may largely attribute to levels of fish growth.

According to Mengistu *et al*. (2019), yield gaps exist among fish rearing systems. Low annual fish production in the range of 1000-3000 kilograms per hectare characterizes sub-Saharan Africa (Frimpong, 2018) yet increased output is required for profitable aquaculture production. According to Frimpong (2018), no dispute regarding the positive correlation between fish yield and profitability exists in pond-based tilapia. Investigators including Mensah & Attipe (2013), Cai *et al*. (2018) attributed high profit margins to increased fish yields. Although fish yield was the basis for evaluating the performance of fish feeds (Altoire-Jacome *et al*., 2012)) the response is not yet popular among feeding trials.

Fish mortality varies largely due to differences in management and stability of culture conditions. Gonzales-Felix *et al*. (2010) indicated higher fish survival under artificial production systems compared to semi-artificial production systems. Earthen ponds where small and medium tilapia is commonly reared (Mengistu, 2029) are prone to fish mortality. This phenomenon accounts for the variations in yield among fish reared under semi-intensive systems. Although fish feeds induce increased growth (Obirikorange *et al*., 2016), large harvest size (Egware &Urawa, 2013) and high net yield (Limbu, 2020), certain feeding trials resulted into losses in fish biomass. According to Hassan & Datta (2012) and Royes *et al*. (2013), feed input in rearing systems led to fish mortality. For example, aflatoxin contamination of dietary oil seed meals is lethal in farmed animals (Murjan, 2003) while the deadly cracked head disease in catfish (*Clarias griepinus*) was due to shortage of vitamin C (Abiodun, 2006).

In addition, indirect effects of aqua feed accounted for the mortality in cultured fish. According to Bolivar *et al*. (2011), uneaten and decomposing feed reduced water quality, stressed the culturing environment and ultimately resulted into fish mortality. Irrespective of high quality, pollution may limit feed performance due to induced fish mortality. According to Mustapha *et al*. (2014), mortality is increasingly becoming a tool for evaluation of fish feed.

Although mortality is common in smaller than bigger fish (Phiri *et al.* 2018), the impact on profitability is more significant in the latter due to its high value. Fish that die later during the grow-out period lead to increases in both waste and cost of feed. Subsequently, the combined negative effects render fish mortality economically important in farmed fish. According to Kwame (2015), farmers may incur losses due to fish mortality irrespective of increased farm-gate prices. Authors have reported a close relationship between fish mortality and farm profitability. Aware & Urawa (2013) stated that fish loss correlates negatively with productivity and profitability. Ultimately, the impact of mortality on profitability partially accounts for the low viability of fish farming in many countries.

Earthen ponds that are largely preferred by farmers (Liti *et al*., 2006; Hassan & Datta, 2012; FAO, 2013, Dagne *et al.*, 2013; Opiyo *et al.*, 2014; Robnison, 2015; Limbu, *et al*., 2016) are more prone to fish mortality relative to other production systems. Mengistu *et al*. (2019) reported high Mortality Rates ranging between 25-60% in pond cultured Nile tilapia. Loss of fish in earthen ponds due to predators (Bolivar *et al.*, 2011; Saidyleigh, 2018) has rendered the production systems unpopular among farmers. The unverifiable fish loss characteristic to the semi-intensive fish production systems (Phiri, 2018) accounts for the poor feed evaluation characteristic to majority of feeding trials. Despite the limitations, earthen ponds reflect the real field condition under the practice of fish farming.

Burczynski (2006) reported that uncontrolled mortality distorts the actual fish biomass required for estimation of feed efficiency. Uncertainty on mortality losses in earthen ponds renders the ascertaining of quantity of fish biomass difficult, consequently complicating the evaluation of feed performance in cultured species. Studies by Techna Group (2015) and Mengistu *et al*. (2019) concluded that fish mortality is the major challenge of FCR under semi-intensive systems. The poor understanding on fish feeding under earthen ponds (Hasan, 2001) prompted investigators such El-Sayed (2006) to seek further clarifications on fish nutrition in the fish farming system. The recommendation for further studies on mortalities in earthen ponds (Ali *et al*., 2020) should be coupled with feed evaluation under the production system.

Since feed was the single largest expenditure in fish culture operations (Mbahinzireki *et al.*, 2001), it became the major determinant of profit margins on fish farms. Authors including Makwinja & Kapute (2015) revealed that farm profit margins largely linked to cost of fish diets. According to Balirwa (2006), fish feed accounted for an average of 70% of the total management and operating costs. The high expenditure on commercial diets accounts for the neglected fish farms in many countries. The consistent focus on input costs without regard to output values became a limitation for majority of investigations on fish feeding. Although farmers resorted to cheap fish feed (World Fish Centre, 2009; The Fish Site, 2010; Hardy, 2010), quality was largely compromised subsequently reducing fish productivity. Despite the lowered diet costs, profit margins in farmed species remained marginal due to the poor production performances.

According to Cai *et al*. (2018), profitability is the ultimate aim of feed application on animal farms. That explains why fish nutritionists should aim at a combination of low feed cost, improved production and marketability. Although improved profitability was limited to a combination of low feed cost and maximized fish production (Mmanda, 2020), output markets have become important. Profitable fish farming equates to sale price minus the cost of production (Cai & Leung, 2018). The bias towards the factors at farm production level may fail to mitigate the lowered farm profitability due to fish feeds. Sustainable profitability of fish feeding on farms will depend on the combined variables at production and post-harvest levels. Experiments on fish feeding applied bio-economic indicators of performance such as the Economic Conversion Ratio (ECR) (Umaru *et al*., 2016). According to Sachezlozano *et al*. (2007), ECR is the product of Feed Conversion Ratio and diet cost. Although ECR compares the cost of converting fish feed into biomass (Gebhart, 2000), it is insensitive to the output market implying that tool is limited to farm level of fish production. The Profit Index (PI) that is equivalent to value of fish produced divided by diet cost (Anani *et al*., 2017) has become essential in fish feeding trials. Since the performance indicator explores the marketing of the farm ouput, it demands for data collection even after closure of the feeding trial. The changing trend characterized by rising fish prices amidst increased cost of feed (Hyuha *et al*., 2011; Martinez-liorens *et al*.,2011; Land-based Aquaculture, 2018) is influencing investigators to resort to the Profit Index (PI) despite its complexity.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study took place in Busoga sub-region of Eastern Uganda located at 00º-1º 00'' north, 33´00- 34º 00'' east 30º (Figure 3.1). Lake Victoria in the south, L. Kioga in the North, River Nile in the west and R. Mpologoma in the East separate Busoga from surrounding sub-regions. The Basoga belonging to the larger Bantu community is the indigenous and dominant ethnic group in the study area. Busoga sub-region is a constituent of the Lake Victoria basin characterized by bi-modal type of rainfall pattern. Long and short rains often commence from March to September respectively (Lake Victoria Basin Commission, 2016). In addition to the seasonal rains, the weather is warm and humid throughout the year.

The local community livelihood in Busoga sub-region and agricultural production are highly linked because the latter accounts for 80% of the household incomes (Uganda National House hold Survey, 2016). Annual crops largely dominate the agricultural production; maize (*Zea mays*), ground/peanut (*Arachis hypogea*), beans (*Phaseulus vulgaris*) and sweet potato (*Ipomoea batatus*). Livestock rearing focuses on local (Nsoga) types of poultry and cattle. Intensification of agricultural production in the sub-region has led to excessive exploitation of wild terrestrial and aquatic resources. Subsequently, scattered shrubs coupled with depleted wetlands characterize the local environment. Fish farming is more recent relative to other enterprises in the sub-region. The farming system largely depends on earthen ponds for fish production. Locally farmed species include Nile tilapia *(Oreochromis niloticus L.)* and African catfish (*Clarias gariepinus).* The small catfish (*Clarias carsonii*) dominates the wetlands of Busoga sub-region. Other wild counterparts particularly Nile perch (*Lates niloticus*) and mukene fish (*Rastrineobola argentea*) largely are restricted to the major water bodies; L. Victoria and L. Kioga.

The study area consisted of experimental and sample survey sites for capturing both fish production and marketing (Figure 3.1).

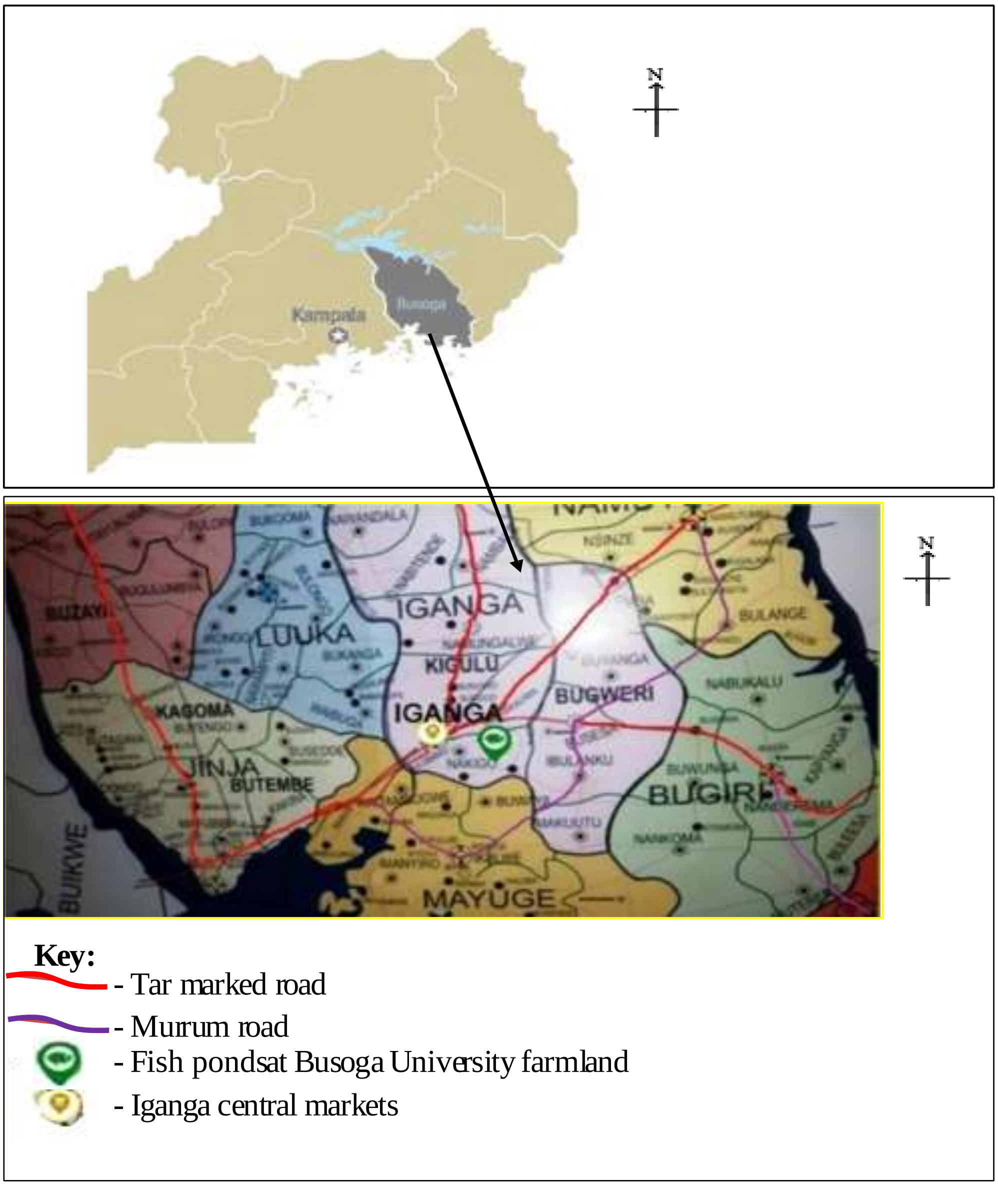


Figure 3.1 Map of Uganda showing the study area and sites

3.1.1 Experimental station

The experimental station occurred in Iganga District at Busoga University located 00º 36´ 33´´ N /33º, 28´ 7´´E.

Plate 3. 1 Earthen ponds after stocking at experimental site A

Trials at the experimental station aimed at generating data on biological responses in Nile tilapia fed test diets. There were two experimental sites; site A and B.Guided by Rohani *et al*.

(2009) and Poot-Lopez & Gasca-Leyva (2009), a time-based replication involving dry and wet season experiments considered the effect of weather on performance of the experimental fish. Consequently, the experiments at site A and site B commenced during the dry and wet weather respectively. The initial trials at experimental site A and replicates at site B were functional from 8^{th} January to 28^{th} May 2016 and 18^{th} March to 8^{th} July 2016 respectively.

The two experimental sites at the station were 12 meters apart besides a wetland. A narrow flowing stream existed between the wetland and the experimental sites. Prior to preparation of the experimental sites, the following largely characterized the local environment; elephant grass (*Pannisetum purperium*), nut grass (*Cyperus rotundus*), star grass (*Cynodon dyctylon*) wondering jew (*Commelina benghelensis*), predatory frogs *(Rana temporaria*), green iguana (*Iguana iguana*), long-necked turtle (*Chelodina lonicollis*) and social weaverbird (*Philetairus socius*). A drainage channel surrounded the sites to prevent possibilities of flooding. Light clay soils characterized the experimental zone. The culturing of Nile tilapia occurred in earthen ponds after stocking following Liti *et al.* (2006) and Rohani *et al.* (2009). Each experimental site consisted of 20 pond units of uniform size of 3.0 x 4.0 x 1.0 cubic meters (Plate 3.1). Slanting dykes measuring 1.0 and 1.5 meters existed between the pond units and treatment groups respectively.

3.1.2 Sample survey sites

Two sample surveys were conducted at sites I and 2. The former was involved in vauation of feed ingredients in commodity markets. The site was located at 00º 36´ N/ 33º 28´ 84´´ E. Data collection at the site coincided with the trials at experimental site B in order to link the cost of test feeds to the trials from 18^{th} March to 8^{th} July 2016. The local markets valuated the feed inputs via the prevailing unit prices (price per kilogram) of feed ingredients following ElHaroun (2007). The site consisted of three commodity markets; main market, veterinary farm input market and miller‟s market. Intensive trade in commodities relevant to the study was the basis for selection of the local markets. Clustered retail traders characterized each of the commodity markets. The main market dealt in both agricultural and non-agricultural products Fresh and dried types of the former existed in the market. The market survey was restricted to commodities relevant for formulation of the Nile tilapia feed namely dried mukene, peanut meal, soybean meal and cassava flour.

Sampling sites in fish markets along the main roads network of Busoga sub-region constituted Survey site 2. Intensive trade in Nile tilapia from local water bodies (Victoria and Kioga) accounted for the site selection. The site stretched from Kamuli trading centre in the Northeast (00º 56´ 25´´ N/ 33º 7´ 30´´ E) to Namayingo trading centre in the South West (00º 23´ 53´´ N/ 33º 53´ 3´´ E. The sample survey occurred from 04^{th} January to 14^{th} March 2017. Fish markets located along crisscrossing roads constituted the sampling frame. A network consisting of tar-marked (all weather) and mar ram (earthen) types of roads connected the fish markets as indicated by the reddish and purplish linear markings respectively. The selected fish markets included Kamuli, Namwendwa Kaliro, Busembatia, Namutumba Bugiri, Nakivumbi Iganga, Namayingo, Mayuge, Musita, Magamaga, Bugembe, Mafubira and Buwenge.

3.2 Study design

The study design was both experimental and non-experimental. The diversification aimed at attainment of all the study specific objectives.

3.2.1 Experimental design

Since the experimental units (earthen ponds) were largely homogenous and complied with randomization and replication, a Completely Randomized Design (CRD) was applied following Gupta *et al*. (2016). Forty eight fish were stocked per each pond unit of uniform size 3.0 x 4.0 x 1.0 cubic meters. Guided by Opiyo *et al.* (2014) „all-male‟ Nile tilapia (*O. niloticus L*.) were stoked at a rate of four fish per cubic meter of pond water. The Sun Fish Farm hatchery in Jinja district of Eastern Uganda supplied fingerlings in the pond units that were stocked at the age of eight weeks. The mean body weights at stocking were 22.2 g and 21.7 g for experimental sites A and B respectively.

The stocked ponds were sixteen out of the 20 ponds at each site. Among the stocked ponds, four (One per treatment group) were maintained as fish reserve ponds for mitigating possibilities of fish losses. In addition, the four non-stocked remainders acted as water reserves. One water reserve was used for maintaining the recommended water level for ponds in a particular treatment group. All the earthen ponds were subjected to uniform conditions in preparation for stocking, maintaining consistency across multiple factors. Specific variables, however, were targeted for adjustment. Prior to stocking, calcium carbonate was applied in the ponds at a standardized rate of five grams per cubic meter of water to stabilize the pH levels prior to stocking.

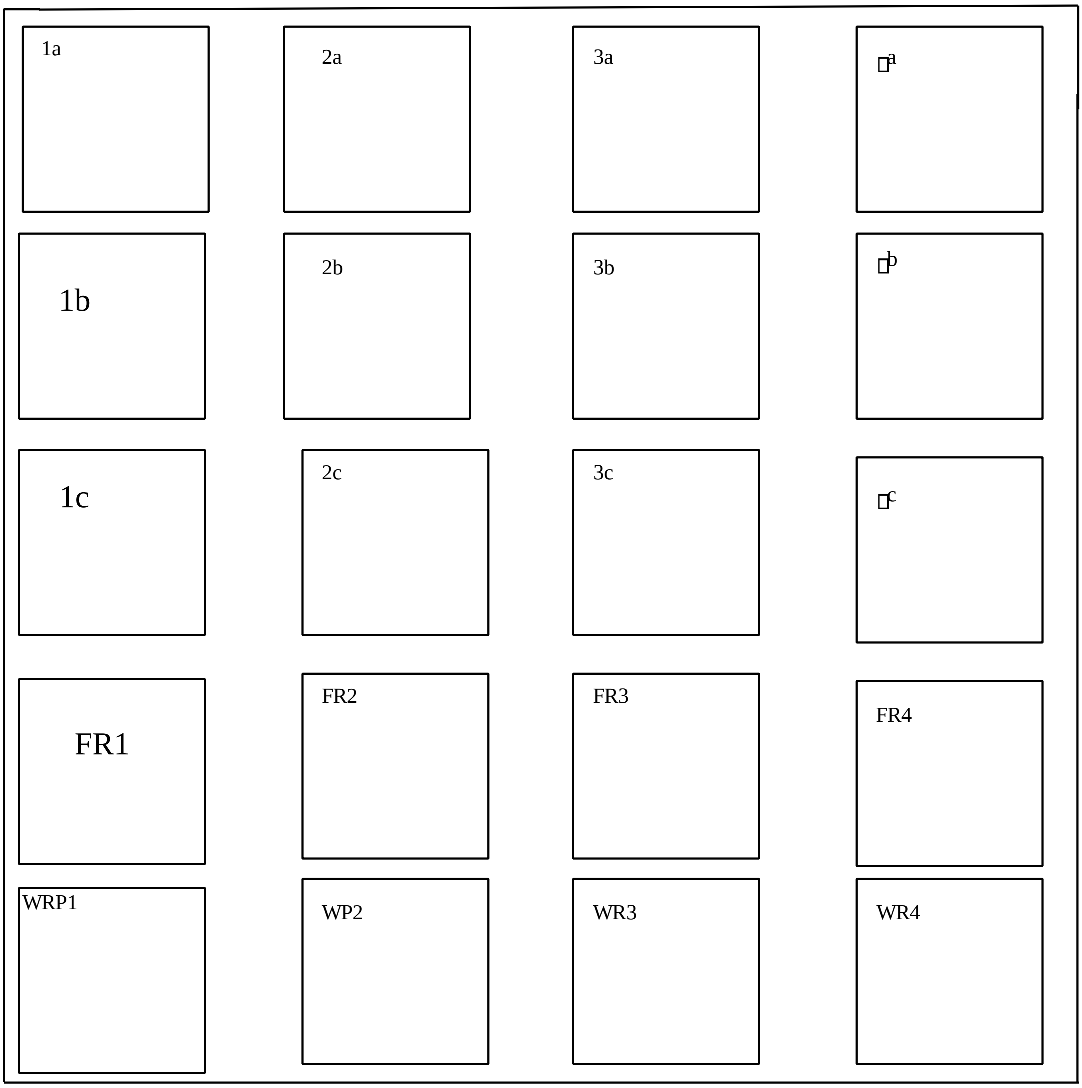
Throughout the trials, water quality was tested after every 28 days. The water parameters monitored included; water temperature, Dissolved Oxygen, pH, unionized ammonia and nitrite nitrogen. Insertions of wire meshes onto the pond in-let and over-flow plastic pipes eliminated fish loss and predation. Periodic seine netting checked on possibilities of fish loss in the pond units. The fish and water reserve ponds maintained a uniform stock density and the 75centimeter pond watermark respectively.

