# GROWTH PERFORMANCE, SURVIVAL AND ECONOMICS OF *Clarias gariepinus* (BURCHELL 1822) UNDER MONO- AND POLYCULTURE WITH *Oreochromis niloticus* ON VARYING CRUDE PROTEIN LEVELS

**BY**

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## DECLARATION

I declare that this is my original work and has never been presented for award of a degree in any University.

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We confirm that the work reported in this thesis was carried out by the above candidate under our supervision and has been submitted for examination with our approval.

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This thesis is dedicated to God Almighty through Jesus Christ for special favour and guidance during the entire study period.

## ABSTRACT

With the progressive decline of capture fisheries and human population upsurge worldwide, aquaculture is expected to play a great role in ensuring sufficient fish in the market. Thus, aquaculture is promoted by world food production agencies and governments, and has experienced significant growth. However, for African countries such as Kenya, aquaculture production is disproportionately lower than capture fisheries. Thus, there is urgent need to improve aquaculture production in these countries to meet the growing demand for fish through effective aquaculture practices and systems. Clarias gariepinus, a fish that has been underutilized, with qualities such as high fecundity, fast growth, and high tolerance to environmental changes is a key candidate for improving aquaculture production in Africa. Currently, there are no affordable and quality feeds, and suitable aquaculture production systems for *C. gariepinus*. The full potential of growth performance of *C. gariepinus* in cages fed on low CP is yet to be established.Fry/larval survival in most hatcheries is low and requires improvement. Hence, this study aimed to evaluate the growth performance, survival and economics of *C. gariepinus* raised as monoculture and in polyculture with *Oreochromisniloticus*, to determine the effectiveness of low crude protein (CP) level in *C. gariepinus* diets andalso in fry/larval to fingerling survival. *Clarias gariepinus* and *O. niloticus* weighing averagely 3.0 ± 0.001 g and 10.0 ± 0.001 g respectively were placed at a stocking density of 70 fish in a 2 m by 2 m hapa as mono- or 1:1 ratio in polyculture. The hapas were placed randomly in 400 $m^2$ earthen pond. The fish were fed on diets containing caridina, soybean, wheat pollard and cotton seed cake combined in different CP ratios to give 25%, 30%, and 35%. Crude protein ratio of 28% was used as control.Feeding was done thrice daily at 3% body weight for 182 days. Growth parameters and survival data were taken fortnightly. Enterprise budgets were used to compare the relative profitability of monoculture and polyculture system fed on varying CP diets. For fry/larval experiment, fish larvae (0.03 ± 0.01 g) were stocked in glass aquaria (15 liters) at the rate of seven fish/liter and cultured for six weeks with measurements of parameters being taken weekly. Statistical comparisons were performed by one-way ANOVA with Tukey’s post-test or Unpaired t-test using GraphPad Prism software. *Clarias gariepinus* fed on formulated diets had significantly higher growth performance with respect to weight gain(CP 35% $p<0.001$), length gain(CP 35% $p<0.001$), specific growth rate(CP 35% $p<0.01$). However for feed conversion ratio and survival there were no significant differences from those fed on commercial diet. Results on culture systems indicated that polyculture had significant output than monoculture on all feeds ($p<0.001$).The performance and economicindices of polyculture were significantly higher than monoculture system irrespective of the CP level ($p < 0.05$). Moreover, *C. gariepinus* larvae fed on the formulated diets exhibited higher performance and survival than those fed on commercial feed ($p < 0.05$). These results demonstrated that formulated feed with relatively low CP levels could potentially be utilized as an alternative to the commercial feed in *C. gariepinus* fingerling or grow-out culture. Further,*C. gariepinus* polyculture with *O. niloticus* is more promising in terms of performance and economics than the monoculture system. The present findings strongly suggest that farmers and policy makers could adopt *C. gariepinus* polyculture systems with cheap and low CP diets to maximize aquaculture productionin-order to meet the country’s animal protein need and the overall agenda on food security.

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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **ANOVA** | Analysis of variance |
| **CF** | Crude fiber |
| **cm** | Centimeter |
| **CP** | Crude protein |
| **CSM** | Cotton seed meal |
| **DO** | Dissolved oxygen |
| **ECR** | Economic conversion ratio |
| **EE** | Ether extract |
| **FAO** | Food and Agricultural Organization |
| **FCE** | Feed conversion efficiency |
| **FCR** | Feed conversion ratio |
| **g** | Gram |
| **h** | Hour |
| **ha** | Hectare |
| **K** | Condition factor |
| **KIRDI** | Kenya Industrial Research and Development Institute |
| **Kg** | Kilogram |
| **KMFRI** | Kenya marine and fisheries research institute |
| **L** | Liter |
| **m** | Meter |
| **mg** | milligram |
| **ml** | Milliliter |
| **mm** | Millimeter |
| **MonoCL** | Clarias gariepinus raised in monoculture system |
| **N** | Nitrogen |

NARDTC National Aquaculture Research and Development Training Centre - Sagana

**NFE** Nitrogen-free extracts

**$NH_3$** Ammonia

**P** Phosphorus

**PI** Profit index

**PolyCL** Clarias gariepinus raised in polyculture system

**SBM** Soya bean meal

**SEM** Standard error of mean

**SGR** Specific growth rate

**USA** United States of America

**USD** United States dollar

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# CHAPTER ONE

# INTRODUCTION

## 1.1. Background

Over the last 50 years, growth of global aquaculture industry has been sporadic with the global production capabilities of culture and capture fisheries being almost comparable according to Food and Agriculture Organization report (FAO, 2018). Nevertheless, the growth rate of global aquaculture has varied across continents. Continental Asia has become the giant in aquaculture production despite Africa having the availability of enormous natural resources in some regions (FAO, 2010). With the progressive decline of capture fisheries and population upsurge worldwide, aquaculture is expected to play a great role in ensuring sufficient fish in the market (FAO, 2018). Thus, aquaculture is promoted by world food production agencies and governments, and has experienced significant growth. Africa has great potential for fish farming with 37% of its surface area suitable for artisanal fish farming and 43% for commercial fish production (Aguilar-Manjarrez & Nath, 1998). However, for African countries, aquaculture production is disproportionately lower than capture fishery production. Thus, there is urgent need to improve aquaculture production in the African countries to meet the growing demand for fish. This necessitates development of better aquaculture approaches.