Table 3.1: Randomization of the fish stock among ponds of dietary treatment groups

PCn	Rn	DT		PU		PSt	
		(D$_1$,..D$_4$)				PSe	PSr
1	5 2						
	1	ˇ					
2	16	4		4			ˇ
3	9 3		1	ˇ			
4	15	4		3	ˇ		
5	2 1		2	ˇ			
6	13	4		1	ˇ		
7	10	3		2	ˇ		
8	6 2		2	ˇ			
9	8 2		4			ˇ	
10	11	3		3	ˇ		
11	3 1		3	ˇ			
12	14	4		2	ˇ		
13	7 2		3	ˇ			
14	4 1		4			ˇ	
15	1 1		1	ˇ			
16	12	3		4			ˇ

*PCn= paper cards serial number, Rn= Random number, paper card position after shuffling, DT= dietary treatment, D1= fishmeal-based dietary treatment, D2= peanut meal-based dietary treatment D3= Mixed plant meal-based dietary treatment, D□= control treatment, PU= pond unit, PSt= pond stock type, PSe= experimental pond stock PSr= reserve pond stock.

Simple Random Sampling (SRS) under the lottery method (Craig *et al*. 2006; Oehlert, 2010) based on paper cards facilitated the random assignment of stock to the dietary treatment groups (Table 3.1). Sixteen paper cards of similar size, shape and colour were numbered from 01 to16 in order to correspond to the temporary holdings (plastic bags) prior to pond stocking.



*FRP=fish reserve pond, WRP=water reserve pond, D1=fish meal-based dietary treatment,

D2= peanut meal-based dietary treatment D3=Mixed plant meal-based dietary treatment, D□=control treatment.

Figure 3.2 Layout of earthen ponds in treatment groups at each of the experimental sites

A five-minute shuffling of the deck of cards specified the positions of the stock holdings via the generated random numbers. The positioning of cards and corresponding stock guided the assignment into the treatment groups. Subsequently, the layout of stocked and non-stocked ponds at each of the experimental sites A and B was established (Figure 3.2).

3.2.2 Two-stage Cluster Design

The Two-Stage Cluster Sampling applied for selection of both the clusters and sampling units in the commodity markets at survey site 1 following Ajit *et al*. (2008) and Bob-manuel & Erandu (2010).

Table 3.2: Randomization during selection of sampling units at the commodity markets in Iganga Central Division

Dc	Test ingredients											
	FM		PNM		SBM		CFb		MB		MNp	
	Rn	Su	Rn	Su	Rn	Su	Rn	Su	Rn	Su	Rn	Su
0	44		33		12	5	15	4	30		38	
	14	2	19		34		23		36		12	1
	28		11	3	48		49		13	4	25	
	51		41		28		31		42		41	
	47		35		46		22		48		50	
28	35		07	1	10	5	44		22		24	
	20		55		47		22		07	2	35	
	16		22		34		07	2	47		09	3
	02	4	44		20		09		26		15	
	49		17		17		45		33		47	
56	45		52		16		02	3	19		23	
	36		22		39		04		23		20	
	39		06	2	46		45		42		25	
	15		43		03	2	28		10	1	48	
	06	1	36		38		37		52		18	2
84	29		18	4	34		19	5	38		36	
	50		50		12	4	23		16		14	
	27		27		51		40		37		28	
	46		39		42		31		42		11	4
	03	1	31		39		34		49		42	
112	02	4	39		19		17		31		09	2
	19		32		38		42		13	3	24	
	21		46		09	3	29		19		26	
	49		16	3	45		26		37		43	
	27		22		27		08	1	46		27	

Dc=number of days after commencement of the sample survey, FM=fishmeal, PNM=peanutmeal, MPM=mixed plant meal, CFb=cassava feed binder, MNp=micro-nutrient pre-mix, Ru=random number, Su=sampling unit.

The sampling occurred in commodity markets (Survey Site 1). The clustered units at the commodity markets rendered the design appropriate relative to other methods. The target were unit prices unit costs (cost per one kilogram) of test feed ingredients. The retail traders in the commodity markets acted as the respondents. The primary stage involved non-random sampling of six clusters corresponding with number of test ingredients. The first four clusters A, B, C and D in the main market traded in fishmeal, peanut meal, and soybean meal and cassava flour binder respectively. The miller‟s market and veterinary input markets constituted cluster E and cluster F respectively. The former and latter were involved in the sale of maize bran and micro ingredients respectively.

Selection of respondents at the sampling units during data collection in each of the six clusters was based on the Simple Random Sampling under the 52 standard deck of cards following the procedure indicated. Prior to data collection at a particular cluster, only five of the cards were marked with identification codes corresponding to the sampling frame. The entire set of cards were shuffled and reshuffled for five minutes in order to create randomization. The code of card occupying the top most position identified the sampling unit for data collection.

Data collection for each of the six clustered ingredient was restricted to the selected sampling unit. Data capture from all clusters occurred on the same day and was periodic after every 28 during the 112 sample survey.

3.2.3 Linear Systematic Design

Following Khan *et al.* (2011), Linear Systematic Design was the most appropriate for data collection in trading centres along the main roads network (survey site 2). The design was characterized by Simple Random Sampling that led to selection of sampling units. The sampling frame consisted of 15 trading centres interconnected with a road work; Namayingo, Bugiri, Nakivumbi, Mayuge, Musita, Magamaga, Bugembe, Mafubira, Buwenge, Kamuli, Kaliro, Iganga, Busembatia, Namutumba and Buseesa.

The selection of trading centers from the sampling frame commenced with a random start *r* as the initial sampling unit. It proceeded as follows; 15 thin, rigid and rectangular paper cards represented the sampling frame. Only one name of a specific trading center was inscribed at the underside each paper card. The name indicated by the top most paper card after a fiveminute reshuffling acted as the *r*. Namayingo trading center equated to *r* as the initially selected trading center. Selections at the secondary stage depended on a pre-determined sampling interval *K*. A sampling interval of two guided the selections as indicated (Figure 3.3). In addition to Namayingo, other selected trading included Mayuge, Bugembe, Kamuli and Busembatia.

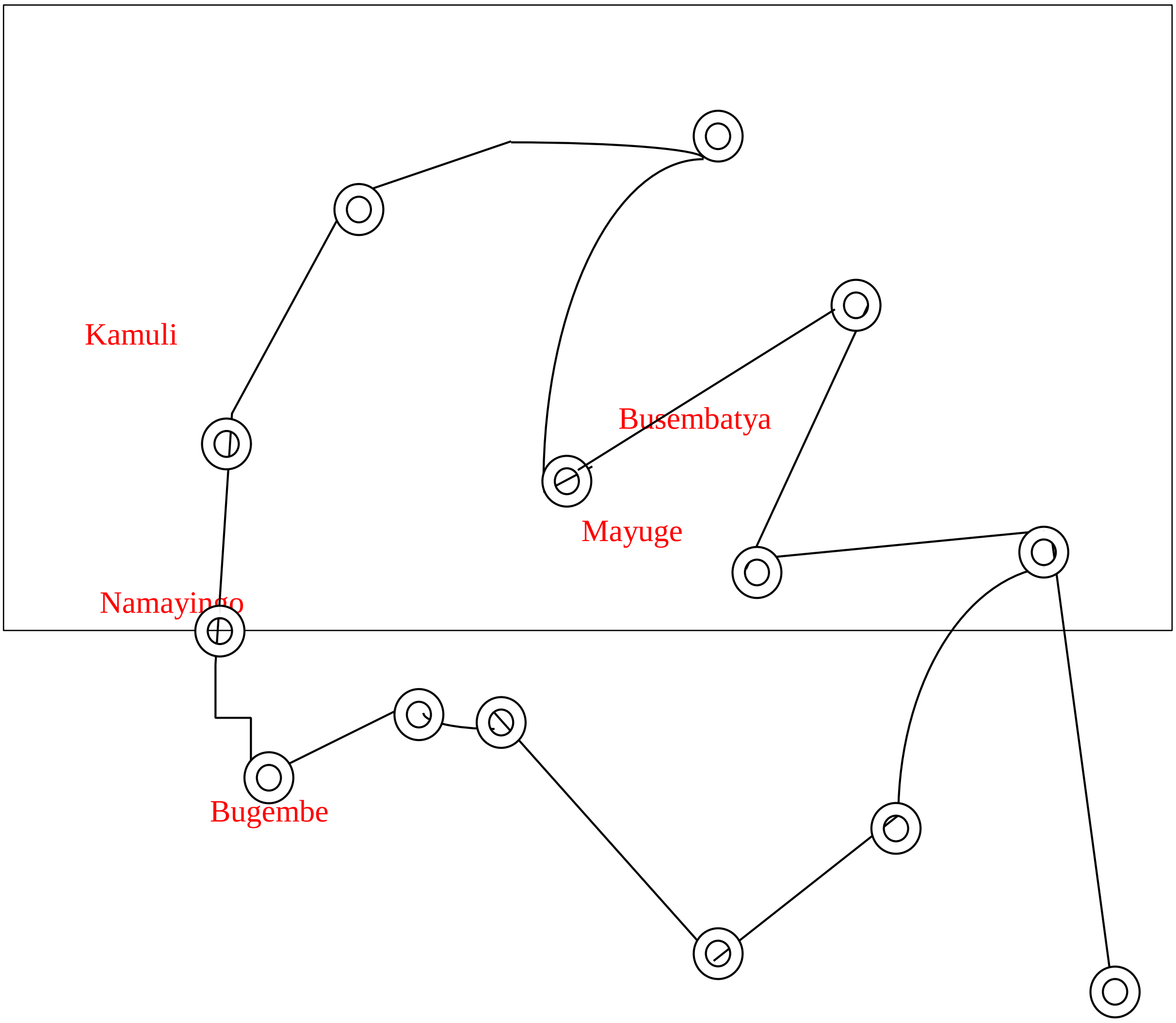


Figure 3.3 Selected trading centers at survey site 2 along the main roads network of Busoga sub-region

The periodic selections of one out of five respondents at the fish markets of selected trading centers were based on Simple Random Sampling involving the standardized deck of cards as explained earlier (Section 3.2.2). Following the purchasing and recording of fish sale prices from the selected respondent, an electronic balance (Model 572-33, Germany) measured the respective body weights. Basing on the variables (sale price and body weight), the unit price or price per kilogram of Nile tilapia fish at each sampling unit was determined following Khan *et al*. (2011) (Table 4.10). The unit prices indirectly determined the sale prices and corresponding Product Values for the different treatment groups (Table 4.11) following Mirilovic (2015). Sampling proceeded on the same day for all the five sampling units at survey site 2. Data collection from the samples was periodic after every 14 days during the 70 days survey.

3.3 Feed input in the fishponds

The following stages constituted the feeding trial prior and during the experiments;

3.3.1 Proximate analysis for the test ingredients

The proximate analysis followed the procedure of Association of Official Analytical Chemists (AOAC) (2005). The process aimed at detecting presence and levels of selected nutrients in the tested nutrients particularly maize bran, fishmeal, peanut meal and mixed plant meal (Table 3.3).

Table 3.3: Levels of relevant nutrients in the test feed ingredients

Dietary nutrients	Grams of feed ingredients (%)			
	Fish meal	Peanut meal	mixed plant meal	maize bran
Crude Protein	38.68	55.16	44.5	6.8
Crude fat	4.58	35.07	29.81	
Crude Ash	20.15	2.82	3.26	

Prior to the analysis, a three-day exposure to sunshine for eight hours daily dried the feed ingredients. From each of the 100-kilogram bags ground and packaged 10-gram samples were tested at Makerere University‟s Faculty of Agriculture. The targeted nutrients included Crude Protein, Crude Fat, and Crude Ash. Determination of CP contents of test ingredients involved the Micro-Kjeldahl apparatus where each sample was boiled in sulphuric acid prior to conversion of nitrogen to ammonia. Subsequent multiplication of the amounts of nitrogen by a factor (6.25) determined the CP contents. Subsequently, CP weights divided by the original sample weights and multiplied by 100 in order to obtain percentages of the variable in the tested samples.

The ether extraction method tested the amounts of fat in the tested samples. During the process (Dry Extraction Method), an oven dehydrated the constituents prior to refluxing with ether. The constituents separated consequently eliminating the fat molecules. The resultant ether extract equated to the Crude Fat. The latter divided by the original sample weight and multiplied by 100 in order to convert to percentage.

Crude ash (CA) was determined by combusting samples in a muffle furnace for four hours at

103^0 while the elevation of temperatures to 550^0 C eliminated the carbon fraction. The remnant fraction equated to the amount of CA present in the tested samples. The latter were divided by the original sample weights prior to percentages.

3.3.2 Inclusion of protein supplements in test diets

The protein supplements included Fishmeal (FM), Peanut meal (PNM) and mixed plant meal (MPM) for the FM-based, PNM-based and MPM-based diets respectively. Fishmeal and peanut meal acted as sole protein sources in their respective test diets while a combination of peanut meal and soybean meal in a ratio of 50: 50 constituted the mixed plant (MPM)-based diet (Table 3.4) following Cost *et al*. (2001) and Gosh & Mandal (2015).

Table 3.4: Inclusion levels for protein supplements in test diets prior to the experiments

Test diets	Protein sources		
	fishmeal	Peanutmeal	mixed plant meal
Fishmeal-based diet	100	0	0
Peanut-based diet	0	100	0
Mixed plant-based diet	0	5	50

The PNM and MPM-based diets were the two peanut derived test diets. Guided by Mugabundi *et al*. (2103) and Opiyo *et al*. (2014), the reference and control were the 100% FM inclusion level and the locally purchased for Nile tilapia grow-out diet containing 25% Crude Protein.

3.3 Standardization, feed formulation and rationing

The test diets were rendered iso-caloric (5.3627 Kcal/g) via caloric values and unit values for the energy nutrients following Borski *et al*. (2011). Guided by the procedures of Bainempaka (2006) and Ajonina & Nyambi (2013), the Pearson Square adjusted the Crude Protein contents of feed ingredients to the desired levels in test diets. The process of obtaining iso-nitrogenous test diets involved both protein and basal supplements. During the first feeding regime for juvenile stages of the experimental fish (0-12 weeks); test diets were standardized to 30% Crude Protein (Appendix 7.1.19). The desired protein content resulted when 23.2 kilograms (Kg) of the protein supplements: fishmeal, peanut meal and mixed plant meal were combined with 8.68, 26.16 and 14.5 kg of maize bran respectively (Table 3.5).

Table 3.5: Ingredient proportions in the formulated test diets during the study

DT	Fi (g)						
		FM	PNM	MPM	MB	FBc	MNp
FiFishmeal-based diet	Rf_1	23.2			8.68	2.391	0.797
	Rf_2	18.2			13.68	2.391	0.797
Peanut-based diet	Rf_1		23.2		26.16	3.515	1.172
	Rf_2		18.2		30.16	3.515	1.172
Peanutmeal-based diet	Rf_1			23.2	14.5	2.827	0.943
	Rf_2			18.2	19.5	2.827	0.943

*DT= Fi=feed ingredient, dietary treatments, D1= fishmeal-based diet, D2= peanut mealbased diet, D3= mixed plant meal-based diet, FM= fishmeal, PNM= peanut meal, MPM= mixed plant meal, MB=maize bran, FBC=cassava feed binder, Rf = feeding regime.

*MNp=micro nutrients pre-mix; vitamins (A, C & B12) and minerals (NaCL & Feso4

Due to the declining demand for dietary protein as fish grew, the CP contents reduced to 25% as guided by Fitzsimmon (2009). Consequently, during second feeding regime (Appendix 7.1.20) only 18.2 kg of the protein supplements; FM, PNM and MPM mixed with 13.68, 30.16 and 19.5 kg of MB respectively. Additional dietary inclusions particularly micronutrients pre-mix at 2.5% and 7.5% of the already mixed proportion respectively provided the minimum requirements for proper fish growth (Table 3.5) following Agbo *et al*., (2007) and Trunshaki & Rumbeso (2014).

Prior to mixing, a top loading electronic balance (version 3.1, 2009) of 0.01-gram readability was used to weigh the ingredients. Disposable gloves acted as hand protectors during mixing. Contact with hot water at varying centigrade degrees; 75º, 55º and 60º effectively mixed the FM, PNM and MPM-based diets respectively. A hand-operated table equipped with 2.5-

millimeter diameter holes produced the pellet strands from the dough. The pellets were sun dried for at least eight hours prior to storage at room temperature as recommended by Suleiman & Ahmed (2011). The feeds served for a period not exceeding 28 days. All the experimental fish in treatment groups at a particular site were fed on equal amount of feed. Following Opiyo *et al*. (2014), the feed rations changed after every 28 days in response the increasing fish weight. The fish were fed twice daily at 9.00 am and 5.00 pm throughout the experimental period. The Daily Feeding Ration (DFR) was determined following Nandal & Pickering (2004) as indicated;

DFR= MW x 5/100 x SD

Where;

DFR= Daily Feeding Ration (g)

MW = mean weight of fish sampled from all treatment groups (g) SD = stocking density of pond units (No./pond).

Table 3.6: Periodic feed rationing during the 16 weeks experimental period

Experimental site	Dc	MBW (g)	IFR (g)	DFR (g/pond)	PFR (g/pond)	TFR
A	0-28	22.2	1.110	53.3	1492	
	28-56	39.45	1.973	95.0	2460	
	56-84	69.23	3.462	166.0	4648	
	84-112	102.3	5.115	245.0	6860	15,660
B	0-28	2 1.7	1.085	52.0	1456	
	28-56	41.6	2.080	99.8	2800	
	56-84	67.18	3.359	161,0	4508	
	84-112	103.0	5.150	247.0	6916	15,680
						15,670

*Dc=number of days after commencement of the experiment, *MBW=mean of body weight of the experimental fish from different dietary treatment groups

*IFR=individual feeding rate= 5% x MBW

*DFR=Daily Feeding Ration= IFR x Stock Density (48 fish per pond unit).

*PFR=Phased feeding ration=DFR x feeding duration (28 days).

*TFR=Total Feed Ration=summation of phased feeding rations

Feeding was adjusted to create feeding phases of 28 days in order to accommodate the varying fish sizes. Summation of all the phased rations for the entire experimental period equated to the Total Feed Ration (TFR). The TFR was the average of sub-totals of feeding regimes at experimental sites A and B (15,670 g) (Table 3.6).

3.4 Fish growth in earthen ponds during the feeding trial

The experimental period lasted for 16 or 20-weeks depending on the targeted response. Data capture on fish growth and corresponding yield and survival were periodic after every 28 days between 9.30 am -12.00 pm. An electronic balance (Model KERN 572-33, GERMANY) with readability of 0.01 was used to weigh the fish specimens. Weight measurements for the experimental fish were conducted as follows; a partially filled transparent trough accommodated the fish specimens prior to the weight measurements;

BWg= (BW+TW)-TW

Where;

BWg= body weight gain in fish specimen (g)

BW= body weight in the fish specimen (g)

TW= weight of plastic trough (g).

Guided by Opiyo *et al*. (2014), the fish specimens were returned to their respective pond units after the data collection.

During the periodic samplings, only 30 fish specimens were measured from every treatment group. Ten fish were randomly scooped by pond seine nets from each of the three pond units constituting a dietary treatment group. The fish were returned back after the measurements. At the end of the experimental period all ponds were drained in order to measure all the stocked fish.

3.5 Indicators for water quality in the earthen fishponds

The tests in ponds targeted parameters such as water temperature, Dissolved Oxygen (DO), pH, unionized ammonia (NH_3) and nitrite (NO_2-) that influence growth and survival in farmed fish (Table 4.1) following Lucy (2014). Parameters measurements occurred during daytime starting at 12.00 pm throughout the experimental period (after and before the morning and evening feedings respectively). One pond of each treatment group was involved in water testing during every sampling. The ponds were alternated during subsequent samplings.

Apart from water temperature where data was collected daily, other parameter measurements occurred on a weekly basis. The test for water temperature involved insertion of a cylindrical mercury thermometer for five minutes at 30 centimeters (cm) below the water surface following Onada *et al*., (2015). Guided by Ajibonge *et al.* (2015), the Lamotte Fresh Water Kit (Model AQ-2) tested other water parameters on a weekly basis Measurements for DO concentrations across dietary treatments involved the following; tightly capped plastic bottles withdrew pond water samples at 10 cm depth below the surfaces. Eight drops of manganous sulphate solution followed by another eight drops of alkaline potassium iodide azide reagent added to the half-filled bottles prior to capping. Precipitates formed after vigorously shaking the mixture for two-minutes. To dissolve the precipitates, the bottles were opened and eight drops of sulphuric acid added. Yellowish colours characterized the fixed samples prior to determination of DO levels via titration. After the process, the DO was determined by direct observation from the glass tube displays.