Kenya is endowed with several inland natural water resources including lakes: Victoria, Turkana, Baringo, Naivasha, Chala, Kanyaboli, Jipe, among others. Major rivers include the Tana, Athi, Nyando, Nzoia, Gucha, Migori, Yala and Mara. In addition, Kenya boasts of approximately 600 km of coastal shoreline with an Exclusive Economic Zone of 200 nautical miles, which could be utilized to enhance aquaculture. Despite most parts of the country being suitable for aquaculture, only about 0.014% of the 1.4 million ha of potential aquaculture sites are used for aquaculture and about 95% of fish farming is on a small scale (Otieno, 2011).

The fisheries subsector earns the country an average of US$ 70 million annually from exports (Ngugi & Manyala, 2009). By 2011, the fish exports earnings had declined to US$ 40.5 million (SDF, 2012). In 2010, the average per capita annual fish consumption was 5 kg person−1 year−1 which is far below the FAO recommended average of 20 kg person−1 year−1 (Rothuis et al., 2011). Freshwater fish consumption in 2014 was estimated at 195,206 tonnes. To meet the gap between fish production and the increasing demand for food fish, Kenya imports about 5900 metric tons (MT) annually from other countries (State Department of Fisheries (SDF), 2014). Thus, better ways are needed to boost aquaculture production to meet the deficit. Recognizing aquaculture as one of the viable options for revamping the country's food sector, the Kenyan government has designated several aquaculture facilities in various parts of the country to serve as research centers, training facilities, and sources of fingerlings and feed for fish farmers, including National Aquaculture Research Development & Training Center (NARDTC) in Sagana, Kisii Fish Farm Training Center, Kiganjo Trout Farm, Ndaragua Trout Farm, Chwele fish farm, Lake Basin Development Authority (LBDA) in Kisumu, Wakhungu fish farm in Busia, Sangoro research station, Kegati research station, and Kabonyo and Ngomeni fish farms. However, most of these centers lack basic laboratory equipment and human capacities to spur significant aquaculture production (Munguti et al., 2014).

In Kenya, warm water fishes comprise: Nile tilapia (Oreochromis niloticus) constituting 75%, African catfish (Clarias gariepinus), and other species comprising 25% (Mbugua, 2008; Opiyo et al., 2018). There have been attempts to culture indigenous fish, e.g. the African carp (*Labeo victorianus*), original Lake Victoria tilapia (Oreochromis esculentus) and Victoria tilapia (*Oreochromis variabilis*) (Maithya et al., 2017; Orina et al., 2018). However, culture of these indigenous species have remained on experimental basis and are not widely adopted by farmers due to low survival and poor yields (Orina et al., 2018).

Thus, *C. gariepinus* is a key fish capable of alleviating animal protein deficiency due to its high fecundity, fast growth and high adaptability to environmental changes. However, its production is limited by lack of affordable and quality feeds and effective production systems. Hence, there is need for studies to better understand the performance of *C. gariepinus* on low and cheaply available sources of proteins which have the potential to make a significant contribution to aquaculture growth. Currently, *O. niloticus*is the only fish cultured in cages (Aura et al., 2018), there is need to evaluate the performance of *C. gariepinus* in cages (hapas), which can reduce loss of feeds and the possibility of disappearance of *C. gariepinus* in muddy ponds. Should this evaluation be successful, the fish can also be cultured in cages in Lake Victoria where the cost of investment is further reduced by the elimination of costs of excavating fish ponds. Another constraint to Clarias gariepinus aquaculture development is use of seedlings of unknown genetic stock including highly retrogressed populations (Barasa et al, 2004).

The dismal performance of the aquaculture sector is due to a number of constraints, such as unavailability of efficient and inexpensive fish feeds for different stages of development and limited species of the cultured fishes and low quality seed fish (Munguti et al., 2012; Shitote et al., 2013). Fish meal is a good protein source for aqua feed because it has a high protein level (65% to 72%) and also it contains all the ten indispensable amino acids that meet the requirements of all fish species. However, finding alternatives to fish meal has become an absolute necessity in order to reduce the over-reliance of aquaculture on fresh water and marine ingredients which are expensive compared to plant sources. The competition between human food and animal feed has had negative impact on the sustainability of these resources (Francois and Sadavisam, 2009). Other animal protein sources which have been tried as possible substitutes for fishmeal include meat meal, bone meal, blood meal, poultry by-product meal, hydrolysed feather meal. However most of these are not available to fish farmers. Therefore plant sources have been tried in –order to overcome the problem. These include, soy meal, rapeseed meal, sunflower meal, grasses, oat groats, leaf protein, cottonseed meal, vegetable silage, wheat bran and pollard (FAO, 1980)

Studies have investigated the performance of the fish, *C. gariepinus* on various fish feeds. A study by Omeru and Solomon (2016) evaluated the growth performance of *C. gariepinus* fed on earthworm meal and a manufactured Commercial Fish Feed (by Coppens Company Limited) for three months. The mean growth rate, weight gain, growth rate, and specific growth rate of *C. gariepinus* fed on earthworm meal were significantly higher than for those fed the commercial feed. However, earthworm could be largely unavailable to most farmers, hence unsustainable for large-scale fish production. The other possible fishmeal substitute that has been tried is sunflower seed meal (Ogello et al. 2017).

Further, several reports showed that growth performances of hybrid catfish fry (Diyaware et al., 2009), Chrysichthysnigrodigitatus fingerlings (Adewolu & Benfey, 2009) and in Heterobranchuslongifilis (Babalola & Apata, 2006) were influenced by the CP levels in the diets. More specifically, Diyaware et al. (2009) reported that growth rate and weight gain increased progressively with dietary protein level to a maximum of 50% crude protein. A high weight gain and specific growth rate was observed in milkfish (Chanoschanos) fed at 40% protein level (Jana et al., 2006). Further, a paper(Edea et al., 2018) showed that cage-reared *C. gariepinus* fed on 45% CP exhibited better growth performance than those reared in tanks. However, there was no significant difference in survival of fish reared in cage or tanks. However, the two previous studies evaluated high levels of CP which could be expensive to fish farmers. The performance and survival of *C. gariepinus* on low CP diets and in cage system remains poorly understood. A better understanding of these could lower the cost of *C. gariepinus* production on efficient but cheap feeds.

Aquaculture production can be in form of polyculture or monoculture. Polyculture increases productivity by a more efficient utilization of the ecological resources in the pond (Lutz, 2003). Stocking two or more complementary species can increase the maximum standing crop of a pond by taking advantage of a wider range of available foods and ecological niches. Nile tilapia, *Oreochromis niloticus*, is an omnivorous filter feeder and African catfish is considered as a predator targeting fish fry and fingerlings (Ibrahim & Gamal, 2010). In Kenya, tilapia farming is mainly carried out in monoculture systems (Opiyo et al., 2018). A survey conducted in Western Kenya targeting 1000 farmers indicated that a high proportion of farmers (74%) cultured Nile tilapia and African catfish in monoculture systems, while 26% of farmers carried out polyculture of the two species (Jacobi, 2013). This was attributed to inadequate knowledge of polyculture by farmers (FAO, 2016). The production of an aquaculture system depends on the type of culture system adopted. Consequently, studies have looked at the various dynamics of the mono- and polyculture systems.

Aquaculture as a farming enterprise requires inputs e.g. fish feeds, seedlings, water, labour, technical skills, land space. The outputs or products may be for subsistence or commercial use. Better economic returns may be achieved through economy of scale given that fish farming system has a direct bearing on the economics. Thus, studies have attempted to evaluate the performance and economics of polyculture and/or monoculture of *C. gariepinus* and *O. niloticus* (de Graaf et al., 1996a; Isyagi 2005; Ibrahim & Gamal, 2010;Haruna & Ipinjolu, 2013). However, previous studies were not conducted in hapas, to open the way for its possible culture in cages just like *O. niloticus* in Lake Victoria(which also creates a different ecological environment) and used high CP diets, hence might not give a true potential of *C. gariepinus* raised as mono- or in polyculture. A better and comprehensive understanding of the economics of *C. gariepinus* raised in monoculture or polyculture and fed on low CP diets and in hapas-in-earthen pond system is yet to be understood. Success in its farming is therefore critical. However, the performance of C. gariepinus in cages (hapas), which can minimize losses in muddy ponds has not been fully investigated. This information is necessary and would inform on the most profitable *C. gariepinus* farming system to be adopted to boost the dwindling aquaculture production levels in Kenya.

Insufficient availability and quality of fingerlings for stocking are key constraints for the development of aquaculture in Kenya (Opiyo et al., 2018). In spite of the escalating demand for *C. gariepinus* fingerlings for stocking fish ponds, this species is also used as bait fish in capture fishery, leading to increased demand every year (Ngugi et al., 2007). The Fisheries Department estimated that the annual demand for catfish fingerling in Lake Victoria was 10 million/year for aquaculture and 18 million/year for bait (Ngugi et al., 2007). Currently, the total demand for both catfish and tilapia fingerling is estimated at 100 million yr–1 (Charo-Karisa & Gichuri, 2010; Opiyo et al., 2018). Despite government efforts to improve existing fish breeding centers, this huge annual demand for fingerlings cannot be attained unless further development by the private sector is realized. In addition, the quality of fingerling supplied needs to be ensured. To achieve good quality seed fish, aquaculture experts have encouraged measures to obtain same-sex fingerlings using sex reversal and hybridization techniques (Opiyo et al., 2018). However, such initiatives are still unpopular among fish farmers due to the technical knowledge and facilities required. These are some areas that private investors could link to support fish farming in Kenya. So far, the Kenyan government through the aquaculture working group which brings together researchers, fisheries officers, fish farmers, Kenya Bureau of Standards (KBS), and other stakeholders has authenticated fish hatcheries nationwide and are in the process of drafting seed fish quality standards, which are expected to solve problems of substandard seed fish in the aquaculture market. On average, the hatcheries record a survival of 70% of the hatched crop which are sold to farmers at fry or fingerling stage (Opiyo et al., 2018). There is a direct correlation between quality feeds and fingerlings. Furthermore, feed cost has a direct influence on the cost of fingerlings sold to farmers. Thus, there is need for production of efficient and cheap feeds that would in turn result in sufficient quality fingerlings that are affordable to farmers. To this end, the present study evaluated the diet protein level that gives reasonable larval to fingerling survival.

Therefore, the present study sought to better understand the performance, survival and economics of *C. gariepinus* raised as monoculture and/or in polyculture with *O. niloticus* , and the effectiveness of low crude protein (CP) level in *C. gariepinus* diets including fry/larval to fingerling survival.

### 1.2 Statement of the problem

Aquaculture productivity is important in bridging the deficit of fish in the market. The gap between production and consumption is significantly high and requires urgent measures to boost the production of fish for the market. *Clarias gariepinus* is a key fish that has a high growth rate, high fecundity and survival against environmental pressures of water quality deterioration, which this research effort aims to take advantage of through an alternative culturing system. Success in its farming is therefore critical. However, the performance of *C. gariepinus* in cages (hapas), which could minimize possible handling problems of the fish in muddy ponds has not been fully exploited. Further, the performance of *C. gariepinus* on low CP diets that are of acceptable quality and cheap is yet to be fully established. Moreover, the economic performance of *C. gariepinus* in mono- and polyculture systems when fed on low CP diets remains unclear. In addition, there are no efficient and cheap feeds that would in turn result in sufficient quality fingerlings that are affordable to farmers (Munguti et al, 2014).Thus, performance, survival and economics of *C. gariepinus* raised as monoculture and/or in polyculture with *Oreochromis niloticus,* and the effectiveness of low crude protein (CP) level in *C. gariepinus* diets including for fry/larval to fingerling survival were evaluated.