Other tests such as pH, NH_3 and NO_2- across treatment groups were conducted based on visual tests under the colorimetric procedure following the method of Ajibonge *et al*. (2015). Appropriate reagents treated the water samples consequently inducing coloured reactions. The Octa-Slide Viewer compared the coloured samples with inherent standard colours. Parameter values equated to specific sample colorations that were comparable to the standard colours.

3.6 Data analysis

Data from the experimental and sample surveys was analyzed as indicated below;

3,6.1 Water quality and fish biomass production in Nile tilapia fed on the test diets

Unlike the pH and DO that were determined by direct readings, other water parameters were derived indirectly. The NO_2- and NH_3 were derived indirectly following Onada *et al*. (2015) as shown below:

a) NO_2- = (NO_3-N) x 3.3

Where;

NO_2- =nitrite nitrogen (Mg/L) (NO3-N) nitrate nitrogen (Mg/L) b) NH_3 = (NH_3-N) x1.2

Where;

NH_3 = unionized ammonia (Mg/L)

(NH_3-N) = ammonium nitrogen (Mg/L)

Initially, the one-way Analysis of Variance (ANOVA) and post-hoc tukeys Honestly Significant Difference (HSD) were applied for every tested water parameter across dietary treatment groups to detect significant differences p□0.05 and the significantly paired group means respectively. Subsequently, the Multivariate Pearson Correlation (one-tailed) tested the relationship between the water quality parameters and biomass production in Nile tilapia fed on test diets (Tables 4.2 & 4.3).

3.6.2 Feed Conversion Ratios in Nile tilapia fed on test dies

Calculation of FCRs followed the procedures of Amisa *et al*. (2009) where the total amount of feed administered to fish was divided by total fish biomass produced in the pond units.

During the current study the following stages were involved;

Averages for fish weight gains from each of the six pond units at sites A and B were multiplied by the stock density (48 fish per pond unit) in order to obtain the fish biomass

FBg=MWg x PSD

Where;

FBg=fish biomass gained (g/pond)

MWg=mean weight gained by individual fish (g) PSD=pond stock density (No/pond) ii) The FCR per pond unit (Table 4.4) was determined after relating the Total Feed Ration (15,670 g/pond) to the fish biomass produced; FCR=TFR/FBg.

Where;

FCR=Feed Conversion Ratios

TFR=Total Feed Ration (g/pond)

FBg=total fish biomass gained during the feeding trial (g/pond)

3.6.3 Relative Growth Rates in Nile tilapia fed on the test diets

During the current study, the Relative Growth Rates (RGRs) were determined following the procedures of Abdul *et al.* (2012) as indicated below;

RGR= BWh-BWi/BWix100

Where;

RGR=Relative Growth Rate of the experimental fish

BWi= initial body weight of experimental fish (21.95 g)

BWh= harvest body weight of the experimental fish (g)

Divisions of weight gains by initial weights of the experimental fish followed by conversion into percentages equated to the Relative Growth Rates (Table 4.5).

3.6.4 Net Fish Yields in Nile tilapia fed on the test diets

The Net Fish Yields were determined following El-haroun (2007) and Akinawole & Faturori (2007) . Subsequently during the current experiment;

Subtraction of stocking biomass from harvest biomass equated to gain in fish biomass or Net Production in the pond units; NP= FBh-FBi.

Where;

NP= Net Production by end of the experiment (g/pond)

FBh= fish biomass at harvest (g/pond)

FBi= initial fish biomass at stocking (g/pond)

Total fish biomass loss in a treatment group was equivalent to number of lost fish multiplied by the mean of fish weight gain; TFBl= Fl x BW.

Where;

TFBl= total loss of fish biomass (g/treatment)

Fl= fish loss (g/treatment)

BW= weight of fish (g)

Loss in fish biomass per pond unit equated to the division total fish biomass by the six pond units of a treatment group; TFBl/6=FBl.

Where;

TFBl = Total loss of fish biomass (g/treatment) FBl = Loss of fish biomass in pond units (g/pond) iii) Ultimately, the Net Fish Yields per pond unit was determined after subtraction of the loss from gain in fish biomass (Table 4.6). NFY = NP-FBl. Where;

NFY= Net Fish Yield by end of the experiment (g/pond)

NP= Net Production in pond units by end of the experiment (g/pond)

FBl = fish biomass loss by end of the experiment (g/pond)

3.6.5 Survival Rates in Nile tilapia fed on the test diets

During the current experiment, the Survival Rates (Table 4.7) in Nile tilapia were determined following Mustapha *et al*. (2014) and Makwinja & Kapute (2015) as indicated; SR= SD-Fl/SD x 100.

Where

SR= Survival Rate of fish in the pond unit (%/pond)

Fl= loss of fish in the pond unit (No./pond)

SD= Stocking Density of the pond unit (No/pond)

3.6.6 Economic Conversion Ratios in Nile tilapia fed on test diets

Following Piedecausa *et al.* (2009) and Martinez-Liorens (2011), the Economic Conversion Ratios (ECRs) in the experimental fish were detrmined as follows; ECR= UCf x FCRm.

Where;

ECR= Economic Conversion Ratio

UCf= Unit cost of feed or cost for test feeds (USD/Kg)

FCRm= mean value for Feed Conversion Ratios from the different dietary treatment groups. Consequently, during the current study, the unit a (price per kilogram) of feed ingredients recorded at the local markets were multiplied by their corresponding percentage proportions in the formulated test feeds to derive the the proportional/partial costs. Guided by MartinezLlorens (2011) and Yelazco-Vagus *et al.* (2013), the sum of partial costs of constituent ingredients equated to the unit costs of test feeds as indicated below;

UCf= PCPS+ PCMB+ PCFBc+ PCMNp

UCf= unit cost of feed/cost of one kilogram of feed (USD/kg) PC_{PS} = partial cost for the protein supplement (USD)

PC_{MB}= partial cost for the maize bran (USD) PC_{CFb}= partial cost for the feed binder (USD) PC_{MNP}= partial cost for the micro nutrient pre-mix (USD)

Multiplication of the unit costs of test feeds by the mean value for Feed Conversion Ratio equated to Economic Conversion Ratios (ECRs) in Nile tilapia (Table 4.9).

3.6.7 Profit Indices in cultured Nile tilapia fed on test diets

Profit Indices (PIs) were calculated following El-Saidy & Gaber (2003) and El-Haroun (2007); Profit Index (PI) = value of fish/cost of feed (USD). The determinations of PIs in the experimental fish from dietary treatment groups involved the following stages: i) Total cost of test feeds

Calculation of the total costs for each test feeds per pond unit of different treatment groups was based on the formula indicated.

TCf=UCf x TFR.

Where;

TCf=total cost of feed (USD) UCf=unit cost of feed (USD/Kg)

TFR=Total Feed Ration (USD)

ii) Fish biomass produced in the dietary treatment groups

The fish biomass was calculated following Rauw *et al*. (2016), where the averages of weight gains for all the fish stocked (Table 4.19) were multiplied by the pond stock density (48 fish per pond unit);

Bf=Wf x PSD. Where;

Bf=fish biomass (g/pond^{-1}) PSD=pond stock density (No/pond)

iii) Farm-gate prices and Product Values in Nile tilapia in dietary treatment groups;

Sale prices for fresh Nile tilapia in local markets indirectly determined the farm- gate prices following Opiyo *et al.* (2014) and Malcon & Froukje (2016). The mean values for unit prices at the fish markets equated to the farm-gate prices.

UPf= Pf/Wf x 1000. Where,

UPf= unit price of fish specimen at the sampling unit (USD/kg)

Pf= sale price of fish at the sampling unit (USD) Wf= weight of fish at the sampling unit (g)
Following Mirilovic (2015), Product Value equated to the gained body mass multiplied by farm-gate price.

PV= FBm x FGp.

Where;

PV = Product Value (USD)

FBm= mean value for fish biomass (g/pond) FGp= farm-gate price (USD/kg)

Subsequently, the PI equated to division of mean Product Value by the total cost of feed (Table 4.11); PI=PVm/TCF.

Where;

PI= Profit Index

PVm= mean of Product Value

TCF= total cost of feed

Since the target was only a single variable at more than two groups, for majority of performance indicators indicated (FCRs, RGRs, NFYs, SRs, ECRs and PIs), one-way ANOVA based on the F-statistic was applied using SPSS (Version 17.0) for detecting differences among group means. The variations were regarded significant at p□0.05 following Opiya *et al*. (2014).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effect of test diets on water quality in Nile tilapia cultured in earthen ponds

Water parameter levels in pond units of different dietary treatment groups are indicated (Table 4.1). All parameters varied within and across treatment groups. Apart from water temperature, significant differences (p□0.05) in mean values occurred among other tested parameters: pH, DO, NO_2- and NH_3. Similarly, Manda *et al*. (2020) reported slightly higher water temperature in fish fed on the FM-based diet than other test diets.

Table 4.1: **Mean values (mean ± SE) for selected water quality parameters of dietary treatment groups at the experimental study sites**

Dietary treatment	Temp.	DO (mg/L)	pH	NH_3 (mg/L)	NO_2- (mg/L)
Fishmealbased diet	28.0 ± 0.6^{a}	4.0 ± 0.1^{b}	7.0 ± 0.15^{b}	1.8 ± 0.125^{b}	0.05 ± 0.003^{b}
PNM-based diet	27.9 ± 0.5^{a}	6.0 ± 0.5^{a}	8.0 ± 0.25^{a}	1.5 ± 0.15^{a}	0.025 ± 0.001^{a}
MPM-based diet	27.3 ± 0.4^{a}	6.0 ± 0.25^{a}	$8.0 \pm 0,05^{a}$	1.5 ± 0.075^{a}	0.025 ± 0.008^{a}
Control diet	27.2 ± 0.4^{a}	5.0 ± 0.1^{b}	7.0 ± 0.1^{b}	1.25 ± 0.075^{b}	0.025 ± 0.005^{a}

*Paired group means along the columns having different subscripts denote that the values are significantly different (p□0.05) and vice versa.

Results for the FM and peanut-based diets (PNM and MPM-based diets) in terms of DO, pH, NH_3 and NO_2- were significantly different (p□0.05) while no statistical differences (p□0.05) were observed among the PNM and MPM-based diets which were for all parameters in treated ponds. Sayed *et al.* (2018) reported similar observations when no differences (p□0.05) occurred among the following parameters; temperature, pH and DO in cage cultured *labeo rohita* fed on closely related diets. Subsequently, level of nutritional similarity accounted for the differences in performances among the test diets. The current findings concur with the investigation by Seargent (2014) where variations in water quality mirrored chemical differences among the introduced feed materials.

Although there were no significant differences (p□0.05) across dietary treatment groups, the fishmeal-based diet corresponded with the highest mean water temperature. In line with the current results, the feeding trial conducted by Mmanda (2020) showed a slightly higher water temperature for the FM than alternative tilapia diets. The structure of the animal-based product accounted for the higher values characteristic to the FM-based diet. Unlike the test diet, Miles & Chapman (2006) revealed that plant proteins are associated with indigestible oligosaccharides and fiber components that are capable of resisting decomposition. Consequently, rapid organic matter decay could have accounted for the elevated water temperature in ponds treated with the FM-based. The findings are consistent with the investigation of Themelis (2005) where rate of organic matter composting correlated positively with level of heat generation.

Despite the significant differences (p□0.05) among the majority of water parameters namely pH, DO and NO_2- the culturing environment was appropriate for Nile tilapia. The levels for temperature (26-30□C) (Hargreaves & Tucker; 2004), pH (6.5-8.5) (The Fish Site, 2015), DO (4.0-6.0 mg/L^-) (Marty, 2003) and NO_2^-; (0.0146 mg/L^-) (Rhida, 2006) were favorable for proper growth and survival of the farmed species. The observation is comparable to the trial by Mugaji (2019) where fish culture conditions were good for the fish culture irrespective of the significant differences (p□0.05) in water quality. Although poor water quality could be a stressful condition leading to retarded growth and mortality in fish, (Mustapha, 2014), adjustments in water parameters due to the dietary applications during the current study fell below the threshold of negatively affecting fish biomass production.

The higher values relative to the Pearson Coefficient significance level under the Multivariate Pearson Correlation were indicators of a positive (p□0.05) correlation among certain water quality parameters; temperature versus pH, NH_3 and NO_2^-, DO versus pH, NH_3 verses NO_2^-. On the contrary, negative (p□0.05) correlations among certain parameters existed; temperature verses DO, DO verses NH_3 and NO_2^-, pH verses NH_3 and NO_2^-. Water temperature exhibited a positive correlation (p□0.05) with, NH_3 and NO_2^- across the dietary treatment groups.

Similarly, Hargreaves & Tucker (2004) concluded that water temperature, NH_3 and NO_2- often correlate directly.

During the current study, high water temperatures led to reduced DO and corresponding accumulations of both NH_3 and NO_2- in the earthen ponds. The findings are in tandem with several investigators. Bhatnager & Devi (2013) specified that low oxygen solubility builds-up of ammonium compounds while Sayed *et al*. (2018) revealed that level of aeration influences the retention of NH_3 and NO^{2-}.in water ponds.

Table 4.2: Comparison between unionized ammonia levels and fish biomass production in dietary treatment groups

Dietary treatment	NH_3 (mg/L)	Fl (No.)	MFBl (g/pond)	MFBg (g/pond)
Fishmeal-based	1.8 ± 0.125^b	25	539^b	6207^b
Peanutmeal based	15 ± 0.15^a	22	40^a	5286^a
Mixed meal based	1.5 ± 0.075^a	20	419^b	6044^b
Control	1.25 ± 0.075^c	23	401^a	5029^a

*NH^3= unionized ammonia, Fl= fish loss, MFBl= mean value for loss in fish biomass, MFBg= mean value for gain in fish biomass

*Group means having a different superscript along the column denote that the values are significantly different (p□0.05) and vice versa.

The tested relationship between NH_3 and fish biomass production indicated a positive correlation with both the individual fish loss and biomass loss in earthen ponds for all dietary treatment groups. Similarly, Onada (2015) reported a positive correlation between ammonia level and mortality in fishponds. Although ammonia build up in water bodies may be due to decaying organic matter (Onada *et al.* 2015), contamination with protein- enriched feeds remains the greatest inducement. The findings agree with Hargreaves & Turker (2004) who concluded that protein sources in feed formulations are the major sources of NH_3 in fishponds.

NH_3 accumulation was highest in ponds units treated with the FM-based diet. According to Kenawy *et al.* (2008), variation in protein sources can create changes in water pH ultimately adjusting the levels of unionized ammonia. The FM-based diet with the highest level of accumulated NH_3 was coupled with increased losses in the experimental fish and corresponding fish biomass in the pond units (Table 4.3). In a study by (The Fish site, 2015; Young *et al*., 2018) on feeds, NH_3 concentration generated by the FM-based (1.25-1.8 mg/L$^-$) rose above the recommended level of 0.028-0.035 mg/L accounting for the increased fish biomass loss. Olapode & Quinn (2019) obtained similar results when NH_3 concentration above the recommended range resulted into fish mortality.

Table 4.3: Correlation between unionized ammonia and fish biomass production

		NH_3 (Mg/L)	FBp NH		
3 (Mg/L)	Sig.		Fl	MFBl	MFBg
		1	(No.)	(g)	(g)
		-	445	.885	.835
			.278	.057	.082
FBp (g)	Pearson Correlation Sig.	445	.1	.725	.078
	Pearson	.278	-	.138	.461
	Correlation Sig.	.885	.725	.1	.743
	Pearson				
	Correlation Sig.	.057	.138	-	.128
		.835	.078	.743	.1
		.082	.461	.128	-

Pearson Correlation

*Sig. =siginificancy level, FBp=fish biomass production, Fl=fish loss, MFBg=mean of fish biomass gain, MFBl=mean of fish biomas loss.

*Correlation is significant at 0.05level (1-tailed).

Although fish survival negatively influenced fish production (Bolivar *et al.* 2011; Oluwaloya & Adedeji, 2019), the trend reversed during the current trial. Despite the higher NH_3 level and significantly increased fish biomass loss (p□0.05) in pond units treated with the FM-based diet, the biomass gained remained better (Table 4.2) than other test diets. The relatively good performance of the FM-based was due to the larger harvest sizes of the remnant fish. The bigger residual fish mitigated the biomass loss consequently improving performance of the FM-based diet. The findings concur with the study of Reigh (2008) where high fish yield occurred in spite of the increased fish mortality.

4.2 Feed Conversion Ratios in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal

The first stage involved obtaining data on weight gains in the experimental fish and corresponding fish biomass production in the pond units of treatment groups. The division of Total feed Ration (15670 g) by the fish biomass in each pond unit derived the Feed Conversion Ratios (Table 4.4)

Table 4.4: Determination of Feed Conversion Ratios based on feed input and fish biomass gain in pond units after the 16-week experiment

Variables		Dietary sources in test diets			
		FM	PNM	MPM	Control
FBg (Wg*SD) (g/pond)		6121	5258	6074	4990
		6074	5223	5958	4897
		6218	5189	5891	4959
		6293	5403	6145	5104
		6218	5276	6097	5172
		6319	5366	6098	5055
FCR (TFR/FBg)		2.56	2.98	2.58	3.14
		2.58	3.00	2.63	3.20
		2.52	3.02	2.66	3.16
		2.49	2.90	2.55	3.07
		2.52	2.97	2.57	3.03
		2.48	2.92	2.57	3.10
FCR values	$\sum x$	15.15	17.79	15.56	18.67
	$\sum x^2$	38.26	52.76	39.37	58.30
		2.525^{a}	2.965^{b}	2.593^{a}	3.116^{b}

*TFR=Total Feed Ration, SD=stocking density, Wg= weight gain FCRm= mean value for Feed Conversion Ratio, D=diet, D1=fishmeal-based diet, D2=peanut meal-based diet, D3=mixed meal-based diet, D4=commercial feed, TFR=Total Feed Ration, FBg= fish biomass gain, FCR= Feed Conversion Ratio.

*Values (mean ± SE) in the same row having different superscripts denote that they are significantly different (ANOVA, p□0.05) and vice versa.

ANOVA F-test revealed the F-value (221.3) that in turn equated to a Critical Value of 3.1 (F-distribution table at 0.05 (3, 20) and the indicated p-value. The smaller p-value than the significance level (0.05) implied that at least one of the mean values for Feed Conversion Ratios was significantly different. Consequently, the result guided the null hypothesis rejection.

According to the q-distribution table, the value at alpha 0.05 (3, 20) was 3.578. The Turkey‟s HSD as a post-hoc test ascertained the significance levels among paired group means based on the calculated value (0.226). Differences among paired group means; 0.068 and 0.151 were lower than the HSD consequently accounting for lack of significant differences (p□0.05) in performances of the FM and MPM-based diets and PNM and control diets respectively. On the contrary, significant differences (p□0.05) existed due to the higher levels than the HSD among another group means. A high FCR indicated a good performance and vice versa. Performance of test diets in Nile tilapia was as follows; FM-based diets> MPM-based diet> PNM-based diet> Control diet.

Maintenance of the stock density of 48 fish per pond throughout the current study facilitated the determination of FCR. Although uneven feed consumption due to uncontrollable survival rate under the earthen ponds was reported (Berzi-Nagy *et al*. 2021), the fish reserve ponds under the current trial mitigated the possible fish losses via instant substitution. The unpredictable loss of fish biomass coupled with uneven levels of feed availability often complicate the accurate determination of FCRs under the earthen pond system. The findings conform to Hassan & Soto (2017) who concluded that managing FCR in the face of uncontrolled mortality remains largely frustrating.

The FCR 2.48-3.20 range (lowest to the highest value across treatment groups) was higher than the recommendation for Nile tilapia. According to Craig & Helfrich (2009), 1.5-2.0 is most suitable for farmed species. Several trials have reported poorer FCRs under earthen ponds rendering the fish production systems less efficient in terms of feed utilization. For example, the investigation by Mengle & Edwin (2015) on cultured catfish (*C. gariepinus*) indicated FCRs of 2.5 and 1.8 for earthen ponds and glass tanks respectively.

Although diet FCR is primarily influenced by composition (Robinson, 2015), the culturing environment has become important. For instance, the poor performance of Nile tilapia in terms of FCR during the current study links to the earthen ponds. Contamination with the mud-laden ponds resulted into wasted feed, poor feed utilization and ultimately poor FCRs in the experimental fish. The findings are in tandem with Julian *et al.* (2018) who stated that the efficiency of turning feed into meat depends on the nature of production system and Robinson (2015) who indicated better conversion of feed under optimum than less ideal environmental conditions.

Other trials under earthen ponds reported poorer FCRs than the current one. For example, Ahmed (2013) obtained FCRs in the range of 3.3-6.2 in Nile tilapia reared in earthen ponds. The relatively lower and better FCR characteristic to the current study were attributed to fish reserve ponds that maintained pond stock densities via instant compensation of fish loss throughout the culture period. The sustained fish biomass accounts for the improved FCRs in the experimental fish under earthen ponds. The findings are in line with Hua & Stugnella (2019) where maximization of fish survival led to optimization of feed conversion and Hassan & Soto (2017) who concluded that fish mortality even at low levels can negatively impact on FCR.

The lowest FCR that corresponded with the FM-based diet (2.525) implied best performance among test diets. Authors including Mmanda (2020) published similar results. Although feed input was uniform for all the pond units, the consumption varied depending on palatability.

Subsequently, the experimental fish utilized more of the highly palatable FM-based diet than the alternatives. The current findings are consistent with Miles & Chapman, (2006) and Bureau (2007) who stated that fishmeal is highly palatable in cultured species yet (Afram *et al.*, 2021) revealed that a positive relationship exists between feed intake and fish growth. Although Anani *et al*. (2017) linked the differences in feed conversion to nutrient composition, access to feed largely accounted for the current results.

Performance was better for the FM-based diet than MPM-based diet (2.953) despite lack of a significant difference ($p>0.05$) among the test diets. Similar results were obtained from the study on juvenile Nile tilapia by Agbo (2008) where increasing levels of dietary soybean meal resulted into reduced feed utilization. Since soybean meal is deficient in the growth-promoting nutrient referred to as phosphorus (Hardy, 2010) yet it constituted 50% of the MPM protein source during the current trial: retardation in fish growth due to the dietary treatment was inevitable. The findings are in tandem with Ogunji *et al.* (2008) where phosphorus content and palatability accounted for the variable success towards fishmeal replacement in aqua feeds

Similar to the FM-based diet, FCRs were significantly better (p□0.05) for the MPM-based diet than PNM-based diet (2.965). Nile tilapia fed on the PNM-based diet exhibited the highest and poorest FCR among test diets. Cost *et al.* (2001) obtained similar results from a related study on broiler chicken where FCRs became poorer with increasing levels of dietary PNM. In addition, the trial by Silva *et al.* (2017) indicated significantly lower (p□0.05) FCR in Nile tilapia juveniles when PNM completely replaced dietary SBM. The higher level of inhibitors in the sole protein during the current study largely accounted for the poor diet utilization since single sources encourage high concentrations of anti-nutrients relative to the mixed protein sources. The findings are consistent with Agbo (2008) who attributed improved feed efficiency in the combined plant proteins to reduction of anti-nutrients.

Contrary to the superior performance of the FM-commercial feed in mono sex Nile tilapia (Ahmed *et al*., (2013), the commercial (control) diet was the poorest performer (3.116) relative to the counterparts during the current study. Although variation in FCRs is largely a result of differing feed types, the significantly poor FCR existed even with the FM-based diet despite the closer nutritional similarity. The relatively low Crude protein content (25%) of the control diet during the fingerling stages of Nile tilapia growth accounted for the restricted biomass production and ultimately higher FCR than other test diets. The findings are in tandem with Robinson & Li, 2015) who concluded that FCR is a measure of how efficiently an animal convers feed into body mass.

4.3 Relative Growth Rates in cultured Nile tilapia fed on test diets

The growth trial resulted into varying growth rates in Nile tilapia within and among all the dietary treatment groups. At the end of the 140 days, all the fish stock in each of the six pond units per dietary treatment group was measured.

Table 4.5: Determination and differences in Relative Growth Rates in Nile tilapia from the dietary treatment groups Variables Values in ponds of dietary treatment groups

	D1	D2	D3	D4
	143.5	127.5	146.4	130.6
Wg (g)	142.7	121.6	143.3	123.6
	147.3	133.0	147.5	122.7
	151.9	117.5	143.5	115.2
	146.7	130.8	147.0	116.8
	148.2	123.6	147.7	115.5
RGR (%)	654	581	667	595
	650	554	653	563
	671	606	672	559
	692	537	654	525
	666	596	670	532
	675	563	673	526
RGR values				
∑x	4008	3437	3989	3300
$\sum x^2$	2678502	1972267	265247	1818800
	668^a	573^b	665^a	550^b

*PN= pond serial number, D1= Fishmeal-based diet, D2= Peanut meal-based diet, D3= mixed plant meal-based diet, D4= commercial feed for Nile tilapia, RGRs= Relative Growth Rate. *Group means having a different superscript along the row denote that the values are significantly different (p□0.05) and vice versa.

Performance in terms of Relative growth Rates was as follows; FM-based diet> MPM-based diet> PNM-based diet> CF (Table 4.5).

The F- ratio equated to a critical value of 3.1 (F-distribution table, .0.05. 3, 20) and the indicated p-value. The lesser p-value than the significance level (0.05) implied that at least one of the group means was significantly different. Consequently, the result guided the null hypothesis rejection. Following the calculated turkey‟s HSD that equated to 30.87, comparisons with differences of paired group means indicated the following; the group difference (3) that was lower than the standard value rendered the FM and MPM-based diets not significantly different (p□0.05). Grouped means of the FM and PNM an MPM and PNM were higher than the HSD and consequently significantly different (p□0.05) (Appendix 7.5.3).

The mean Relative Growth Rate (RGR) (668%) in Nile tilapia fed on the FM-based diet was highest among test diets. Similarly, the FM-based diet out competed all the tested plant-derived alternatives in the fish growth trials by Hardy (2006), Goda *et al*. (2007), Solta *et al*. (2008), Otubusin *et al*. (2009), Nathan (2014) and Gosh & Mandal (2015). Agbo (2008) equated fishmeal to a „gold standard‟ to which all protein sources must be compared in terms of fish growth performance. In addition, Wu-chang *et al*. (2004), Gonzalex-Felix *et al*. (2010) indicated significantly faster (p□0.05) fish growth rates due to the FM diet than peanut derived diet. Although fish growth rate was attributed to level of feed intake (Mmanda, 2020), utilization efficiency largely accounted for the improved growth in the experimental fish fed on the FM-based diet during the current study.

The desirable amino acid profile characteristic to the test diet accounted for the improved conversion into biomass and resultant rapid fish growth rate. Studies by Nordahl & Pickering (2004) and Olfasen (2006) concur with the current findings on improved fish growth rate due the amino acid profile of dietary fishmeal. However, Ogungi *et al*. (2008) who linked growth performance of dietary FM to high phosphorus content conflicts with the current findings. Although dietary phosphorus is essential for skeletal development in fish (Hardy, 2010), enriched alternatives such as PNM (Peanut Institute, 2003) never matched the fish growth elicited by the dietary fishmeal.

The mean RGR (573%) was significantly lower (p□0.05) for Nile tilapia fed on the PNM-based diet than FM-based diet. PNM-base diet performed poorly among the test diets. Laval *et al*. (2016) reported similar incidences of retarded growth in farmed fish fed on PNM as a sole protein source. Comparisons of growth rates in fish fed on PNM and MPM-based diets followed the same trend. Dernebasi & Karayuce (2017) reported a significantly lower (p□0.05) growth performance induced by PNM than a combination of dietary PNM and Sesame Seed Meal (SSM) in Rainbow trout (*Onchorhynchus mykis*). In addition, Agbo (2008) recorded faster fish growth from a mixture of oil seed meal; SBM, PNM and cottonseed meal (CSM) than a sole source utilized at same inclusion levels.

Although the low weight gain in pacific white shrimp (*Litopenaeus vannamei*) fed on PNM was attributed to poor nutrient digestibility (Liu *et al.*, 2011), the amino acid profile was more important in biomass synthesis. The restricted biomass synthesis due to the deficient amino acid profile accounted for the poor RGR characteristic to the PNM-based diet during the current trial. The current findings concur with similar studies that reported retardations in fish growth due to deficient amino acid patterns in peanut-derived diets (Gatlin, 2007; Agbo, 2008; Agbo *et al*., 2011; Yildrim *et al*., 2014; Gosh & Mandal, 2015; Menghe & Penelope, 2017; Chakraborly, 2019).

There was insignificant difference (p□0.05) among mean RGRs in Nile tilapia fed on MPM and FM-based diets (668% & 665%). Similarly, in rainbow trout (*Oncorhynchus mykiss*), no significant difference (p□0.05) was observed on growth rate when SBM, cottonseed meal (CSM) and completely replaced dietary FM (Lee *et al*., 2002). In addition, dietary SBM, CSM, sunflower meal (SFM) and lin seed meal (LSM) as FM alternatives were not significantly differences (p□0.05) in Nile tilapia growth rates (El-Saidy & Gaber, 2003). The improved performance of the MPM-based diet was due to the modified amino acid pattern and corresponding improvement in protein synthesis following the combination of plant proteins. Specifically, the desirable amino acid profile characteristic to soybean protein (Nordahl & Pickering, 2004) accounted for the competitive performance of the MPM-based diet. According to Kaushik& Seliez (2010), Gonzalex-Felix *et al*. (2010), Duodu *et al*. (2019), perfect combinations of plant-based ingredients can act successfully as alternatives to fishmeal in diets of cultured fish. The current findings are consistent with Tiamiyu *et al*. (2016) and Shukla (2018) who reported improved fish growth due to a combination of dietary PNM and other plant-derived proteins.

The commercial diet exhibited the lowest RGR (550%) among the tested diets. The results conflict with Nathan (2014) who stated that FM-derived diets promote fast growth in farmed fish. Although Latif *et al*. (2008) linked lowered fish growth rate to inferior quality of the applied conventional, the current results are linked to poor feed conversion into fish biomass due to lowered protein inclusion. Consequently, the findings are in line with Klas (2011) who revealed that inappropriate levels of Crude protein retard fish growth via amino acid malnutrition.

4.4 Net Fish Yields in cultured Nile tilapia fed on test diets

Subtraction of gain in fish biomass or Net Production from the loss in fish biomass derived the Net Fish Yields (Table 4.6).

Table 4.6: Determination of Net Fish Yieds in Nile tilapia in different treatment groups

Dietary Treatment	Mt (No.)	MWg (g)	TFBl (g/tr)	FBl (g/pond)	NP (g/pond)	NFY (g/pond)	NFYm (g/pond)
FM-based diet	25	129±2.5	3,232.5	539	6121	5582	
					6074	5535	
					6218	5679	
					6293	5754	
					6218	5679	
					6319	5780	5668^{a}
PNM-based diet	22	109.5±4.45	2,422.2	404	5284	4854	
					5223	4819	
					5189	4785	
					5403	4999	
					5276	4872	
					5366	4962	4819^{b}
MPM-based diet	20	125.8 ± 2.65	2,516	419	6074	5655	
					5958	5539	
					5891	5472	
					6145	5726	
					6097	5678	
					6097	5678	5624^{a}
Control diet	23	104.4 ± 7 2.9	2408.1	401	4990	4589	
					4897	4496	
					4959	4558	
					5104	4703	
					5172	4771	
					5055	4654	4628^{c}

*DT= dietary treatment, D1= Fishmeal-based diet, D2= Peanut meal-based diet, D3= mixed plant meal-based diet, D4= commercial feed for Nile tilapia. TD= test diet, MWg= mean of fish weight gain, Mt= total mortality in treatment group, TFBl= Total fish biomass loss, FBl= fish biomass loss, NP= Net Production, NFY= Net Fish Yields, NFYm= mean values for Net Fish
Yield, tr=treatment group

*Group means having a different superscript along the column denote that the values are significantly different (p□0.05) and vice versa.

The NFYs varied in all experimental ponds (within and among groups). Basing on group means, the FM-based diet showed the highest RGR closely followed by the MPM-based diet. The PNM-based diet performed poorly among test diets.

A one-way ANOVA F-test revealed significant differences (p□0.05) among mean values for NFYs in the different dietary treatment groups. The F-value equated to a critical value of 3.1 (F-distribution table @ 0.05. 3, 20) and the indicated p-value. The smaller p-value than the significance level 0.05) implied a significant difference among the group means. The result guided the null hypothesis rejection.

Turkey‟s HSD identified significant differences (p□0.05) among the different paired groups. According to the calculated HSD (103.7), only the group mean difference (44) was lower than the HSD consequently rendering performances of the FM and MPM-based diets not significantly different (p□0.05). Other differences among paired groups were significantly different (p□0.05) due to possession of relatively higher values than the standard value.

Fish survival and size at harvest generally influenced the Net Fish Yields (NFYs) in Nile tilapia during the current study. Similar variables were attributed to variations in yield performances. For instance, the investigations of Meiludie (2013) on cultured Jipe tilapia (*Oreochromis jipe*) and Limbu (2015) on yield and cost-effectiveness in pond-cultured African catfish (*C. gariepinus*). The current findings are in tandem with Mengistu *et al.* (2019), who concluded that yield gap among farmed fish is due to differences in productivity and survival.

The FM-based diet that exhibited the highest mean NFY (5,668 g/pond) performed better than alternative test diets. Miles & Chapman (2006) reported a similar performance by the test diet in Nile tilapia. Unlike the significantly lower (p□0.05) NFY induced in Silver carp (*Hypophthalminchthys molitrix*) by the FM-based diet (Tuldhar *et al.* 2003), it has largely exhibited a better performance than alternative test diets including combinations of oil-seed meals. The higher gain in pond fish biomass elicited by the FM-based diet counteracted the increased fish loss (Table 4.10) by conserving fish biomass consequently rendering the test diet more superior in terms of NFY. Other authors who indicated a positive correlation between final weight gains and net yields are in line with the current findings; Altorre-Jacome *et al.* (2012) and Mugo-bundi *et al.* (2013), Ogware & Orewa, (2013), Sayed *et al.* (2018) and Limbu (2020).

Performances in Nile tilapia fed on the MPM-based diet (5624, g/pond) and FM-based diet did not differ significantly (p□0.05). Similarly, the study by Nathan (2004) indicated comparable NFYs in hybrid tilapia fed on mixed plant and fishmeal diets. The lower fish loss coupled with competitive growth rate improved yield performance in Nile tilapia fed on the MPM-based diet. The current findings are consistent with investigators Obaroh & Achionye-nzeh (2011), Bolivar *et al*. (2011), Mensah & Attipoe (2013), Meiludie (2013) Wailey *et al.* (2014), Limbu (2015) and Mengistu *et al.* (2019) who indicated that survival rates largely influenced fish yield.

The NFY in Nile tilapia fed on the PNM-based diet was significantly lower (p□0.05) (4819, g/pond) relative to the MPM and FM-based diets. The investigations of Yieldrim *et al.* (2014) and Lawal *et al.* (2016) obtained similar results when dietary PNM induced reduced fish yield. Others included Shukala (2018) who recorded lower biomass when 100% of PNM replaced SBM in the diet of Asian stinging catfish (*Heteropnuestes fossilis*). Although certain investigations attributed the low fish biomass to high mortality (Mensah, 2013; Mengistu *et al*., 2019) the trend differed during the current study. The poor NFY in Nile tilapia fed on the PNM-based diet was largely due to the small-sized fish at harvest. The current findings are contradictory to the feeding trial of Koum *et al.* (2009) where decreased yield in Nile tilapia fed on PNM as dietary FM replacement was attributed to retardation in the fish growth rate.

4.5 Survival Rates in cultured Nile tilapia fed on the test diets

Survival in Nile tilapia was lower at the begging compared to latter stages of the 16-week experiment for all the dietary treatment groups as indicated. Survival Rates in the experimental fish manifested as follows; FM-based diet>, PNM- based diet> MPM-based diet. SRs in Nile tilapia were insignificantly different (p□0.05) among all mean values despite the variations.

One-way ANOVA revealed significant differences (p□0.05) among the grouped means. The ANOVA F-value of 1.13184 equated to a critical value of 3.1 (F-distribution table @ 0.05 3, 20) and the indicated p-value. The greater p-value than the significant level (0.05) implied that there were no significant differences among mean values for survival Rates in the experimental fish. Subsequently, the null hypothesis was not rejected.

Table 4.7: Determination and comparisons in Survival Rates in Nile tilapia from the dietary treatment groups

Variables		Pond units						SRm
Fl (No)	D1	3	5	4	4	5	4	
	D2	4	3	5	3	4	3	
	D3	3	2	4	3	3	5	
	D4	4	3	4	3	4	5	
Fl (%)	D1	6.25	10.4	8.3	8.3	10.4	8.3	
	D2	8.3	6.25	10.4	6.25	8.3	6.25	
	D3	6.25	4.16	8.3	6.25	6.25	10.4	
	D4	8.3	6.25	8.3	6.25	8.3	10.4	
SR (%)	D1	93.75	89.6	91.7	91.7	89.6	91.7	91.44[a]
	D2	91.7	93.75	89.6	93.75	91.7	93.75	92.41[a]
	D3	93.75	95.86	91.7	93.75	93.75	89.6	93.06[a]
	D4	91.7	93.75	91.7	93.25	91.7	89.6	92.04[a]

*Fl= fish loss, SR= Survival Rate of fish, SRm=mean value for Survival Rates of fish, DT= dietary treatment, D1= Fishmeal-based diet, D2= Peanut meal-based diet, D3= mixed plant meal-based diet, D4= commercial feed for Nile tilapia.

The grand mean for Survival Rate of 92.2% (Table 4.7) in the experimental fish agreed with the studies of Furaya *et al*. (2004) and Gonzalex-Felix *et al.* (2010) that reported survival rates above 90% in Nile tilapia. Contrary to the feeding trials, the investigation of Yelazco-Vagus *et al*. (2013) recorded 100% fish survival rates. Although the latter attributed the excellent fish survival solely to feed quality and acceptability, the response is prone to other factors in the culturing environment. The appropriateness of culture conditions largely determines the Mortality Rates in cultured species. The higher variability in water quality accounted for the less than 100% Survival Rate in Nile tilapia in this study. These findings concur with the findings of Fish Site (2015), Limbu *et al*. (2016), Onada *et al*., (2016) and Ngalya *et al*. (2019) who attributed fish survival rates to stress conditions related to water quality parameters outside optimum ranges.

Similar to the investigations conducted by Phiri *et al.* (2018) and Mengistu *et al.* (2020), fish losses in all treatment groups were higher at juvenile than latter stages of fish growth. Although a combination of risk factors contributed to mortality in the early stages of Nile tilapia growth, the lower stock resistance to common frog *(Rana temporaria*) predation accounted for the increased mortality at the onset and earlier stages of the current experiment. The observation concurs with the study by Egwere & Orewa (2013) where predators in earthen raised fish were more common at juvenile than adult stages of growth. On the contrary, Mensah (2013) indicate that handling stress accounted for the mortality in Nile tilapia at the commencement of experiment. Since the fish losses continued albeit at diminishing rate, predation was undoubtedly accounted for the difference in survivability among the different fish growth stages during the current experiment.

The current study revealed no significant difference (p□0.05) among mean Survival Rates in Nile tilapia for all dietary treatment groups. Similarly, differences in the variable were not significant (p□0.05) as reported by investigators; Yieldrim *et al.* (2014) and Kirimi *et al.* (2016) in Nile tilapia (*O. niloticus L.*) and Allan *et al*. (2000) in Silver perch (*Bidyanus bidyanus*). The comparability among dietary treatments implies that variation in test diets did not exhibit a significant effect on fish survival.

Despite the lack of a significant difference (p□0.05) among treatment groups, the lower Survival Rate (91.44%) implied a poorer performance for the FM-derivatives (FM-based diet and commercial diet) relative to the peanut-based diets. The current results are similar to the investigations where peanut-derived diets exhibited higher survival rates than the fishmeal counterparts (Bhatnager & Devi, 2013; Yieldrim *et al.,* 2014; Olapode & Quinn, 2019). The rapid accumulation of the toxic ammonia could have accounted for the lower Survival Rate in Nile tilapia fed on the FM-derivatives during the current study. The findings conform to the studies by Rossana (2019) where rise in unionized ammonia was faster for the fishmeal-based diet than the peanut-based meals and Seargent (2014) and Onada *et al*. (2016) who concluded that fish mortalities are attributed to increased toxic ammonia in water bodies.

The PNM based diet indicated a slightly lower Survival Rate (92.41%) relative to the MPM-based diet (93.06%) during the current study. The variation in performance between the two peanut-derived diets attributes to phosphorus contents. The higher level of phosphorus in PNM relative to other oil-seed meals (Peanut Institute (2018), accounted for the increased pollution and corresponding fish mortality. The findings agree with Hoelscher *et al*. (2015) who linked high phosphorus levels to eutrophication, reduced water aeration and increased fish mortality. In addition, Furuya *et al*. (2004) also reported that the application of phosphorus deficient soybean increased phosphorus pollution.