### 1.3. Study objectives

#### 1.3.1. General objective

To determine the growthperformance, survival and economics of *C. gariepinus* raised in mono- and polyculture with *O. niloticus* raised on varying CP levels inhapas-in-earthen pond system.

#### 1.3.2. Specific objectives

1. To evaluate growth performance of *C. gariepinus* fed on 25%, 30% and 35% crude protein diets formulated with: freshwater shrimps (*Caridina nilotica*), cotton seedcake, soy bean meal and wheat pollard.
2. To determine growth performance and survival of *C. gariepinus* in monoculture and in polyculture with *O. niloticus* in hapas-in-earthen pond.
3. To evaluate the economics of *C. gariepinus* culture under mono- and polyculture with *O. niloticus* farming systems in hapas-in-earthen pond.
4. To determine the effectiveness of low protein level diet for the survival of *C. gariepinus* fry/larval to fingerling.

#### 1.3.3. Null hypotheses

1. There is no significant difference in the growth performance of *C. gariepinus*, fed on 25%, 30% and 35% crude protein diets formulated with: Freshwater shrimps (C. nilotica), cotton seedcake, soy bean meal, wheat pollard.
2. There is no significant difference in the growth performance and survival of *C. gariepinus* in monoculture and in polyculture with *O. niloticus* in hapas-in-earthen pond.
3. There is no significant difference in the economics of *C. gariepinus* culture under mono- and polyculture with *O. niloticus* farming systems in earthen ponds.

4. The low protein level diet will not cause the *C. gariepinus* fry/larvae to survive to fingerling stage.

### 1.4. Justification of the study

Considering the progressive decline of capture fisheries and population upsurge worldwide, aquaculture is expected to play a pivotal role in ensuring sufficient fish in the market. Thus, aquaculture is promoted by world food production agencies and governments, and has experienced substantial growth. Most parts of Kenya are suitable for aquaculture, yet only small fraction of potential aquaculture sites are used for aquaculture and a vast portion of fish farming is on a small scale. The aquaculture production has dropped since 2014 and with the average per capita annual fish consumption lagging far below the FAO recommended values. High price of fish feeds is a key limitation to fish farming development in East Africa (Hecht, 2007; Munguti et al. 2014). Thus, there is urgent need to improve aquaculture production to meet the growing demand for fish. Nevertheless, the aquaculture production has myriads of challenges. Aquaculture is an expensive venture, thus there is need to innovate ways to reduce the cost of production based on culture systems. Secondly, the country over-relies on *O. niloticus*, thus there is need for diversifying aquaculture to adopt other fish species. Third, There is need to innovate new feed formulation that are cheap but efficient. Lastly, there is need for production of cheap and quality feeds. It is envisioned that the findings of the present study would improve production of *C. gariepinus* hence reducing the demand deficit of fish in the market and would improve food security. Presently,there are no affordable feeds and suitable production systems for *C. gariepinus*.

### 1.5. Significance of the study

First, the findingson growth performance and survival of *C. gariepinus* fed on low CP diet would inform policy makers on the use of formulated diets from available raw materials in the local market as a source of feed for *C. gariepinus* farming. Secondly, with further investigations and improvement, cheap low CP diets could potentially be used as the main *C. gariepinus* diet. This could lead to increased production of *C. gariepinus* by the farmers resulting into improved livelihoods and food security. Third, improved growth performance and survival of *C. gariepinus* larvae fed on low CP would advance understanding of aquaculture scientists on the use of low CP ingredients in raising fingerlings. Fourth, a good culture system such as the use of hapas would stimulate *C. gariepinus* production by reducing possible disappearance of *C. gariepinus* in the mud of culture pond.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. Aquaculture and food security

As the world's population approaches 8 billion, the demand for fish and fish products has been thehighest ever in history. For instance, in 2014, the global total fisheries production was 167.2 million tons (FAO, 2016). This demand is ever increasing. The Food and Agriculture Organization (FAO) anticipates that approximately 27 million tons of production will be needed to maintain the present level of per capita fisheries consumption of 20 kilograms or 44 pounds per year by 2030 (FAO, 2016).

As capture fisheries is dwindling due to overexploitation, there is a growing concern for the future food security of the world as it is estimated that fisheries only account for 17% of the global population's intake of protein (FAO, 2016). In the face of these challenges, aquaculture (the breeding, rearing, and harvesting of aquatic plants and animals), has been considered as the silver bullet as it offers a more resource-efficient means of producing protein, taking less feed and space. Aquaculture also allows for a more regulated and controlled means of food production compared to land protein-production (Whiteet al., 2004).

China's fisheries production has risen steadily from 1.23 to 34.13 million tones in the period 1978 to 2008, garnering a 69.7% share of the total aquatic production, making China one of the few countries in the world where aquaculture production exceeds the wild catch (FAO, 2009). In the case of USA, where the mainstay of the aquaculture industry is the production of channel catfish (*Ictaluruspunctatus*) which occurs largely in earthen ponds, aquaculture industry is well established but still faces significantchallenges to maintain continued growth. For instance Catfish represented 81 percent of the 287 132 tones of finfish produced in 2008 which is a decline of about 22 percent as a result of high feed costs and intense competition from imported, frozen fillet products from Asia (FAO, 2009).

Aquaculture has grown strongly in most regions of the world where potential exists, except in Sub-Saharan Africa.A number of countries in sub-Saharan Africa are characterized by low agricultural production, poor management of resources, economic stagnation, persistent political instability, lack of technical knowhow, increasing environmental damage, and severe poverty In the entire African region, only Egypt has achieved the scale of change observed elsewhere. Despite the pressure on water, Egypt has the largest aquaculture industry in Africa. For instance production has increased from about 92.5 thousand tones in 1971to more than 1097,544 t in 2013, with most of this growth taking place in the Nile Deltaregion (Solimanand Yacout, 2016). However in spite of decades of investment and technical input, it has failed to thrive in other African countries where expected, and in many cases remains precarious and marginal, though opportunities for growth and development of the sector still abound (Ayoola, 2010)

In Nigeria, aquaculture development has been driven by social and economic objectives, such as nutrition improvement in rural areas, generation of supplementary income, diversification of income activities, and the creation of employment, but still unable to meet domestic production demand for its populace. Exception is Ghana, where the per capita fish consumption is estimated at 26 kg which is higher than the world's average (20.5 kg) and Africa's average (10 kg) (FAO, 2016). Only five other countries: Zambia, Madagascar, Togo, Kenya and Sudan produce more than1,000tonnes each. This result shows that Africa in general is far behind in aquaculture production (FAO, 2014).

In Kenya,food insecurity remains one of the most visible dimensions of poverty. The increasing population amid competition for land and water resources means that the county's demand for food will continue to increase the food insecurity trend as the population is expected to hit 55 million by 2020 against an annually declining arable land per capita and consequent increase in food prices (Ogello and Munguti, 2018).

Aquaculture has been identified as an important approach in the global fight against food insecurity, particularly in the developing nations. Fish farming provide much needed high quality animal protein and other essential micronutrients because of its affordability to the poorer segments of the community in addition to the provision of employment opportunities and cash income (FAO, 2016).

The fisheries subsector in Kenya earns the country an average of US$ 70 million annually from exports (Ngugi & Manyala, 2009). By 2011, the fish export earnings had declined to US$ 40.5 million (SDF, 2012). Kenya is instead importing about 5,900 MT annually from other countries such as China, to bridge the deficit (SDF, 2014). Kenya is endowed with several inland natural water resources such as Lakes Victoria, Turkana, Baringo, Naivasha, Chala, Kanyaboli, Jipeand many other small inland water bodies. Further, Kenya has major rivers, including the Tana, Athi, Nyando, Nzoia, Gucha, Migori, Yala and Mara. In addition, Kenya boasts of approximately 600 km of coastal shoreline with an Exclusive Economic Zone of 200 nautical miles, which could be utilized to enhance aquaculture. Despite most parts of the country being suitable for aquaculture, only about 0.014% of the 1.4 million ha of potential aquaculture sites are used for aquaculture and about 95% of fish farming is on a small scale (Otieno, 2011). In Kenya, the aquaculture production was on the rise until in 2014 when it began to drop (Opiyo et al., 2018).Decline in aquaculture is as a result of poor water retention capacity of ponds in some counties especially the Coastal and the Eastern region; poor extension services, inadequate capacity support, poor husbandry practices, low quality and quantity of fish farm inputs, poor marketing infrastructure, dependency syndrome on government/donor support and lack of value addition (Opiyo et al., 2018).In 2010, the average per capita annual fish consumption was 5 kg person−1 year−1 which is far below the FAO recommended average of 20 kg person−1 year−1 (Rothuis et al., 2011). Recognizing aquaculture as one of the viable options for revamping the country's food sector, the Kenyan government has designated several aquaculture facilities in various parts of the country to serve as research centers, training facilities, and sources of fingerlings and feed for fish farmers, including National Aquaculture Research Development & Training Centre (NARDTC) in Sagana, Kisii fish farm training center, Kiganjo trout farm, Ndaragua trout farm, Chwele fish farm, LBDA in Kisumu, Wakhungu fish farm in Busia, Sangoro research station, Kegati research station, and Kabonyo and Ngomeni fish farms. However, most of these centers do not have basic laboratory equipment and human capacities to impact significant aquaculture production (Munguti et al., 2014).

According to the Agricultural Sector Development Strategy of 2010-2020 (GoK, 2010), the Kenyan aquaculture subsector has great potential to contribute to the country's economy. Kenya's fisheries sector plays an important role in the country's economic and social development, and includes the aquaculture and the capture fisheries. Besides generating foreign revenue, aquaculture provides a source of subsistence and livelihood to the rural poor. This is because it can provide employment opportunities, earn foreign exchange, reduce poverty and improve food security. However, there is slow growth of the industry despite many government interventions (Nyandat & Owiti, 2013) therefore; the bottlenecks to the industry's growth need to be identified. A study identified the high price of fish feeds as a key limitation to fish farming development in East Africa (Hecht, 2007). Fish farmers in a study done in three Kenyan counties of Kisii, Siaya and Kakamega identified the high feed cost and its low quality as the key challenges they faced in aquaculture (Shitote et al., 2013). Munguti et al. (2012)evaluated the nutritive value of agro-processing by-products e.g. Cotton seed cake, wheat pollard, sunflower seed cake, sweet potato (*Ipomoea batatus*), cassava

(*Manihotesculenta*) and papaya (*Papaya carica*)and identified them as high potential feedstuffs of plant origin either processed or in raw for small-scale fish farming.

The main types of fish currently farmed are tilapia, catfish, carp and trout. Tilapia represents about 75% of total production, followed by catfish (17%), carp (6%) and trout (<1%). Kenya, however, has far greater capacity for fish farming, with over 1.14 million hectares potentially available to enable a production capacity of over 11 million tons per year. However, there has been a decline in the aquaculture fish production in the last few years (Figure 2.1). Thus, development of sustainable and more productive fish farming system is required to meet the growing demand for fish (Musiba et al., 2014).