Performance was poorer for the control diet than the peanut-based diets due to the higher fish mortality experienced. Although increased fish mortality was due to fishmeal inclusion in the control diet (Rossana, 2019), variation in shelf lives contributed to the poor performance of the test diet. Unlike the fixed shelf life (28 days) for the tested diets, the standard was unattainable for the off-farm FM-based diet. Subsequently, there were higher possibilities of exposure to quality deterioration were higher for the control than the tested diets. Although attributing fish mortality to poor culture conditions (Mmanda, 2020) is inconsistent, other studies where feed quality determined fish survival rates (Mustapha *et al*., 2014; Wachira *et al*., 2021) concur with the current findings.

4.6 Economic Conversion Ratios in Nile tilapia fed on test diets

Initially, the unit price of feed ingredients in local markets multiplied by the proportional costs in formulated diets derived the unit costs of test feeds following Yelazco-Vagus *et al*. (2013). The Unit costs of feeds multiplied with the mean Feed Conversion Ratio in each of the treatment groups to determine the Economic Conversion Ratios (ECRs).

There were variations in ECRs in Nile tilapia among the test diets. The lowest value characteristic to the MPM-based diet indicated best performance. The performance in ascending order was as follows; MPM based diet□ FM based diet□ PNM based diet (Table 4.8). The MPM with the lowest ECR emerged as the best performer among test diets. A one-way ANOVA F-test determined the possibility a significant difference (p□0.05) among mean ECRs. The F-value equated to a critical value of 3.239 (F- distribution table @ 0.05. 3, 16) and the indicated p-value. The smaller p-value relative to the significance level (0.05) implied a significant difference among the group means. The result guided the null hypothesis rejection.

Table 4.8: Cost of test feeds during the fierst sampling at Iganga central markets

USD	TFR (%/ pond)	(kg/ Fi pond)	ADi (kg/ pond)	(USD Kg)	(USD/ (USD)	(USD Kg)	USD	
D1 FM	15.67458	20.7	59.03	0.415	0.2451		3.8402	
MB		11.18	31.88	0.141	0.0449		0.7054	
FBc		2.391	6.82	0.063	0.0043		0.0674	
MNp		0.797	2.27	0.027	0.0062		0.0972	
		35.068	100.00			0.3005		4.71
D2 PNM	15.67458	20.7	40.16	0.591	0.23735		3.7204	
MB		26.16	50.75	0.141	0.07154		1.1213	
FBc		3.515	6.82	0.063	0.00430		0.0674	
MNp		1.172	2.27	0.027	0.00620		0.0972	
		51.547	100.00			0.35249		5.53
D3 MPM	15.67458	20.7	49.92	0.426	0.21272		3.3343	
MB		17.0	40.99	0.141	0.05780		0.9061	
FBc		2.827	6.82	0.063	0.00430		0.0674	
MNp		0.943	2.27	0.027	0.00620		0.0972	
		41.470	100.00		0.28102		4.40	
D4	15.67458					0.34291	5.37	

Fi= feed ingredient, TFR= Total Feed Ration, ADi= average of dietary inclusion for the two feeding regimes, UPi= unit price of feed ingredient, FR= feeding ration TCi= total cost of ingredient, DT= dietary treatment, D1= fishmeal-based diet, D2=peanut meal-based diet, D3=mixed plant meal-based diet, D4= commercial diet for Nile tilapia.

*MNp= micronutrients pre-mix; vitamins (A, C, B12) and minerals (NaCl, Feso4).

*ADi= summation of amounts in feeding regimes 1 and 2

*PCi = proportional cost of ingredient (ADi x UCf)

*UCf= unit cost of feed (PC1+PC2…PC4)

*TCf= total cost of feed (UCf x TFR) *USD= 3,500 Ugandan shillings.

Table 4.9: Determination and comparisons among Economic Conversion Ratios in Nile tilapia fed on test diets

DT (No.)	FCRm	Dc	UPi USD/kg	UCf USD/kg	ECR	ECRm
D1	2.525	0	0.415	0.300	0.758	
		28	0.409	0.296	0.749	
		56	0.397	0.287	0.726	
		84	0.381	0.275	0.694	
		112	0.405	0.293	0.739	0.697[a]
D2	2.965	0	0.591	0.352	1.046	
		28	0.615	0.371	1.101	
		56	0.613	0.366	1.001	
		84	0.605	0.361	1.071	
		112	0.636	0.379	0.998	1.043[b]
D3	2.593	0	0.426	0.281	0.729	
		28	0.432	0.285	0.739	
		56	0.417	0.275	0.715	
		84	0.405	0.267	0.693	
		112	0.445	0.289	0.749	0.726[a]
D4	3.116	0	-	0.343	1.069	
		28	-	0.315	0.982	
		56	-	0.295	0.919	
		84	-	0.271	0.844	
		112	-	0.285	0.888	0.948[b]

*FCRm= mean value for the Feed Conversions, UPi=unit price of ingredients, UCf= unit cost of feed, DT=dietary treatment, Dc= Days after commencement of the study, D1= Fishmeal-based dietary treatment, D2= Peanut meal-based dietary treatment, D3= mixed plant meal-based dietary treatment, D4=commercial feed for Nile tilapia, ECR= Economic Conversion Ratio.

*One USD=3500 Ugandan Shillings.

*Group means having a different superscript along the last column denote that the values are significantly different (p□0.05) and vice versa.

The calculated Tukeys (0.099) identified the significantly different (p□0.05) paired groups.

The difference between mean ECRs in Nile tilapia fed on the FM and MPM-based diets (0.029) and PNM-based diet and control diet (0.095) were less than the HSD consequently indicating there were no significant differences (p□0.05) among the diets. On the contrary, other paired group were higher than the HSD which implied that they were significantly different (p□0.05).

Since the challenge of producing fish feeds that are economical and induce acceptable yield has persisted (Turchini *et al*., 2019), performance indicators in feeding trials should balance the two variables. High feed cost can offset a good FCR consequently rendering the fish feeding uneconomical. Although the FCR presents a physical relationship between input and desired output, valuation of the two variables by the ECR is a more efficient method of revealing cost- effectiveness of feed applications in farmed fish. According to Glencross *et al*. (2007), the evaluation of potential alternatives to fishmeal should involve both nutritional and economic values. Unlike the FCRs that are restricted to measuring the efficiency of feed conversion into fish biomass (Bharati, 2020), ECR involves cost of feed considered as one of the most important factors influencing the economics of fish feeding. The findings concur with Sogabesan & Bashir (2008) who stated that cost of feed is the determinant for economical and profitable feeding in Nile tilapia and Hardy & Kaushik (2021) who concluded that ECR directly measures the economic efficiency of fish feed.

Unlike other investigations where prices of feed ingredients accounted for the diet costs (Skiba *et al*. 2015; Taimiyu *et al*. 2016), proportional costs of the protein supplements instead of prices of ingredients largely determined the costs of test feeds (Table 4.8). For example, despite the lower unit price of FM (USD 0.415) than MPM (USD 0.426), the former exhibited a higher diet cost of USD 0.300 than the MPM (USD 0.281). The low-cost carbohydrate source (maize bran) that was included in smaller quantity in the FM-based diet (31.88%) than the MPM-based diet (40.99%) during the standardization of protein prior to feed formulation accounted for the reversed trend. Since there was no mismatch between proportional costs and unit costs of test diets, the former largely influenced the costs and corresponding ECRs of test diets. The findings conflict with the investigation of Yelazco *et al*. (2013) where it was concluded that alternatives to dietary FM should possess lower prices in order to reduce fish production costs and Skiba *et al*. (2015) who reported that feed cost is highly dependent of ingredient prices

The FM-based diet that indicated a lower ECR (0.697) performed best among the tested diets (Table 4.9). Similarly, the study on Gilthead sea bream (*Sparus aurata L*.) by Kissil & Lupatsch (2004) indicated that the use of plant protein mixtures instead of fishmeal in fish diets was more expensive. Despite the higher unit cost, higher efficiency of feed conversion reflected by the lower FCR accounted for the better ECR of the FM-based diet than MPM-based diet (Table 4.8). The findings are in line with authors who concluded that dietary fishmeal promoted faster growth and yield in farmed Nile tilapia (Miles & Chapman, 2006; Agbo, 2008; Gosh & Mandal, 2015).

Although the difference among ECRs in Nile tilapia fed on the MPM and FM-based diets was not significant (p□0.05), performance of the former was lower than the latter. Other investigations are inconsistent with the current results. More economical production in farmed fish by combinations of plant-derived ingredients relative to dietary fishmeal have been published (Agbo, 2008; Obirikorang *et al*., 2016, Turchini *et al*., 2019; Kirimi, 2019). Despite the cheaper unit cost of diet, the relatively poor ECR exhibited by the MPM-based diet relative to the FM-based diet was due to the lowered conversion of feed into fish biomass (Table 4.6). The current findings are in line with Opstvedt *et al*. (2003) who stated that lowered feed prices might not reduce production cost when feed conversion is impaired. In addition to the investigators who attributed the improvements in ECR to alternative variables (Liti *et al*., 2006; Soltan *et al*., 2008: Bamba *et al*., 2014), the findings contradict Kirimi (2019) who concluded that low cost of dietary plant protein sources can compensate for any poor growth consequently improving the economics of fish production.

Nile tilapia fed on the PNM-based diet showed the highest mean ECR (1.043). Consequently, it exhibited the poorest performance compared to counterparts. On the contrary, previous studies consistently indicated that PNM is more economical than FM in fish diets (Ovi, 2007; Agbo, 2008; Agbo *et al*., 2011). Increased diet cost and FCR during the current study negatively influenced the ECR of the PNM-based diet consequently accounting for the poorer results. The findings concur with the following authors where the same factors led to poor ECRs; Gebhart (2000), Sachez-Luzano (2007) and Anani *et al.* (2017). Authors who attributed poor performance in terms of ECR to sole factors; increased feed cost (Yelazaco-vegas *et al.*,2013) and reduced feed conversion coupled with low harvest weight (Mugo-bundi *et al*., 2013) are partially inconsistent with the current findings.

The commercial diet for Nile tilapia indicated a significantly better ECR (0.948) than the PNMbased diet. Although a combination of diet cost and biomass production largely influenced the current results, the lower cost than the PNM-based diet accounted for the better performance of the commercial diet. The findings conform to the study of Martinez-Lolrens, (2011) who reported that ECR is highly dependent on diet cost. On the contrary, Anani *et al*. (2017) revealed that level of cost-effectiveness link to both cost and utilization efficiency of commercial fish feeds.

4.7 Profit indices in cultured Nile tilapia fed on test diets

Determination of Profit Indices in the experimental fish involved consideration of the following stages;

a) Weight gain and the corresponding fish biomass production in pond unit (A.

b) Indirect determination of farm-gate prices via sell prices at the local fish markets.

(Table 4.10). Mean values from sampling units at the trading centers equated to the farm-gate prices.

Table 4.10: Sell prices for fresh Nile tilapia at the sampling units of trading centers at survey site 2

TC	Sn	Dc	Wf (Kg)	Pf (USD)	UPf USD/kg
Namutumba	1	0	0.532	1.65	3.10
Mayuge			0.526	1.80	3.42
Bugembe			0.748	2.46	3.29
Kamuli			0.620	2.3	3.71
Busembatia			0.866	2.78	3.21
Namutumba	2	14	0.844	2.55	3.02
Mayuge			0.756	2.7	3.57
Bugembe			0.532	1.90	3.57
Kamuli			0.545	2.18	4.00
Busembatia			0.983	2.95	3.00
Namutumba	3	28	0.956	3.05	3.19
Mayuge			0.714	2.65	3.71
Bugembe			0.578	1.90	3.29
Kamuli			0.914	3.20	3.50
Busembatia			0.593	1.95	3.29
Namutumba	4	42	0.851	2.80	3.29
Mayuge			0.775	2.65	3.42
Bugembe			0.784	2.80	3.57
Kamuli			0.870	3.15	3.62
Busembatia			0.750	2.25	3.00
Namutumba	5	56	0.853	2.90	3.40
Mayuge			0.891	3.18	3.57
Bugembe			0.742	2.65	3.57
Kamuli			0.672	2.40	3.57
Busembatia			0.738	1.75	2.37
Namutumba	6	70	0.748	2.35	3.14
Mayuge			0.795	2.95	3.71
Bugembe			0.581	1.90	3.27
Kamuli			0.714	2.55	3.57
Busembatia			0.700	1.80	2.57

*Sn= sample number, Dc=days after commencement of the sample survey, TC=trading centers Wf=weight of fish, Pf=price of fish, UPf=unit price of fish.

*USD=3500 Ugandan Shillings.

The PIs in Nile tilapia fed on test diets varied among pond units and treatment groups as indicated below (Table 4.11). The MPM-based diet exhibited the highest mean PI among test diets. The order of superiority in performance is as follows; MPM-based diet□FM-based diet□PNM-based diet. A one-way ANOVA F-test determined the possibility a significant difference among group means. The F-value (72.4) equated to a Critical Value of 3.2 (F-distribution table at 0.05., 3, 16) and the indicated p-value. The small p-value compared to the significance level (0.05) implied a significant difference among treatment groups.

The Tukeys HSD identified the significant levels for the paired group means. According to the q-distribution table, the value of 3.649 at 0.05, (3, 16) translated into the HSD value of 0.0729. According to comparisons with the HSD, the FM and MPM-based diets were not significantly different due to the lower difference among the paired group means (0.056). Other comparisons of paired group means with the HSD were significantly different (p□0.05) since they were higher than the standard value.

Table 4.11: Determination of Profit indices in Nile tilapia from different dieary treatment groups.

DT	FBm (kg/pond)	FGp (UDS/kg)	PV (USD)	PVm (USD)	UCf (UDS/kg)	TCf (USD)	P1	PIm
			19.8	20.8	0.300			
		3.57	22.1	20.8	0.296	4.65	4.47	
		3.43	21.3	20.8	0.287	4.51	4.61	
		3.67	22.8	20.8	0.275	4.30	4.82	
		2.90	18.0	20.8	0.293	4.58	4.53	4.568[a]
D2		3.19	16.9	17.7	0.352			
		3.57	18.8	17.7	0.371	5.82	3.04	
		3.43	18.1	17.7	0.366	5.74	3.08	
		3.67	19.4	17.7	0.361	5.66	3.12	
		2.90	15.3	17.7	0.379 0.	5.94	2.98	3.804[b]
D3		3.19	19.3	20.3				
		3.57	21.6	20.3	0.285	4.46	4.53	
		3.43	20.7	20.3	0.275	4.32	4.68	
		3.67	22.2	20.3	0.267	4.19	4.84	
		2.90	17.5	20.3	0.289	4.53	4.47	4.624[a]
D4		3.19	16.0	16.9	0.343			
		3.57	18.0	16.9	0.315	4.93	3.42	
		3.43	17.2	16.9	0.295	4.62	3.65	
		3.67	18.5	16.9	0.271	4.25	3.97	
		2.90	14.6	16.9	0.285	4.46	3.79	3.594[c]
D1	6.207	3.19				4.71	4.41	
			.	.	. 281	. 4.40 5.37	. 4.60 3.14	.

*MFBg=mean value for fish biomass gains= (∑FB1, 2..6).

*TCf= total cost of feed (UCf x TFR).

*PV=Product Value =FBm x FGp.

* PVm=mean value for Product Values ($\sum PV_{1,\ 2..5}$).

*PI = Profit Index (PVm/TCf)

*PIm=mean value for Profit Indices

*TFR= 5670 g/pond

*USD=3500 Ugandan Shillings.

*DT= dietary treatment, D1=Fishmeal-based diet, D2= Peanut meal-based diet, D3=mixed plant meal-based diet.

Several investigations concluded that high cost of feeding is detrimental to the profitability of aquaculture production (Sogabesan & Basner 2018; Mogaji, 2019; Afram *et al*., 2021). The hike in fish prices due to increased demand (Namatovu, *et al*., 2018) has modified the trend. The Profit Index (PI) that considers both input and out-put valuations (Umaru *et al*., 2016), have become popular for comprehensive economic analyses in fish feeding; Martinez-Llorens, 2011; Umaru *et al*., 2016; Oluwalola *et al*., 2019). Unlike other indicators of economic performance such as ECR, linking feed cost to fish sales is unique to PI and renders it more relevant under unpredictable variations in input and outputs markets. The findings are in line with the study on fish farm profitability analysis by Hyuha *et al.* (2011) who recommended close monitoring feed and product prices.

Diet cost and value of experimental fish accounted for the variations in Profit Indices (PIs) in Nile tilapia fed on test diets in the current study (Table 4.11). The investigations by Sserwambala (2017) where feed cost and farm-gate prices affected profitability of aquaculture enterprises concur with the current study. On the contrary, authors including Egwera & Orewa (2013), Makwaja & Kapute (2015) Kwamena (2015) and Umaru *et al.* (2016) linked profitability in cultured fish to productivity and survival rates. Specifically, Ariana & Maria

(2012) revealed that increase in PI stems from a combination of high productivity and better fish survival. The conflicting findings could be attributed to the fish reserve ponds (Figure 5.0) that stabilized pond stock densities consequently mitigating the variable during the experiment.

Despite the lack of a significant difference (p□0.05), PI was higher for the MPM-based diet than the FM-based diet. Other investigators obtained similar results from comparisons of combined plant protein ingredients as fishmeal alternatives in aqua feeds. The study of El-Saidy and Gaber (2003) on a mixture of soybean meal, cottonseed meal and sunflower meal fed to Nile tilapia as FM substitute produced the highest PI at 100% replacement level. The mean total cost of the MPM-based feed equivalent to 4.38 was the lowest.

Subsequently, although harvest size and farm-gate price contributed, the low diet cost accounted for the superiority in performance in the current study. The findings agree with the significantly higher (p□0.05) PI obtained in African catfish C. *gariepinus*) due to the low-cost water melon seed (*Citrullus lanatus*) based meal by Jimoh *et al.* (2013). In addition, Coyle (2004) and Ahamed (2013) stated that cheap feed enables fish farms to retain high net profits. The current findings partially contradict the trial on oil-seed meals where a combination of low cost and good growth performance accounted for the higher profitability in Nile tilapia. Hassan (2007), Egwere & Owere, (2013) and Abou-Zeid (2015) who concluded that size of fish at harvest and farm-gate price are the most important variables influencing profit margins on fish farms are inconsistent with the findings of the current study.

Contrary to the MPM-based diet, cost of diet and poor water quality negatively affected the performance of the FM-based diet. Although investigators largely pointed at high feed cost; Okumus and Mazlum (2002), Diaal-kenawy, *et al.* (2008), Bob-manuel and Erondu (2010) revealed that lowered profitability in pond raised fish fed on dietary fishmeal may link to reduced yield due to the rapid accumulation of toxic NH_3. Animal-derived products including fishmeal are more prone to decomposition (Themelis, 2005) implying that they readily release NH_3. These findings are consistent with Onada *et al.* (2015) who attributed the high fish mortality in earthen ponds to increased level of NH_3.

The FM-based diet exhibited a significantly higher (p□0.05) PI compared to the PNM-based diet. Performance of the latter was significantly poorer (p□0.05) than all other test diets. Abirike *et al.* (2014) reported similar results indicating a significantly higher PI (p□0.05) for the FM- Pito mash mixture than FM-PNM mixture. Other related investigations indicated contradictory results following the counterbalancing of the reduced fish weight gain by low cost of the peanut-derived feed. Hassan (1991) reported that profitability was higher for the PNM-based diet than FM-based diet in common carp (*Cyprinus carpio L.*). In addition, Agbo *et al.* (2011) indicted a higher PI for the PNM-ased diet than „all fishmeal-diet". The higher diet cost coupled with lower product price accounted for the poorer PI in Nile tilapia fed on the PNM-based diet relative to alternative diets during the current study. The above statement conforms to the investigations by Opiyo *et al*. (2014) and Anani *et al.* (2017) where high feed costs without commensurate increase in the fish prices lowered profitability in cultured Nile tilapia.

The control `diet exhibited the lowest PI among test diets. The cost of feed coupled with level of biomass production and corresponding product value accounts for the profitability of fish feeds. Subsequently the poor performance was attributed to lowered value of fish products compared to the cost of the commercial feed. The above statement conforms to the study conducted by Adriana and Maria (2012) where both fish productivity and gross revenue influenced Profit Indices. The findings are contrary to investigators who restricted the lowered profitability of the commercial feed to sole variables such as high cost (Bolivar *et al*. (2011) Ngalya *et al*. 2019) and level of fish production (Ondhoro *et al*. 2021).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

With exception to NH_3, the significant variations (p□0.05) in selected water parameters levels (DO, pH and NO_2^-) did not affect fish biomass production as indicated in the current results. The direct correlation between unionized ammonia levels and biomass losses in pond units during the feeding trial implied that deterioration in water quality affected the biomass production in Nile tilapia.

The variance in growth and yield performances indicated by Nile tilapia fed on the PNM and control diets during the current study implies that sole application of former in trials on production performance may lead to unreliable results. The fish losses under the earthen ponds demand for comprehensive performance indicators that measure both gains and losses in biomass such as the Net Fish Yield.