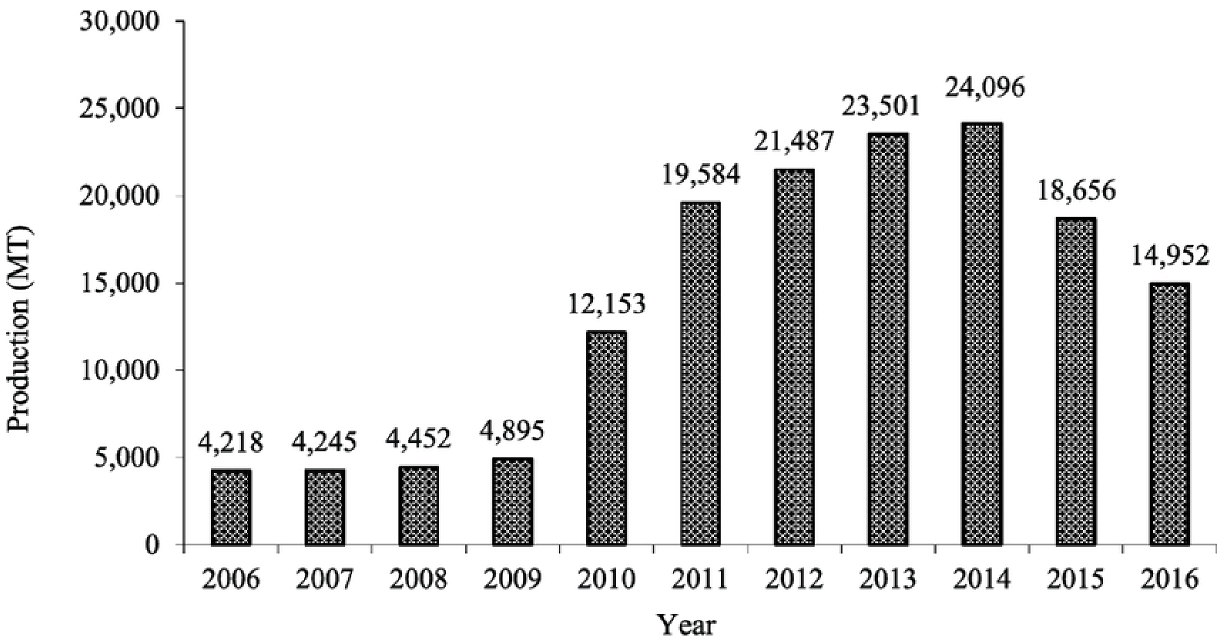


**Figure 2.1. Aquaculture production in Kenya.** The figure illustrates the production of fish within a ten-year period (Opiyo et al., 2018).

### 2.2. Clarias gariepinus: ecology and behaviour

*Clarias gariepinus*, an Actinopterygii that belongs to the order Siluriformes of the family Clariidaeis a large, eel-like fish, usually of dark gray or black colouration on the back, fading to a white belly (Plate 2.1). The *C. gariepinus* is commonly referred to as African Catfish, Sharptooth Catfish, Catfish, Common Catfish, Mudfish, Barbel, Sharp toothed Catfish and North African catfish. With an average adult length of 1–1.5 m it reaches a maximum total length of 1.7 m and up to 60 kg of weight. It is characterized by slender bodies, flat bony heads and broader in size and terminal mouths with four pairs of barbels. The African sharptooth catfish is also gifted with large accessory breathing organs composed of modified gill arches sometimes referred to as rudimentary lungs and only the pectoral fish have spines (Shourbela et al., 2019).

*Clarias gariepinus* is a nocturnal fish like many other species of catfish. Catfish belongs to the family Claridae. It also has rapid growth and breeds easily in captivity (Froese and Daniel, 2011).It feeds on living and dead animal matter. It is also able to swallow relatively large prey whole, because of its wide mouth. It can even feed on large water-birds such as the ommon moorhen. The catfish is mostly found in lakes, streams, rivers, swamps and floodplains which are often subjected to seasonal drying. However, during dry seasons, the African catfish crawl on dry ground to escape drying pools and survives in shallow mud between rainy seasons due to their accessory air breathing organs. Seldom, it produces loud croaking sounds (Mosha et al., 2016).

A protein level of 32-36% CP is recommended for Channel Catfish (Ictaluruspunctatus) culture. This recommended high dietary protein level is one of the factors that make Catfish feeds expensive because the protein fraction of the ration is more expensive than carbohydrates (Munguti et al., 2012).

In the culture of this species artificial reproduction ensures a year-round supply of fish seed. African catfish are relatively insensitive to disease and do not have high water quality requirements. It tolerates high concentrations in the water of ammonia ($NH_3$) and Nitrite ($NO_2$). Low oxygen concentrations are tolerated because the fish utilize atmospheric as well as dissolved oxygen, (air breathing organs well developed). It grows fast and feeds on a large variety of agricultural by products (de Graaf et al., 1996a). It can be raised in high densities resulting in high yields (6–16 tons $ha^{-1}$ $year^{-1}$); and fetches a higher price as tilapia's as it can be sold live at the market. The optimum temperature for growth is 25$^{\circ}$C (Hogendoorn, 1979). Thus, *C. gariepinus* is a key fish capable of alleviating food insecurity hence; there is need for studies to better understand the performance of *C. gariepinus* on low and cheaply available sources of proteins which has the potential to make a significant contribution to aquaculture growth. According to Aura et al. (2018), *O. niloticus* is the only fish cultured in cages. Therefore, there is need to evaluate the performance of *C. gariepinus* in cages (hapas), which can reduce disappearance of *C. gariepinus* in muddy culture ponds.

**Plate 2.1. A photo of C. gariepinus. The Photo was taken at the KMFRI Sangoro Center.**

**2.3. *Oreochromis niloticus*: ecology and behaviour**

Oreochromis niloticus belongs to the family Cichlidae, order: Perciformes and class Actinopterygii. It is a deep-bodied fish with cycloid scales. Silver in colour with olive/grey/black body bars, the Nile tilapia often flushes red during the breeding season (Picker & Griffiths, 2011) (Plate 2.2). It grows to a maximum length of 62 cm, weighing 3.65

kg (at an estimated 9 years of age) (FAO, 2012). The average size (total length) of *O. niloticus* is 20 cm (Bwanika et al. 2004). *Oreochromis niloticus*is native to central and North Africa and the Middle East (Boyd, 2004). It is a tropical freshwater and estuarine species. It prefers shallow, still waters on the edge of lakes and wide rivers with sufficient vegetation (Picker & Griffiths, 2011).

*Oreochromis niloticus* is known to feed on phytoplankton, periphyton, aquatic plants, invertebrates, benthic fauna, detritus, bacterial films and even other fish and fish eggs (FAO, 2012). Depending on the food source, they will feed either via suspension filtering or surface grazing (GISD, 2012), trapping plankton in a plankton rich bolus using mucus excreted from their gills (Fryer & Iles 1972). *Oreochromis niloticus* have been observed to exhibit trophic plasticity according to the environment and the other species they coexist with (Bwanika et al., 2007). Male fish initiate breeding with the creation of a spawning nest, which is fiercely guarded. When the water temperature increases above 24°C, a female will lay her eggs into the nest. These are then fertilized by the males before the female collects them in her mouth (known as mouth brooding). The eggs and the fry which then hatch are incubated and brooded in this manner until the yolk sac is fully absorbed two weeks later (FAO 2012). The number of eggs a female will produce is dependent on body size. This can range from 100 eggs (produced by a 100 g fish) to 1500 eggs (spawned by a 1 kg fish). The females will not spawn while brooding. Males on the other hand fertilise the eggs of multiple females continuously given optimal environmental conditions (FAO 2012).

*Oreochromis niloticus* can live longer than 10 years. Food availability and water temperature appear to be the limiting factors to growth for *O. niloticus* (Kapetsky & Nath, 1997). Optimal growth is achieved at 28-36°C and declines with decreasing temperature (FAO 2012). The ability to vary their diet may also result in variation in growth (Bwanika et al., 2007). In aquaculture ponds, *O. niloticus* can reach sexual maturity at the age of 5-6 months (FAO, 2012).

*Oreochromis niloticus* is a worldwide important species in aquaculture because of its fast growth, firm and tasty flesh, resistance against harsh conditions and ease of production of fingerlings under captivity (de Graaf et al., 1996a; Gómez-Márquez et al., 2003). In the wild, *O. niloticus* starts to reproduce at a total length of 20–30 cm (150–250 g) (Gwahaba, 1973). However, under captivity *O. niloticus* reaches sexual maturity at a relatively smaller size of 8–13 cm (Suresh & Bhujel, 2012).

Depending on the nature of *O. niloticus* farming (i.e. seasonal or year-round production) there are several alternative options for culture. These could be seasonal pond culture; seasonal cage culture in lakes, rivers and dams; or thermally regulated intensive bio-secure recirculation systems in tanks and raceways (Shipton et al., 2008). Of these, freshwater cage culture is considered to represent the highest biosecurity risk (i.e. risk of escapement and/or transfer of pathogens and diseases to wild populations), while culture in raceways or ponds represent a moderate biosecurity risk, and culture in recirculating systems, a low biosecurity risk.

**Plate 2.2. A photo of *O. niloticus* . The Photo was taken at the KMFRI Sangoro Center.**

## 2.4. Overview of common fish feed ingredients used in this study

Up to 36% of the world's total fisheries catch annually is ground up into fishmeal and oil to feed farmed fish, chicken and pigs (Jacquet et al., 2010). However, the steady increase in fishmeal consumption and dwindling fish catches in wild waters predicts that there will be acute shortage of feeds for aquaculture industry unless non-fish alternatives are used for fish feed production. As the consumption rate of fish as human food increases, the use of fish materials for feed production also increases. Thus, development of sustainable aquaculture depends on the establishment of alternative feedstuffs to fishmeal (Olukayode & Emmanuel, 2012). Considering that the success of fish farming is dependent on the provision of suitable and economical fish feeds, there is need to use available feedstuff especially to reduce the price of feeds (Fagbenro, 1999). Several alternatives have been proposed some of which were used in this study as discussed below.

### 2.4.1. Soy bean meal

Soya bean meal(SBM) is the best plant protein source in terms of protein content and essential amino acid (EAA) profile. It has been shown that SBM could be used as a partial or total FM alternative for tilapia, with varying results (Ogello et al., 2014). Soya bean meal could replace between 67 and 100% of fishmeal, depending on fish species, dietary protein level, source, processing methods and culture system used (El Sayed, 1999). Further, studies by Viola and Zohar (1984) reported that supplementing tilapia diets with crystalline EAA did not improve *O. niloticus* performance. This implies that minerals, rather than limiting EAA, may be the limiting factors in the efficient utilization of SBM for tilapia (El Sayed, 1999). Also, the non-inclusion of the limiting EAA to SBM diet did not affect growth and SBM supplemented with 3% di-calcium phosphate and oil completely replaced FM without any adverse effects on tilapia growth (Viola et al., 1988). Davis and Stickney (1978) found that the inclusion of SBM at 15% dietary protein level impaired growth of blue tilapia, while at 36% protein; SBM could totally replace fishmeal in the diets without significant growth retardation.

Soya beans are a species of legume most widely consumed as food. Its nutritional suitability includes vitamins (K- riboflavin, folate, B6- thiamin, and C), organic compounds (iron, manganese, potassium, phosphorus, magnesium, zinc, selenium and calcium), and significant amount of dietary fiber, protein, and antioxidants. The contradiction among researchers regarding the use of SBM as a protein source for fish may be related to the quality and processing of SBM, fish species, size and culture systems. Even though SBM contain some anti-nutritional factors (trypsin) (El Sayed, 1999), thermal processing can be used to make quality feeds out of SBM (Tacon, 1993). Wassef et al. (1988) found that the germination and defattening of SBM reduces the activity of protease inhibitors. Similarly, heating SBM destroys the anti-nutritional factors and improves nutrient bio-availability (Tacon & Jackson, 1985). The safety and use of genetically modified soybean meal (GM SBM) as fish feed protein source has been demonstrated (Suharman et al., 2009). Studies have shown that there are no differences in fish growth, survival, feed conversion, and fillet composition between the fish fed GM soybean and non GM SBM for Nile tilapia (Suharman et al., 2009). According to Watanabe (2002), defatted soybean meal is universally accepted, both qualitatively and quantitatively, has favorable amino acid profile compared with other plant protein sources. Soybean meal is consistently available, cost-effective, and reported to be palatable to most fish species (Watanabe, 2002).

Based on these benefits, several aquaculture nutritionists should aim at totally replacement of fishmeal with SBM as a protein source since many results have indicated that SBM is one of the most promising fishmeal replacements (Watanabe, 2002).