Despite the insignificant difference among the test diets (p□0.05), the higher fish Survival Rate exhibited by the PNM based diet than the FM-based diet indicated that the former is still important in Nile tilapia diet.

The dependency on three variables; diet cost, level of production and farm-gate prices exhibited during the sample survey implies that Profit Indices are more appropriate at measuring fish farm profitability than the Economic Conversion Ratios.

The poor results based on both biological and economic performances reveal that the PNM-based diet is incapable of complete substitution of dietary fishmeal in farmed Nile tilapia. In addition, the lack of significant differences (p□0.05) among all tested parameters equated the MPM-based diet to the FM-based diet.

5.2 Recommendations

Since the unionized ammonia toxicity led to a significant loss (p□0.05) in fish biomass, trials aimed at replacing the conventional dietary fishmeal should consider water testing in order to counteract the possible effect of the aquatic environment on production of farmed Nile tilapia.

Despite the largely similar results exhibited by production indicators, the inclusive Net Fish Yield should supplement growth rates in feeding trials in order to attain valid and reliable alternative diets in farmed fish.

In spite of the poorer performances relative to alternative test diets, the higher survival in Nile tilapia fed on the PNM-based diet justifies the partial inclusion of PNM as a dietary FM substitute in line with the majority of previous investigations.

The contrasting trends in performances of the FM and MPM-diets in relation to biomass production and profitability imply that reliance on biological production without the corresponding cost may be inconclusive in feeding trials.

Since both feed prices and farm-gate prices affected the fish production during the current study, investigations should shift from Economic Conversion Ratios to Profit Indices that are sensitive to the two variables.

The comparable MPM-based diet in terms of results based on biological and economic performances during the current study should completely substitute the conventional FMbased diet in pond cultured Nile tilapia.

The MPM-based feed for farmed Nile tilapia should be restricted to suitable areas where peanut and soybean are farmed locally and cheaply particularly in the Eastern and Northern regions of Uganda. The cropping should integrate with the earthen fishponds in order to ensure a sustainable feed supply.

Feeding trials in farmed species should uphold the fish reserve ponds as applied in the current trials in order to mitigate the challenge of uncontrollable fish losses characteristic to the earthen ponds.

Local prices of agricultural related products including feed ingredients change according to season. Future investigations should consider the annual market trends.

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APPENDICES

Appendix 7. 1: ***Live weight of thirty Nile tilapia specimens from each of the treatment groups at experimental site A on the 28th day after stocking***

DT	Pr	W (g)																													
D1	Wf +Ww	125	102	98	100	64	115	112	100	110	98	97	120	116	112	110	109	135	132	130	126	125	141	140	136	132	131	128	142	140	136
	Ww	90	75	63	69	35	75	73	76	77	78	74	76	64	62	79	49	98	97	85	81	69	83	90	91	82	73	68	97	95	81
	Wf	35	27	25	31	29	40	39	24	43	20	23	56	52	50	31	60	37	35	45	45	56	58	50	45	50	58	60	45	45	55
D2	Wf+Ww	115	135	100	105	135	132	130	126	108	141	132	135	126	90	95	98	99	102	121	126	128	121	128	96	99	83	88	80	95	85
	Ww	95	100	82	85	90	91	95	84	84	91	91	95	98	45	45	43	56	60	71	71	78	91	98	63	64	63	63	42	52	57
	Wf	20	35	18	20	45	41	35	42	24	50	41	40	28	45	50	55	43	42	50	55	50	30	30	33	35	20	25	38	43	28
D3	Wf+Ww	98	83	89	72	79	84	88	110	115	106	118	122	129	127	94	99	102	108	96	92	114	102	110	141	126	127	116	115	121	123
	Ww	60	58	60	42	51	43	52	84	81	61	66	71	82	79	65	75	47	65	51	56	49	74	80	91	85	79	62	56	73	76
	Wf	38	25	29	30	28	41	36	26	34	45	52	51	47	48	29	24	55	43	45	36	65	28	30	50	41	48	54	59	48	47
D4	Wf+Ww	94	99	105	109	112	118	123	120	122	125	128	94	95	92	105	94	91	99	106	123	121	129	139	135	132	95	98	92	91	96
	Ww	64	59	60	60	62	78	83	77	97	97	78	51	60	62	50	59	66	55	66	83	73	79	87	95	97	70	68	67	71	77
	Wf	30	40	45	45	50	40	40	43	25	97	50	43	35	30	55	35	25	44	40	40	48	50	52	40	35	25	30	25	20	19

D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, W= weight of the experimental fish, Ww= weight of water, Wf= weigh to fish, DT=dietary treatment Pr= parameter

2 Body weight of thirty Nile tilapia specimens from each of the treatment groups at experimental site A on the 56th

Appendix 7. : Day after stocking

DT		W(g)																													
D1	WW+Wf	110	115	100	110	95	120	124	132	138	130	96	163	108	99	112	120	123	120	122	130	126	129	121	130	132	130	110	115	122	131
	ww	45	44	46	40	40	40	39	42	40	40	31	65	37	38	47	37	39	42	41	45	61	64	60	52	64	60	52	37	34	51
	wf	65	71	54	70	55	80	85	90	98	90	65	98	71	61	65	83	84	78	81	85	65	65	61	78	68	70	58	78	88	80
D2	WW+Wf	115	105	118	90	105	80	95	100	94	115	109	106	112	125	118	106	110	95	98	96	112	120	124	95	115	95	98	110	115	108
	ww	45	22	28	32	30	35	37	39	39	45	44	41	47	50	48	46	46	41	48	42	52	45	42	39	50	47	42	50	60	43
	wf	70	83	90	58	15	45	58	61	55	70	65	65	65	75	70	60	64	54	50	54	60	75	82	56	65	48	56	60	55	65
D3	WW+Wf	112	120	132	142	145	135	138	120	100	105	124	133	130	134	135	126	122	98	104	121	108	130	140	142	146	121	113	104	121	108
	ww	34	38	39	45	66	69	53	48	45	43	43	47	55	52	54	63	53	43	43	46	45	55	55	57	65	59	52	46	61	56
	wf	78	82	93	97	79	66	85	72	55	62	81	86	75	82	81	63	69	55	61	75	63	75	85	85	81	62	61	58	60	52
D4	WW+Wf	133	128	106	124	120	132	119	116	98	112	110	108	92	99	108	90	98	110	112	128	110	106	113	128	135	141	140	123	112	138
	ww	53	58	48	46	50	54	54	51	38	39	39	41	42	44	48	40	56	49	53	46	45	51	55	60	65	56	59	60	37	68
	wf	80	70	58	78	70	78	65	65	60	73	71	67	50	55	60	50	42	61	59	82	65	55	58	68	70	85	81	63	75	70

D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, W=weight, Ww=weight of water, Wf=weight of fish, DT=dietary treatment, Pr=parameter DT=dietary treatment

3 **Live weight of thirty Nile tilapia specimens from each of the treatment groups at experimental site Aon the 84th after stocking**

DT	Pr	W (g)														
D1	Wf+W	193	189	169	148	159	170	148	190	192	195	149	154	146	143	159
	Ww	36	36	54	23	35	45	48	45	44	45	41	44	51	53	46
	Wf	157	153	115	125	124	125	100	145	148	150	108	110	95	90	113
D2	Wf+W	133	139	141	145	152	161	118	129	143	121	152	143	129	142	153
	Ww	43		52	61	47	46	48	47	42	43	42	38	49	43	43
	Wf	90	75	89	84	105	115	70	82	101	78	110	105	80	99	110
D3	Wf+W	163	166	182	164	167	142	151	143	149	151	145	140	159	145	148
	Ww	33	40	32	36	42	52	36	43	44	46	45	45	57	47	53
	Wf	130	126	150	128	125	90	115	100	105	105	100	95	102	98	95
D4	Wf+W	145	140	150	154	152	148	144	160	143	140	142	148	145	148	135
	Ww	50	50	50	54	63	58	52	45	48	47	62	53	55	53	55
	Wf	95	90	100	90	89	90	92	115	95	93	80	95	90	95	80

DT	Pr	W (g)														
D1	Wf+W	126	122	151	129	135	145	142	152	161	158	148	151	123	120	136
	Ww	40	40	46	44	40	43	42	42	49	53	48	46	37	40	41
	Wf	86	82	105	85	95	102	100	110	112	105	100	105	86	80	95
D2	Wf+W	160	149	135	148	151	129	147	132	143	152	145	141	143	132	128
	Ww	45	41	45	45	42	44	32	34	48	52	53	46	35	36	24
	Wf	115	108	90	103	109	85	113	98	95	100	92	95	108	96	104
D3	Wf+W	141	145	150	151	160	143	145	139	142	140	152	155	160	155	160
	Ww	43	45	45	45	45	52	50	49	44	50	40	35	45	45	42
	Wf	98	100	105	106	115	90	95	90	98	90	112	120	115	110	118
D4	Wf+W	150	152	156	150	142	148	150	171	149	142	140	135	130	132	135
	Ww	48	42	46	45	52	43	42	45	67	55	45	55	52	57	46
	Wf	102	110	110	105	90	105	108	126	82	87	95	80	78	75	89

D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, W= weight, Ww=weight of water, Wf=weight of fish, DT=dietary treatment Pr=parameter, DT=dietary treatment, g=grams.

4 **Live weight of thirty Nile tilapia specimens from each of the treatment groups at experimental site A on the 112th after stocking**

DT	Pr	W (g)																													
D1	Wf+Ww	204	216	215	208	199	220	225	198	156	163	218	185	179	158	161	172	195	190	182	213	220	195	190	195	205	186	169	173	192	190
	Ww	39	36	30	35	37	34	43	38	31	43	40	37	44	48	49	47	50	42	52	43	42	53	45	45	37	51	57	33	47	42
	Wf	165	160	185	173	162	176	162	160	125	120	178	148	133	110	112	125	145	146	130	170	178	142	145	150	168	135	112	140	145	148
D2	Wf+Ww	197	199	164	190	195	196	210	200	183	189	210	190	196	195	184	163	140	172	191	173	169	172	143	196	163	156	148	154	149	155
	Ww	57	58	44	45	55	46	48	42	53	43	42	45	48	55	50	58	49	38	50	47	41	57	37	50	46	26	42	42	41	42
	Wf	140	141	120	145	140	150	162	158	140	146	168	145	148	140	144	105	100	134	141	126	128	115	106	146	117	110	106	112	108	113
D3	Wf+Ww	166	154	210	196	180	164	158	163	194	206	169	220	210	223	214	221	206	205	222	206	214	205	196	189	164	158	209	196	195	190
	Ww	43	36	35	56	45	52	53	48	54	61	42	55	44	38	44	56	46	30	37	41	39	60	56	54	54	43	54	56	55	55
	Wf	143	148	175	140	135	148	105	115	140	145	127	165	166	185	170	165	160	175	185	165	175	145	140	135	110	115	155	140	140	135
D4	W f + W w	183	200	195	210	196	198	200		183	151	224	201	194	182	161	194	199	185	159	153	189	195	182	182	193	195	201	223	212	209
	Ww	58	32	40	45	46	47	44	59	60	55	53	66	57	71	60	58	57	49	56	48	53	49	60	66	67	58	60	73	67	66
	Wf	125	168	155	165	150	151	156	104	123	96	171	135	137	11	101	136	142	136	103	105	136	146	122	116	126	137	141	150	145	143

DT=dietary treatment, Pr=parameter, D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet,

W= weight, Ww=weight of water, Wf=weight of fish, DT=dietary treatment PM=parameter, DT=dietary treatment.

Appendix 7. 5: **Live weight of thirty Nile tilapia specimens from each of the treatment groups at experimental site A on the 140th day after stocking**

TR	Pr	W (g)																													
D1	Wf + Ww	223	247	245	163	184	251	229	235	243	243	241	252	256	260	271	249	233	188	175	261	262	223	225	211	215	205	202	176	142	151
	Ww	65	82	100	48	37	76	49	50	54	51	64	73	80	66	49	48	48	55	66	72	55	70	81	66	65	52	37	51	72	56
	Wf	160	165	145	115	147	175	180	185	189	190	188	183	180	205	200	185	150	140	195	190	168	155	130	128	150	153	165	125	170	195
D2	Wf + Ww	211	220	204	208	196	164	165	194	198	190	184	206	211	261	271	251	247	194	186	251	223	215	196	185	175	183	194	199	185	193
	Ww	41	42	32	40	61	61	36	49	42	20	38	61	41	88	82	61	72	54	56	76	43	62	66	65	72	53	55	57	55	55
	Wf	170	178	172	168	135	103	129	145	156	150	146	145	170	173	189	179	175	140	130	175	180	153	130	120	103	130	149	142	130	132
D3	Wf + Ww	256	22	261	155	241	198	184	250	261	239	241	220	196	197	222	234	192	241	251	194	216	192	188	193	225	227	241	258	263	228
	Ww	76	44	57	54	61	53	49	60	66	67	91	80	75	57	62	74	67	66	71	34	48	45	68	53	55	42	61	63	83	48
	Wf	180	178	204	201	180	145	135	190	195	172	150	154	161	180	160	160		175	180	160	169	147	160	140	170	185	180	195	180	193
D4	Wf + Ww	241	225	213	190	200	242	245	261	273	272	193	205	211	198	210	184	176	161	183	195	199	193	201	214	221	185	182	180	175	192
	Ww	91	80	71	50	35	72	60	71	103	147	68	50	51	43	80	59	51	60	58	57	54	38	36	44	61	60	87	68	50	58
	Wf	150	145	142	140	165	170	185	190	170	125	125	155	160	155	130	125	125	141	125	138	185	135	165	170	160	125	125	112	125	145

DT=dietary treatment, Pr=parameter, D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, W= weight, Ww=weight of water, Wf=weight of fish, DT=dietary treatment PM=parameter, DT=dietary treatment.

Appendix 7. 6: **Live weight of thirty specimens of Nile tilapia from each of the treatment groups at experimental site B at 28th day after stocking**

DT	Pr	W(g)																													
R	Wf+Ww	120	121	111	108	105	103	100	98	96	192	122	188	186	192	188	186	181	180	115	113	110	106	103	99	153	148	147	143	1	138
	Ww	66	63	58	62	55	46	41	56	63	71	86	148	176	161	158	145	143	165	72	23	61	56	73	39	116	112	102	27		86
	Wf	**54**	**58**	**53**	**46**	**50**	**57**	**59**	**42**	**45**	**54**	**36**	**30**	**26**	**31**	**30**	**41**	**38**	**25**	**48**	**25**	**51**	**50**	**30**	**60**	**37**	**36**	**45**	**46**		**52**
D2	Wf+Ww	185	181	179	173	171	170	168	120	117	116	112	109	107	153	151	147	145	144	140	182	180	177	175	171	170	166	144	141	1	136
	Ww	140	135	154	132	139	140	128	87	62	64	62	54	77	118	101	96	105	103	97	137	130	139	145	143	140	131	104	113	1	106
	Wf	**45**	**46**	**25**	**41**	**32**	**30**	**40**	**47**	**50**	**52**	**50**	**55**	**30**	**35**	**50**	**51**	**40**	**41**	**43**	**45**	**50**	**38**	**35**	**28**	**30**	**35**	**40**	**28**		**30**
D3	Wf+Ww	115	113	109	108	104	101	98	155	153	150	146	145	143	141	140	137	158	156	154	153	150	143	180	177	175	172	171	167	1	110
	Ww	80	83	71	78	71	66	63	125	113	134	90	93	115	85	115	131	113	111	100	103	100	91	134	132	123	117	114	132		58
	Wf	***35***	***30***	***38***	***30***	***33***	***35***	***35***	***30***	***40***	***24***	***50***	***52***	***28***	***56***	***35***	***36***	***45***	***45***	***54***	***50***	***50***	***52***	***54***	***45***	***52***	***55***	***57***	***35***		***52***
D4	Wf+Ww	144	141	140	137	135	130	185	182	180	199	178	174	191	187	185	182	180	179	126	123	120	118	117	114	133	132	129	127	1	122
	Ww	94	99	100	91	81	90	135	136	140	127	128	133	146	141	145	132	125	139	91	85	77	83	92	94	101	94	93	107		85
		50	***42***	***40***	***46***	***54***	***40***	***50***	***46***	***40***	***52***	***50***	***41***	***45***	***46***	***45***	***50***	***55***	***40***	***35***	***38***	***43***	***35***	***25***	***28***	***32***	***38***	***36***	***20***		***37***

D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, Ww=weight of water, Wf=weight of fish, DT=dietary treatment PM=parameter.

Appendix 7.7: **Live weight of thirty specimens of Nile tilapia from each of the treatment groups at experimental site B at 56th day after stocking (second sample)**

W (g)

D1	Wf+Ww	157	153	152	146	141	162	160	156	155	151	148	146	143	156	154
	Ww	94	81	97	51	46	78	115	93	102	69	71	61	62	92	92
	Wf	63	72	55	95	95	84	55	69	53	82	77	85	81	64	60
D2	Wf+ww	134	128	125	113	118	115	113	110	106	140	136	134	131	129	127
	Ww	87	57	51	68	57	67	58	53	51	86	65	81	52	69	52
	Wf	59	71	74	55	61	48	55	63	55	66	71	73	79	60	75
D3	Wf+Ww	139	136	134	130	125	120	118	115	113	108	140	138	132	130	125
	Ww	64	50	54	68	67	50	28	49	32	45	82	65	82	35	32
	Wf	75	86	80	62	58	70	90	66	81	63	62	73	50	95	92
D4	Wf+ww	143	140	138	135	131	129	127	120	156	154	150	147	145	140	136
	Ww	74	75	85	67	66	63	66	60	94	80	96	92	84	76	77
	Wf	69	65	53	68	65	66	61	60	62	74	66	55	61	76	59

D1	Wf+Ww	150	147	143	111	136	135	130	149	147	143	141	139	135	133	130
	Ww	81	62	71	76	56	71	70	84	70	86	71	59	53	75	67
	Wf	71	85	72	65	80	64	60	65	77	69	70	80	82	78	77
D2	Wf+ww	121	119	117	114	145	141	139	136	132	139	155	151	149	147	144
	Ww	68	58	62	53	89	70	75	76	69	64	100	82	84	92	81
	Wf	53	61	55	61	56	71	64	60	63	66	55	69	65	55	63
D3	Wf+Ww	113	120	156	154	150	147	145	140	136	133	131	129	127	125	120
	Ww	38	64	101	101	80	91	85	69	68	78	56	49	57	60	52
	Wf	85	56	55	53	70	58	60	71	68	55	75	80	70	65	72
D4	Wf+ww	134	131	128	159	155	153	150	146	144	142	137	141	139	135	133
	Ww	91	80	64	101	85	81	85	70	89	74	83	85	68	73	78
	Wf	43	51	64	85	70	72	65	76	65	68	54	56	71	68	55

D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, Ww=weight of water, Wf=weight of fish, DT=dietary treatment PM=parameter.

Appendix 7. 8: **Live weight of thirty specimens of Nile tilapia from each of the treatment groups at experimental site B at 84th day after stocking (third sample)**

DT	Pr	Fish growth (g)																													
D1	Wf+Ww	183	180	176	174	170	168	155	190	187	185	181	177	160	153	150	148	168	166	175	174	170	165	160	156	150	148	163	160	158	155
	Ww	78	80	68	64	12	63	64	106	90	53	51	62	34	21	26	48	33	30	35	63	28	70	64	41	60	53	57	60	33	50
	Wf	105	100	108	110	98	105	91	86	97	132	130	115	126	132	124	100	135	136	140	111	142	95	96	115	90	95	106	100	121	105
D2	Wf+ww	161	158	156	153	151	148	146	142	140	136	170	168	164	162	159	157	154	151	181	178	175	173	170	166	164	161	157	155	152	150
	Ww	57	58	65	57	46	45	65	36	48	60	77	67	69	57	87	77	48	69	69	75	95	75	70	60	62	69	61	57	67	45
	Wf	104	100	91	96	105	103	91	106	92	76	93	91	95	105	72	80	106	82	112	103	80	98	100	106	102	92	96	98	85	105
D3	Wf+ww	153	150	148	145	141	158	185	180	175	113	170	168	165	160	153	171	168	166	163	160	158	155	152	150	182	180	176	174	171	165
	Ww	49	44	50	27	45	33	56	50	51	48	54	58	57	60	65	76	63	68	55	42	68	53	27	45	62	65	65	39	67	44
	Wf	104	106	98	118	96	125	129	130	124	125	116	110	108	100	98	95	105	98	108	119	90	102	125	115	120	115	91	135	104	121
D4	Wf+ww	153	150	146	144	142	140	160	157	155	152	150	163	160	157	155	170	168	165	160	155	152	150	148	145	143	140	136	134	132	128
	Ww	73	68	51	52	62	45	62	48	60	54	58	56	50	72	67	81	73	85	78	79	72	59	52	63	43	44	46	32	36	25
	Wf	90	82	95	92	82	95	102	109	95	98	92	107	110	85	88	89	95	80	82	76	80	91	96	92	100	96	90	102	108	102

DT=dietary treatment, Pr=parameter, D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, Ww=weight of water, Wf=weight of fish, DT=dietary treatment PM=parameter, DT=dietary treatment.

Appendix 7.9: **Live weight of thirty specimens of Nile tilapia from each of the treatment groups at experimental site B at 112th day after stocking (Fourth sample)**

DT	Pr	W (g) 2 3
	Wf+Ww	210 207 202 196 193 191 18 177 175 202 196 194 190 188 210 208 205 200 230 227 224 220 215 213 207 205 195 190 183 180
	Ww	49 65 57 44 33 56 6 32 30 54 36 32 22 30 47 48 40 30 73 62 99 100 70 67 72 92 70 45 53
	52	
		161 142 145 152 160 135 11 142 145 148 160 162 168 158 163 160 165 170 163 165 125 120 145 146 135 113 125 145 130 128
	Wf	
D2	Wf+ww	205 202 200 198 195 192 19 188 185 181 175 173 170 160 210 208 205 202 198 196 193 213 210 208 205 203 200 198 195 191
	Ww	85 63 65 29 55 86 8 60 60 65 55 58 54 34 100 93 59 54 93 76 68 102 75 72 62 72 85 90 99
	87	
		120 139 135 169 136 106 10 128 125 116 120 115 116 126 110 115 146 148 105 120 125 131 135 126 142 141 115 108 96
104		
	Wf	
D3	Wf+Ww	349 345 311 298 311 320 33 373 312 325 334 355 346 331 322 361 345 337 331 323 338 380 384 349 342 332 342 311

328 353 Ww 203 200 193 190 188 185 19 197 193 190 188 213 210 209 206 203 200 197 195 193 190 215 212 209 206 203
200 198 195 191

Wf 146 145 118 108 123 135 14 176 119 125 146 142 136 122 116 158 145 140 136 130 148 165 172 140 136 129 142 113 133 162

D4 Wf+ww 183 180 177 175 171 210 20 204 202 198 196 193 191 185 183 251 243 241 236 232 230 249 246 243 240 237 235 261 255
217 Ww 77 71 51 90 51 84 7 98 77 100 86 88 91 75 77 143 123 143 120 96 118 121 126 118 112 131 100 131 145 136

Wf 106 109 126 85 120 126 13 106 125 98 110 105 100 115 106 108 120 98 116 136 112 128 120 125 128 108 135 130 110
115

DT=dietary treatment, Pr=parameter, D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet,

W=weight, Ww=weight of water, Wf=weight of fish, DT=dietary treatment PM=parameter, DT=dietary treatment, g=grams.

Appendix 7. 10: **Live weight of thirty specimens of Nile tilapia from each of the treatment groups at experimental site B at 140th day after stocking (Fifth sample)**

DT	Pr	W (g)																													
D1	Wf+Ww	260	256	254	250	247	245	240	237	235	274	271	267	265	261	260	257	255	251	248	246	241	240	240	236	232	263	260	258	254	251
	Ww	74	76	78	57	56	65	85	52	60	103	121	124	120	108	90	88	60	84	65	66	76	80	76	60	107	110	70	61	83	112
	Wf	186	180	176	193	191	180	155	185	175	171	150	143	145	153	170	169	195	167	183	180	165	160	180	172	156	150	188	195	181	139
D2	Wf+ww	248	246	243	241	237	235	231	228	253	250	248	244	241	236	234	231	259	256	254	257	246	245	243	240	239	262	260	257	255	253
	Ww	67	112	103	136	97	93	100	98	108	103	73	76	94	83	51	63	84	126	102	82	90	110	108	97	109	125	135	116	122	124
	Wf	181	154	130	125	140	142	131	130	145	147	175	168	147	153	173	168	175	130	152	169	156	135	138	143	130	137	125	141	133	129
D3	Wf+ww	264	261	260	257	252	250	246	245	242	241	238	235	232	230	271	263	261	258	256	252	250	246	242	240	261	256	255	251	248	243
	Ww	92	106	54	92	100	87	66	79	57	66	43	38	44	65	111	108	113	112	92	69	61	51	52	92	104	97	91	80	88	82
	Wf	172	155	186	145	152	163	160	166	185	175	195	198	168	165	160	155	148	166	164	183	189	195	190	148	157	159	164	171	160	161
D4	Wf+ww	246	243	240	238	237	235	260	258	254	251	250	247	245	244	241	237	235	232	230	226	271	268	265	261	254	251	246	244	241	236
	Ww	140	124	119	103	69	100	114	138	104	106	114	137	127	113	98	84	87	90	90	98	121	113	100	101	113	121	106	102	108	99
	Wf	106	119	126	135	168	135	146	120	140	145	136	110	118	131	143	153	148	142	140	128	150	155	165	160	141	132	140	142	133	137

DT=dietary treatment, Pr=parameter, D1=fishmeal-based diet, D2=peanut-based diet, D3=mixed plant-based diet, D4=commercial diet, W=weight, Ww= weight of water, Wf=weight of fish, DT=dietary treatment, PM=parameter, DT=dietary treatment.

Appendix 7. 11: Body weights of Nile tilapia in the first row of ponds across treatment groups of **experimental site A at 16 weeks after stocking**

R1		Wf (g) D2			D1 D3
	CF				
	165	114401	114438	116285	
	160				
	118753	111124450500	111145345508	111156550351	
	162				
	8				
	11176602	11164528 0	11165455 0	11152046 3	
	116250	114668	114675	110701	
178	145 165	135 148			
	111344551	111110444080045	111114466665750	111114032327631	
	125				
	142				
	148	134	132	136	
	1305	111422168	111667558	111030356	
	17				
	178	115	145	146	
	142	106	140	122	
	111456508	114167	116557	111266	
5	110 155	137 1 5			
	163	11106 2	114405	115401	
	111145440857	11144253 9	1114456 21	11144435 0	
	163	11230 5	114360	11006 8	
	11165256 4	1111123420 84	11113455249 8	1111011336 84	
	145				
	146				
	11448 5	113280	114458	11124 9	
	111633305	111134639655 9	1111534623 57	11185223505	
	1113449 36	11122351 0	1116351 96	1112027 45	
	116628	152	132	110	
	159		156	149	
115					

R1=replicate 1, D1=Fishmeal-based diet, D2=Peanut-based diet, D3=Mixed plant meal-based diet, D4-Commercial feed for Nile tilapia,

Wf=Final weight of Nile tilapia

12 **Body weights of Nile tilapia in the second row of ponds across treatment groups of**

Appendix 7.   : **experimental site A at 16 weeks after stocking**

R2	D1	D2	D3	D4
	166	120	152	132
	134	110	163	137
	150	106	124	141
	140	112	140	153
	145	111	142	145
	146	113	135	143
	157	129	131	142
	162	123	141	106
	165	135	136	108
	130	132	159	120
	173	124	142	103
	145	118	135	116
	153	143	138	134
	148	120	159	119
	140	138	120	125
	133	135	163	99
	162	166	135	120
	135	136	142	128
	134	149	157	135
	144	127	141	124
	146	131	139	127
	162	124	136	110
	168	118	128	110
	157	116	166	115
	165	140	143	126
	154	141	148	168
	182	128	170	155
	173	145	140	163
	162	140	135	152
	177	151	161	151
	182	162	105	156
	160	158	145	104
	126	140	168	123
	120	146	145	102
	178	168	129	171
	146	147	165	135
	135	148	166	137
	165	140	168	123
	135	144	170	111
	125	105	165	136
	143	105	160	140
	148	135	175	136
	130	141	182	103
	173	126	165	105
	178	128	171	136
	142	116	145	145

144 106 140 122 ______ 147 147 163 120

D1=Fishmeal-based diet, D2=Peanut-based diet, D3=Mixed plant meal-based diet, D4-

Commercial feed for Nile tilapia. R=Replication, Wf=Final weight of the experimental fish

Appendix 7. 13 Body **weights of Nile tilapia in the third row of ponds across treatment groups of experimental site A at 16 weeks after stocking**

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R3	D1	D2	D3	D4
	163	133	156	123
	123	124	144	105
	145	138	133	116
	146	138	138	134
	147	120	149	119
	145	138	147	122
	133	135	123	91
	157	163	135	121
	135	136	142	125
	166	149	157	135
	143	125	149	124
	146	133	139	127
	162	156	136	108
	167	118	122	110
	159	123	156	115
	165	140	143	127
	160	145	148	148
	185	120	170	155
	172	145	161	120
	162	140	135	150
	176	128	156	151
	182	142	162	134
	160	158	160	104
	155	135	140	123
	128	146	145	108
	178	146	127	171
	148	145	163	140
	135	128	166	137
	146	137	165	123
	145	144	167	112
	155	105	165	136
	142	105	144	142
	148	134	175	136
	135	141	180	103
	170	126	165	110
	179	130	175	136
	142	125	145	146
	145	106	143	122
	150	146	135	116
	162	152	116	126
	135	156	155	137
	167	126	165	141
	139	112	140	134
	145	108	147	145
	146	113	135	140
	157	126	152	140
	159	148	138	107
	161	136	157	110

D1=Fishmeal-based diet, D2=Peanut-based diet, D3=Mixed plant meal-based diet, D4-Commercial feed for Nile tilapia. R=Replication, Wf=Final weight of the experimental fish

14 **Body weights of Nile tilapia in the first row of ponds across treatment groups of experimental site B at 16 weeks after stocking**

R1	Wf(g)			
	D1	D2	D3	CF
	161	138	145	146
	142	120	158	133
	145	139	134	126
	152	135	149	106
	160	169	147	120
	135	136	142	126
	115	153	176	135
	142	104	159	106
	145	128	128	125
	148	125	146	130
	160	116	142	110
	162	120	136	134
	168	138	158	100
	158	116	166	115
	163	126	158	106
	160	110	145	108
	165	145	140	120
	170	146	136	123
	163	148	156	157
	165	105	148	136
	125	120	148	146
	120	125	172	128
	145	131	140	120
	146	135	165	125
	135	126	149	128
	113	142	142	153
	125	141	156	120
	145	148	163	130
	130	108	162	110
	128	129	146	115
	131	134	145	241
	140	104	139	133
	145	120	151	120
	148	139	150	126
	160	135	129	135
	162	169	152	135
	147	136	140	125
	158	106	136	140
	163	104	130	110
	160	128	148	105
	140	155	165	100
	170	161	172	115
	163	120	140	106
	165	135	136	108
	125	153	159	120
	120	124	142	103
	145	138	153	152
	146	140	135	136

D1=Fishmeal-based diet, D2=Peanut-based diet, D3=Mixed plant meal-based diet, D4-Commercial feed for Nile tilapia. R=Replication, Wf=Final weight of the experimental fish

:

Appendix 7. 15 **Body weights of Nile tilapia in the second row of ponds across treatment groups of experimental site B at 16 weeks after stocking**

R2	156	109	150	109
	140	120	120	111
	145	139	168	126
	152	135	123	150
	160	169	134	120
	135	136	142	126
	115	166	176	135
	142	108	158	106
	145	128	128	125
	148	125	147	155
	160	116	142	110
	162	120	136	105
	168	115	122	100
	156	148	162	116
	163	126	159	106
	160	152	142	110
	165	117	140	120
	169	146	136	102
	156	145	145	116
	165	155	148	136
	145	128	165	123
	120	125	170	128
	145	131	143	118
	146	135	136	125
	141	126	135	128
	113	145	140	121
	128	141	153	125
	145	135	133	130
	130	108	162	110
	128	96	146	115
	131	134	145	241
	146	126	139	135
	145	140	151	120
	148	139	150	126
	160	135	159	135
	162	169	138	106
	168	136	140	125
	148	153	154	158
	163	104	164	112
	160	128	148	106
	165	125	165	123
	125	116	172	110
	120	120	140	106
	145	135	136	148
	141	123	159	112
	163	124	142	104
	170	115	133	156
	165	142	138	132

D1=Fishmeal-based diet, D2=Peanut-based diet, D3=Mixed plant meal-based diet, D4-Commercial feed for Nile tilapia. R=Replication, Wf=Final weight of the experimental fish

16: **Final body weights of Nile tilapia in the third row of ponds across treatment groups of experimental site B at 16 weeks after stocking**

R3	D1	D2	D3	D4
	147	132	149	130
	158	123	151	136
	155	132	137	143
	143	138	145	132
	135	128	132	128
	137	136	135	125
	142	128	144	125
	150	104	139	135
	145	123	151	120
	148	140	155	128
	165	135	129	135
	160	167	138	162
	148	136	143	125
	157	106	136	124
	163	104	130	110
	145	128	148	105
	165	125	165	129
	171	146	172	115
	163	120	140	106
	145	135	136	108
	126	132	155	118
	123	124	142	103
	145	155	163	116
	146	140	138	134
	148	120	149	138
	145	138	135	124
	133	135	159	133
	160	169	135	127
	135	136	142	125
	123	149	125	135
	143	125	141	144
	140	128	140	125
	148	125	146	131
	158	116	145	110
	162	120	136	105
	160	120	135	150
	158	116	158	115
	163	132	158	136
	160	110	144	128
	146	122	140	120
	175	146	139	104
	162	120	163	105
	168	118	152	140
	159	116	153	115
	163	126	157	135
	152	135	145	108
	154	125	140	120
	174	145	142	157

D1=Fishmeal-based diet, D2=Peanut-based diet, D3=Mixed plant meal-based diet, D4-Commercial feed for Nile tilapia. R=Replication, Wf=Final weight of the experimental fish

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Appendix 7. 17: **Body weight gains for Nile tilapia in pond units at 16 and 20 weeks after stocking**

Weeks After stocking		Fish body weight (g/pond)					
16	FM	127.52	126.54	129.55	131.10	129.55	131.65
	PNM	110.09	108.82	108.10	112.58	109.92	111. 79
	MPM	126.55	124.13	122.73	128.02	126.98	127.04
	Control	103.96	102.03	103.32	106.34	107.75	105.32
20	FM	143.5	142.7.	147.3	151.9	146.7	148.2
	PNM	127.5	121.6	133.0	117.5	130.8	123.6
	MPM	146.4	143.3	147.5	143.5	147.0	147.7
	Control	130.6	123.6	122.7	115.2	116.8	115.5

18 **Determination of caloric values for dietary nutrients**

DC= Lc+Pc

Where;

Dc = caloric value of diet (Kcal)

Lc = caloric value of lipid (Kcal)

Pc = caloric value of protein (Kcal)

Identifying the caloric gaps among test diets based on one with the higher caloric value (D2). Sums of each the hypo-caloric diets (D1 & D3) and respective caloric gaps equated to the D2.

i) D1c = (D2c − D1c).

Where;

DIc = caloric value for diet 1 (Kcal)

D2c = caloric value for diet 2 (Kcal)

ii) D3c = (D2c − D3c). Where;

D3c = caloric value for diet 3 (Kcal)

D2c = caloric value for diet 2 (Kcal)

c) The amount of lipid equalizer (cod liver oil) for the D1 and D3 was determined as follows;

i) D1Le= (D2c-D1c)/ULc.

Where;

D1Le = lipid equalizer for diet 2 (g)

D2c = caloric value for diet 2 (Kcal)

D1c = caloric value for diet 1 (Kcal)

ULc = caloric value for unit of lipid (Kcal/g^{-1})

ii) $D3Le = (D2c - D3c)/ULc$. Where;

$D3Le$ = lipid equalizer for diet 3 (g)

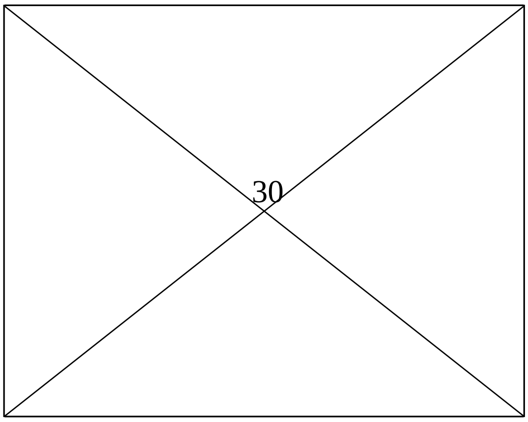
$D2c$ = caloric value for diet 2 (Kcal)

$D3c$ = caloric value for diet 3 (Kcal)

ULc = caloric value for unit of lipid (Kcal/g^{-1})

19 Balancing the Crude Protein content of the fish meal-based diet during the first feeding regime using the Pearson Square Method

% of CP for FM=38.68 23.2 kg of FM

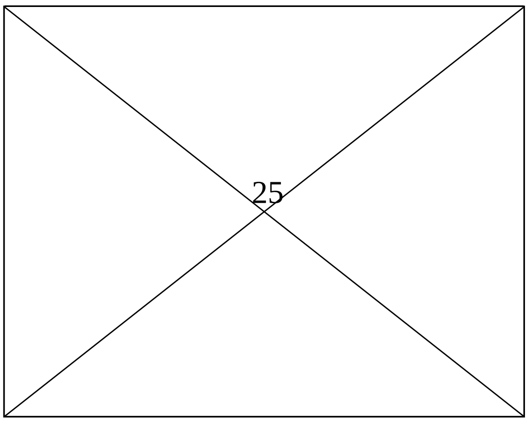


% of CP for MB= 6.80 8.68 kg of MB/

31.88 kg of feed *CP=Crude protein, FM=fishmeal, MB=maize bran, kg=kilogram.

20 **Balancing the Crude Protein content of the fish meal-based diet during the second feeding regime using the Pearson Square Method.**

% of CP for FM=38.68 18.20 kg of FM



% of CP for MB= 6.80 13.68 kg of MB/

31.88 kg of feed

*CP=Crude protein, FM=fishmeal, MB=maize bran, kg=kilogram.

Appendix 7. 21: .Net Fish Yields in Nile tilapia in pond units of different treatment groups after the 16-week experiment

Stock type	Pond unit number	NFYs g/pond^{-1}) D1	D2	D3	D4
DSS	1	5582	4854	5655	4589
	2	5535	4819	5539	4496
	3	5679	4785	5472	4558
WSS	4	5754	4999	5726	4703
	5	5679	8472	5678	4771
	6	5780	4962	5678	4654

*NFYs=Net Fish Yields D1=fishmeal-based diet, D2= peanut-based diet, D3 = mixed plant meal-based diet, D4= commercial feed for Nile tilapia, DSS= dry season stock, WSS= wet season stock.

Appendix 7. 22: Performance of test diets based on ranges and mean values for Net Fish Yields of Nile tilapia in different dietary treatment groups

DT	NFY (g/pond^{-1})	NFYm (g/pond^{-1})	LP
D1	5535-5582	5668	1
D2	4785-4999	4819	4
D3	5472-5726	5624	2
D4	4496-4771	4628	3

*DT= Dietary treatment, D1= Fishmeal-based diet, D2= Peanut meal-based diet, D3= mixed plant meal-based diet, D4= commercial diet for Nile tilapia. NFYr= range of Net Fish Yield, NFYm= mean value for Net Fish Yield, LP= Level of performance.

Appendix 7. 23: **Fish losses in dietary treatment groups during the experimental period**

	Fish losses (No./pond^{-1})				TFl
DCe	28	56	84	112	
D1	12	5	5	3	25
D2	13	6	2	1	22
D3	9	6	3	2	20
D4	12	5	4	2	23

*DCe= Days after commencement of the experiment, D1= FM-based diet, D2= PNM-based diet, D3= MPM-based diet, D4= Commercial diet, TFl= total of fish loss.

Appendix 7. :

24 **One-way Analysis of Variance F-test that determined the possibility of a significant difference (p□0.05) among Survival Rates in Nile tilapia**

SOV	SS	DF	MS	F-value	p-value
TRb	9.4968	3	3.1656	1.05	.367839.
TRw	60.2449	20	3.0132		
Er	45.953	15	2.7969		

*SOV= source of variation, SS= Sum of squares, DF= Degrees of freedom, MS= Mean square, TRb= between treatments, TRw= within treatments, Er=error.

25 Unit prices of feed ingredients at the local markets of survey site 1

Fi	UPi (USD/Kg^{-1})				
FM	0.415	0.409	0.397	0.381	0.405
PNM	0.591	0.615	0.613	0.605	0.635
MPM	0.426	0.432	0.417	0.405	0.445
CFb	0.0631	0.0630	0.0632	0.0635	0.0634
MB	0.1412	0.1413	0.1410	0.1409	0.1413
MNp	0.0270	0.0265	0.0275	0.027	0.027

*Fi= feed ingredient, UPi= unit price of feed ingredient, FM= fishmeal, PNM= peanut meal, SBM= soybean meal, FBc= cassava feed binder,

* MNp= micronutrients pre-mix; vitamins (A, C, B_{12}) and minerals (NaCl, $Feso_4$).

*Exchange rate for one USD was averagely 3500 Ugandan shillings.

Appendix 7.   :

26 One-way Analysis of Variance F-test that determined the possibility of a significant difference (p□0.05) among Economic Conversion Ratios in Nile tilapia

SOV	SS	DF	MS	F-value	p-value
TRb	0.4297	3	0.1463	48.76	<.00001.
TRw	0.0534	16	0.003		
Er	0.0449	12	0.0037		

*SOV= source of variation, SS= Sum of squares, DF= Degrees of freedom, MS= Mean square, TRb= between treatments, TRw= within treatments, Er=error.

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Appendix 7. 27 **Unit prifor fresh Nile tilapia at the sampling units of survey site B**

Dc	UPf (USD/Kg.)				
	NAM	MAY	BUG	KAM	BUS
0	3.10	3.42	3.29	3.71	3.21
14	3.02	3.57	3.57	4.00	3.00
28	3.19	3.71	3.29	3.50	3.29
42	3.29	3.42	3.57	3.62	3.00
56	3.40	3.57	3.57	3.57	2.37
70	3.14 3.71	3.29 3.57	2.57 3.19	3.57 3.43	3.67 2.90
X					

*SN Sample serial number, Dc= days after commencement of the sample survey, Up=unit price, SN=sampling number, Kg=kilogram, USD=United States dollar, NAY= Namayingo, MYG= Mayuge, BUG= Bugembe, KAM= Kamuli, BUS= Busembatia

*USD=3500 Ugandan Shillings.

Appendix 7. 28: Calculation of the total of feed input per pond unit by end of the experimental period

Test diet	Type of stock	Sample number	Date of sampling	Unit cost of feed USD/kg	TFR (kg)	TC of feed (Sh.)
				1052.5	15.670	16,492.675
				1038.8	‘’	16,277.996
				1007.5	‘’	15,787.525
				962.5	‘’	15,082.375
				1025.0	‘’	16,061.750
				1235.0	‘’	19,352.450
				1300.0	‘’	20,371.000
				1282.6	‘’	20,098.342
				1265.0	‘’	19,822.550
				1327.5	‘’	20,801.925
				983.8	‘’	15,416.146
				997.5	‘’	15,630.825
				965.5	‘’	15,129.385
				935.0	‘’	14,651.450

DSS=dry season stock. WSS=wet season stock, TFR=Total Feed Ration, TC=Total Cost

:

Appendix 7. 29 **Determination of the value of experimental fish from different treatment groups**

Dietary treatment	Average of the total BWG (kg)	Mean of retail prices (Ug.sh.)	Value of fish (Ug. sh.)
FM-based diet	6.2070	11,167	69,313.57
		12,500	77,587.50
		12,000	74,484.00
		12,840	79,697.88
		10,160	63,063.12
PNM- based diet	5.2858	11,167	59,026.50
		12,500	66,072.50
		12,000	63,429.60
		12,840	67,869.67
		10,160	53,703.73
MPM-based diet	6.0437	11,167	67,490.00
		12,500	75.587.50
		12,000	72,524.40
		12,840	77,601.11
		10,160	61,403.99

BWg=body weight gain of the experimental fish, D1= fishmeal-based diet, D2= peanut-based diet, D3= mixed plant meal-based diet, =D4commercial feed for Nile tilapia

Appendix 7. 30 One-way Analysis of Variance F-test that determined the possibility of a significant difference (p□0.05) among Profit Indices in Nile tilapia

SOV	SS	DF	MS	F-value	p-value
TRb	8.5583	3	2.8528	72.4	<.00001.
TRw	0.631	16			
		12	0.0394		
Er	0.3197		0.0266		

*SOV= source of variation, SS= Sum of squares, DF= Degrees of freedom, MS= Mean square, TRb= between treatments, TRw= within treatments, Er=error

:

Appendix 7. 31 **Unit prices for fishmeal at the main market of Iganga Municipality**

Tm	Cl	Fi	Sn	Dc	PC	Rs	UPi (USD/Kg^{-1})
Main market	A	FM	1	0	PC03	NE	0.415
					PC01		
					PC05		
					PC04		
					PC02		
			2	28	PC05	MW	0.409
					PC01		
					PC03		
					PC02		
					PC04		
			3	56	PC01	MA	0.397
					PC02		
					PC04		
					PC03		
					PC05		

4	84	PC02	BF	0.381
		PC03		
		PC01		
		PC05		
		PC04		
5	112	PC04		
		PC02		
		PC05		
		PC01		
		PC03	KR	0.405

*Fi=feed ingredient, FM=fishmeal, Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPi= unit price of ingredient

*NE=Nainiba Eseza, MW=Mulondo Wilson, MA=Muzira Ali, BF=Byaka Fred.

Appendix 7. 32: **Unit prices for soybean meal at the main market of Iganga Municipality**

TM	Fi	Sn	Dc	PC	Rs	UPi (USD/Kg^{-1})
Main market	SBM	1	0	PC02		
				PC03		
				PC05		
				PC01	MG	0.261
				PC05		
		2	28	PC03		
				PC01	NW	0.249
				PC05		
				PC03		
				PC04		
		3	56	PC04		
				PC03		
				PC05		
				PC03		
				PC01	MS	0.221
		4	84	PC01	ND	0.205
				PC05		
				PC04		
				PC02		
				PC03		
		5	112	PC04		
				PC03		
				PC05		
				PC02		
				PC01	WE	0.255

*Fi=feed ingredient, SBM= soybean meal, Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPi= unit price of ingredient =Mukuunya George, NW=Namwase Winny, MS=Masajage Simon, ND=Nandase Deborah, WE=Weere Elliot.

33 **the feed binder at the main market of Iganga** Municipality

Appendix 7.   : **Unit prices for**

TM	Fi	Sn	Dc	PC	Rs	UPi (USD/Kg^{-1})
Main market	FBc	1	0	PC02 PC01 PC04 PC05 PC03	BA	0.0631
		2	28	PC05 PC01 PC02 PC03 PC04	ND	0.0630
		3	56	PC04 PC03 PC05 PC01 PC02	KB	0.0632
		4	84	PC05 PC01 PC04 PC02 PC03	MS	0.0635
		5	112	PC01 PC03 PC05 PC02 PC04	MA	0.0634

*Fi=feed ingredient, FBc= Cassava feed binder, Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPi= unit price of ingredient
*BA=Bagaga Aggrey, ND=Nandase Deborah, KB= Kabaale Goerge MS= Masajage Simon,

MA=Muzira Ali.

34 **maize bran at the miller's market in Iganga** Municipality

Appendix 7. : **Unit prices for**

TM	Fi	Sn	Dc	PC	Rs	UPi (USD/Kg^{-1})
Miller"s market	SBM	1	0	PC02 PC01 PC03 PC05 PC05	LA	0.1412
		2	28	PC03 PC05 PC04 PC03 PC01	KW	0.1413
		3	56	PC04 PC03 PC05 PC01 PC03	NE	0.1410
		4	84	PC04 PC05 PC02 PC01 PC03	GK	0.1409
		5	112	PC01 PC04 PC02 PC05 PC03	OW	0.1413

*Fi=feed ingredient, Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPi=unit price of ingredient

*LA= Lubanga Amuza, KW= Kiwanuka Wilson, NE=Namwase Esther, GA=Gabula Albert, OW=Ojambo Wilson.

35 **micro nutrient pre-mix at the veterinary input market in Iganga Municipality**

Appendix 7. : **Unit prices for**

TM	Fi	Sn	Dc	PC	Rs	UPi (USD/Kg^{-1})
Miller‟s market	MNp	1	0	PC02		
				PC04		
				PC03		
				PC01	BK	0.0270
				PC05		
		2	28	PC03		
				PC05		
				PC04		
				PC01	BS	0.0265
				PC02		
		3	56	PC04		
				PC01	MY	0.0275
				PC05		
				PC02		
				PC03		
		4	84	PC04		
				PC05		
				PC02		
				PC03		
				PC01	LB	0.0270
		5	112	PC04	MW	0.0270
				PC02		
				PC01		
				PC05		
				PC03		

*Fi=feed ingredient, MNp=micro-nutrient pre-mix, Sn= sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPi= unit price of ingredient

*BK= Bagoole Kenneth, BS= Baligeya Stephen, MY= Mwebya Yusufu, LB= Lubanga Benon, MW= Mudhasi Wilson.

Appendix 7. : **fish**
36 **Sampling at markets of trading centres along the main roads network**

Dc
0

TC PC Rs UPf (USD/Kg^{-1})
NAM PC03
PC02
PC05
PC01 WA 3.10
PC02 14 PC03 PC01 KM 3.02
PC02
PC05
PC04
28 PC01 SD 3.19
PC02
PC04
PC03
PC05 42 PC02 PC01 BA 3.29
PC03
PC05
PC04
56 PC04
PC03
PC05
PC04
PC01 DK 3.40
70 PC04
PC03
PC01 OL 3.14
PC04
PC05

*TC=trading centre, NAM=Namutumba Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPf=unit price of Nile tilapia fish.

*WA=Walugono Amina, KM=Kiirya Martin, SD=Samanya Dhabuliwo, BA= Balidawa Ausi,

Appendix 7. 37: Sampling at fish markets of trading centres along the main roads network

0L=Omondi Lawrence

TC	Dc	PC	Rs	UPf (USD Kg^{-1})
MAY	0	PC03		
		PC01	MW	3.42
		PC05		
		PC02		
		PC02		
	14	PC03		
		PC05		
		PC02		
		PC01	KC	3.57
		PC04		
	28	PC01	OL	3.71
		PC02		
		PC04		
		PC03		
		PC05		
	42	PC02		
		PC03		
		PC01	OD	3.42
		PC05		
		PC04		
	56	PC03		
		PC05		
		PC05		
		PC04		
		PC01	WI	3.57
	70	PC03		
		PC01	KB	3.71
		PC05		
		PC04		
		PC02		

*TC=trading centre, MAY=Mayuge, Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPf=unit price of Nile tilapia fish.

*MW=Masega winnie, KC=Kyalo Chris OL=Omondi Lawrence, OD=othieno David, Wamala Isaac, Kasana Barbra

Appendix 7. : **fish**
38 **Sampling at markets of survey site 2 in trading centres along the main roads network**

TC	Sn	Dc	PC	Rs	UPf (USD Kg)
BUG	0		PC04		
			PC02		
			PC05		
			PC01	WI	3.29
			PC03		
	14		PC03		
			PC01		
			PC01	KY	3.57
			PC05		
			PC04		
	28		PC01	OC	3.29
			PC02		
			PC04		
			PC03		
			PC05		
	42		PC02		
			PC03		
			PC01	BG	3.57
			PC05		
			PC04		
	56		PC02		
			PC03		
			PC05		
			PC04		
PC01 KD 3.57 70 PC03 PC01 KC 3.27					
			PC05		
			PC04		
			PC03		

*TC=trading centre, BUG=Bugiri, Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent=unit price of Nile tilapia fish.

WI=Wamamala Isaac, KY=Kaloo Yonaani, OC=Ochan Charles, BG=Bagoole George, KD=Kintu Daniel, KC=Kyalo Chris.

Appendix 7. :

39 **Sampling at fish markets of s u r v e y s i t e 2 i n trading centres along the main roads network**

TC	Dc	PC	Rs	UPf (USD/Kg)
KAM	0	PC01	MW	
		PC02		
		PC05		
		PC02		
		PC03		
	14	PC03		
		PC04		
		PC03		
		PC05		
		PC01	NR	4.00

28 PC02 PC01 KI 3.50

		PC04		
		PC03		
		PC05		
	42	PC04		
		PC03		
		PC02		
		PC05		
		PC01	KC	3.62

56 PC02 PC01 BP 3.57

PC03

PC04

PC05

70 PC02 PC01 MG 3.57

PC05

PC04

PC03

*TC=trading centre, KAM=Kamuli Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPf=unit price of Nile tilapia fish.

*MW=Masega winnie, NR=Namwase Rose, KI= Kalinaku Isaac, KC=Kyalo Chris, BP=Batanda Peter, MG=Mulero George.

Appendix 7. 40: **Sampling at fish markets of suvey site 2 in trading centres along the main roads network**

TC	Dc	PC	Rs	UPf (USD Kg)
BUS	0	PC03	OJ	
		PC01		3.21
		PC05		
		PC02		
		PC04		
	14	PC03		
		PC04		
		PC04		
		PC01	WS	3.00
		PC05		
	28	PC02		
		PC03		
		PC01	MW	3.29
		PC04		
		PC05		
	42	PC04		
		PC03		
		PC01	BG	3.00
		PC05		
		PC02		
	56	PC01	KR	2.37
		PC05		
		PC03		
		PC04		
		PC02		
	70	PC02		
		PC01		
		PC05		
		PC01	TA	2.57
		PC04		

*TC=trading centre, BUS=Busembatia Sn=sample number, Dc=days after commencement of study, PC=paper card, RS=respondent, UPf=unit price of Nile tilapia fish

*OJ=Ojambo Martin, WS=Wandera Simon, MW=Masega Winnie, BG=Bagoole George, KR=Kauma Rose,TA=Tibenda Amina.

Appendix 7. 41: Computation of the F-statistic was as follows under the one-way ANOVA

$$C = \frac{n(\Sigma X^2)}{N}$$

$$SST = \Sigma X^2 - CF$$

$$SSG = \left(\frac{\Sigma X^2}{n}\right) - CF$$

$$SSE = SST - SSG$$

$$MSG = \frac{SSG}{DFG}$$

$$MSE = \frac{SSE}{DFE}$$

$F = \frac{MSG}{MSE}$. Where:

$C =$ Correction factor

$SST =$ Total Sum of Squares

$SSG =$ Sum of Squares for Group

$SSE =$ Sum of Squares for Error

$MSE = \text{Mean Square for Error}$

$MSE = \text{Mean Square for Groups}$

Since the study involved equal sample sizes, the Turkey‟s Honestly Significant Difference (HSD) was the most appropriate for pair wise comparisons during the post-hoc testing following Oehlert, (2010). The (HSD) ascertained the significantly different (p□0.05) paired group means. Calculation of the HSD followed Amisa *et al*. (2009) basing on the formula indicated below:

$$HSD = \frac{q\sqrt{MSE}}{n}.$$

Where;

$q = \text{studentized range test}$

$MSE = \text{mean square for error}$

$n = \text{number of observations in a treatment group.}$

Appendix 7. 42: **Published articles from the PhD thesis**

SDRP JOURNAL OF AQUACULTURE, FISHERIES & FISH SCIENCE

2016

OPEN ACCESS

RESEARCH

Comparison of Economic Conversion Ratios of fishmeal and peanut-based meals fed to pond -cultured Nile tilapia, *Oreochromis niloticus L.*; a case for Busoga sub-region, Eastern Uganda.

DOI: 10.15436/JAFFS.1.1.3

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CONFLICTS OF INTEREST

THERE ARE NO CONFLICTS OF INTEREST FOR ANY OF THE AUTHORS.

ABSTRACT:

Scarcity and rising cost of fishmeal-based aqua feeds has led to the need for low cost and locally available alternatives that are capable of sustaining rapid fish growth. A field experiment was conducted in order to compare Economic Conversion Ratios (ECR's) of fishmeal and peanut-based diets as sources of dietary protein for pond-cultured Nile tilapia *Oreochromis niloticus L*. Earthen ponds were used as the rearing units at Busoga University farm and were stocked with six-week old mono-sex fingerlings. A sample survey targeted local fish markets located in Busoga sub-region of Eastern Uganda in order to determine the local Retail Prices(RP's) for Nile tilapia fish. Dietary treatments included the fishmeal (FM)-based diet and two peanut (PN)-based diets; the peanut meal (PNM)-based diet and the mixed plant meal (MPM)-based diet. The locally available Nile tilapia commercial feed (CF) acted as the control diet. Results indicated no significant difference ($p>0.05$) in mean values for Economic Conversion Ratios (ECR's) of the FM and MPM-based diets. However, a significant difference in ECR's existed ($p< 0.05$) between the FM and PNM-based diets and MPM and PNM-based diets. Since FM and MPM-based diets exhibited similarity in ECR's, MPM-based diet should be used for complete substitution of the FM-based diet in aqua feeds for pond-cultured Nile tilapia.

KEYWORDS: Fish meal, peanut-based diets, Nile tilapia

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Comparison of net fish yields in pond cultured Nile tilapia (*Oreochromis niloticus* L.) fed on peanut-based meals as alternatives to dietary fishmeal

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Abstract
Although net yield directly relates to actual production at harvest, feeding trials aimed at replacing dietary fishmeal in cultured fish have largely ignored the performance indicator. A 16-week experiment aimed at comparing Net Fish Yields in Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal took place at Busoga University farmland in Eastern Uganda. Earthen ponds of size 4.0 x 3.0 x1.0 for length, width and depth respectively were used for culturing the experimental fish. Each of the 16 pond units were stocked at a density of 48 Nile tilapia fingerlings of initial live weight of 21.95 grams. Iso-nitrogenous diets containing 30% and 25% Crude Protein (CP) for the first 12 and last four weeks respectively, were used during the trial. Dietary treatments included the fishmeal (FM)-based diet and two peanut-based diets. The latter consisted of peanut meal (PNM)-based diet and mixed plant meal (MPM)-based diet in a ratio of 50:50. The commercial feed (CF) for grow-out Nile tilapia containing 25% CP acted as a control diet. NFYs of 5668 and 5624 kilograms per pond unit for Nile tilapia fed on the MPM and FM-based diets respectively, showed no significant difference (p 0.05). On the contrary, NFY of 4819 kilograms characteristic to the PNM-based diet was the lowest and significantly poorer ($p<0.05$) than the two test diets. Basing on the comparable NFYs, the MPM-based meal should substitute the conventional fishmeal in the diet of pond cultured Nile tilapia.

Keywords: peanut-based meals, net fish yields

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Profit Indices in Nile tilapia (*Oreochromis Niloticus L.*) Fed on Peanut-Based Meals as Alternatives to Dietary Fishmeal in Grow-Out Earthen Ponds

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Abstract. Persistence of dietary fishmeal probably accounts for the low profitability in farmed Nile tilapia in Uganda. A 24 week field study was conducted in Busoga sub-region of Eastern Uganda to compare profit indices in pond cultured Nile tilapia fed on peanut-based meals as alternatives to dietary fishmeal. It consisted of an experiment and sample survey that targeted fish biomass production and input -output valuation respectively. Each of the 12 earthen ponds measuring 12 cubic meters were stocked with 48 'all male' Nile tilapia *(Oreochromis niloticus L.)* fingerlings of mean initial weight of 21.7 grams. Iso -nitrogenous diets containing 30% and 25% Crude Protein were applied for the first eight and last four respectively. Dietary treatments included fishmeal-based diet and two peanut-based diets; peanut meal-based diet and mixed plant-based diet. Profit indices for the fishmeal and mixed plant-based- diets were not significantly different (p 0.05). On the contrary, the Profit index characteristic to the PNM-based diet was significantly lower ($p \leq 0.05$) than the other test diets. Accordingly, the mixed plant meal should be used for complete substitution of dietary fishmeal in pond cultured Nile tilapia.

Keywords: Nile tilapia, Peanut-based diets, Profit indices.

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Dietary Fishmeal Substitution by Peanut-Based Meals in Nile Tilapia (*Oreochromis Niloticus L.)*: Effect of Pond Water Quality on Biomass Production

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Abstract. A 16 week experiment was conducted in earthen ponds in Iganga District of Eastern Uganda to investigate the effect of water quality on biomass production in Nile tilapia *(Oreochromis niloticus L.)* fed on peanut-based meals as alternative dietary fishmeal. Iso-nitrogenous diets containing 30% and 25% Crude Protein were applied for the first 12 weeks and last four weeks while the control was a local diet for Nile tilapia of 25% Crude Protein throughout the experiment. Treatments included the fishmeal-based diet and two peanut-based diets; peanut meal-based diet and mixed meal-based diet. Each of the 16 pond units measuring 3.0 x 4.0 x 1.0 were stocked with 48 fish fingerlings of 21.7 grams mean weight. Significant differences ($p \leq 0.05$) in mean values occurred among targeted parameters; pH, Dissolved Oxygen, nitrite nitrogen and unionized ammonia with exception to temperature. Apart from the unionized ammonia, the significant variations ($p \leq 0.05$) in water quality parameters did not significantly affect ($p \geq 0.05$) biomass production because they were maintained in suitable ranges for Nile tilapia.

Keywords: Nile Tilapia, water quality, peanut-based meals.