### 2.4.2. Cotton seed meal

Cotton seed meal (CSM) has good protein contents and amino acid profile depending on processing methods (El sayed, 1999). However, CSM is limited in Cystein, Lysine and Methionine and has high content of gossypol, an anti-nutrient compound, which may limit the use of CSM in animal feeds (El Sayed, 1999). The use of CSM as protein sources for tilapia has given mixed results (Ogello et al., 2014). El-Sayed (1990) successfully used prepressed solvent extracted CSM as a single dietary protein source for *O. niloticus* and they performed better than fishmeal-fed fish. However, El-Sayed (1990) found that *O. niloticus* and O. aureus fed on CSM-based diets grew at slower rates compared to fish fed fishmeal-based diets, probably due to the gossypol and cyclopropionic acids contained in CSM. El-Sayed (1987) found that Tilapia zillii grew best on diets containing 80% CSM protein. El-Sayed and Kawanna (2008) found that CSC (42% CP) used as the only feed input for *O. niloticus* reared in earthen ponds, fertilized with cattle manure for 100 days, resulted in a sharp increase in fish weight. Cotton seed meal is readily available and cheap plant protein source in most parts of the world (Ogello et al., 2014).

### 2.4.3. Caridina nilotica meal

The freshwater shrimp Caridina nilotica (common name: Ochonga) may be a suitable protein source for making aquaculture feeds. It is a natural prey of *O. niloticus* and a bycatch that constitutes 10% of Restineobola argentea landed (Kubiriza et al., 2016). The decline in Nile perch (Lates niloticus) stocks in Lake Victoria (Taabu-Munyaho et al., 2013) has led to increased abundance of C. nilotica. Considering that annual catch of R. argentea is about 120,000 MT on the Ugandan side of Lake Victoria alone (Taabu-Munyaho et al., 2014), as much as 12,000 MT of C. nilotica may be available annually for fish feeds in Uganda alone. Of note, about 50,000 MT of C. nilotica could be accessed for fish feed production from the estimated 500,000 MT of R. argentea landed from the whole of Lake Victoria annually (Kubiriza et al., 2016).

### 2.4.4. Wheat by-products

Cereals such as wheat, rice, maize, sorghum, other millets and cassava are cultivated extensively in many countries. Wheat and its by-products such as wheat bran and wheat pollard are conventionally used in aquaculture feeds (Ogello et al., 2014).

Wheat byproducts contain less than 9.5% crude fiber. Variety of wheat and type of processing affect the nutrient composition. Nutrient composition will usually vary less within one supplier than between different suppliers. Crude protein content of wheat byproduct is 18.4%, which is higher than corn or barley (10% to 13%), and is a suitable replacement for most of these cereals. However, wheat byproducts are low in undegradable protein (25% UIP-CP) compared to corn (50% UIP-CP) and soybean meal (35% UIP-CP) (Munguti et al., 2012).

## 2.5. Types of fish production systems

Fish culture is classified based on the number of fish species as monoculture and polyculture. Monoculture is the culture of single species of fish in a pond or tank. The culture of *C. gariepinus* only or *O. niloticus* or Heterotis or Gymnarchus are typical examples of monoculture. The advantage of this method of culture is that it enables the farmer to make the feed that will meet the requirement of a specific fish, especially in the intensive culture system. Fish of different ages can be stocked thereby enhancing selective harvesting (Verreth et al., 1987).

Polyculture is the practice of culturing more than one species of aquatic organism in the same pond. The motivating principle is that fish production in ponds may be maximized by raising a combination of species having different food habits. The mixture of fish gives better utilization of available natural food produced in a pond (Ali & Jauncey, 2004). Polyculture began in China more than 1000 years ago. The practice has spread throughout Southeast Asia, and into other parts of the world (Singh et al., 1991). Ponds that have been enriched through chemical fertilization, manuring or feeding practices contain abundant natural fish food organisms living at different depths and locations in the water column. Most fish feed predominantly on selected groups of these organisms (Akinwole & Faturoti, 2006). Polyculture should combine fish having different feeding habits in proportions that efficiently utilize these natural foods. As a result, higher yields are obtained (Ali & Jauncey, 2004).

Combinations of three Chinese carps (bighead, silver and grass carp) and the common carp are most common in polyculture. Other species may also be used. While fish may be grouped into broad categories based on their feeding habits, some overlap does occur. Descriptions of the feeding habit categories and examples of fish from each category are as follows. Plankton Feeders - Plankton is usually the most plentiful food in a pond, so it is essential to include a plankton-feeding fish in a polyculture system. This group of fish feeds on the tiny, free-floating plants (phytoplankton) and animals (zooplankton) which multiply abundantly in fertilized ponds. Two fish typical of this group are the silver carp, Hypophthalmichthysmoliirix and the bighead carp, Aristichthysnobilis. Herbivores - This group of fish feeds on aquatic vegetation. The grass carp, Ctenophanjngodonidella, is most noted for this behaviour and is stocked in ponds for weed control. Bottom Feeders - Fish in this group feed primarily at the pond bottom (Ali & Jauncey, 2004). They consume a variety of decaying organic matter, aquatic organisms such as clams, insects, worms, snails, and bacteria living in or on the sediments. The common carp, Cyprinuscarpio, is well noted for this behaviour. Piscivorous Fish - These predatory fish feed on other fish and must consume about 5 to 7 g of prey to grow 1 g. They are frequently stocked in ponds to control unwanted reproduction, particularly in tilapia, and other fish that enter the pond with the water supply and compete for food with the stocked fish. Commonly used predator fish include the sea bass, Lates spp.; catfish, Clarius spp. and Silurus spp.; snakeheads, Ophicephalus spp.; cichlids, Cichla spp.; Hemichrotnisfasciatus and Cichlasomamanaguense; knife fish, Notopierus spp.; and largemouth bass Micropierussaimoides (Ali & Jauncey, 2004).

Adding predator fish to a polyculture system increases the average weight of prey species. It is most efficient to use a predator fish that consumes small prey. This prevents the prey from growing large enough to compete for food with larger fish of its species. Use of predator fish in polyculture systems is experimental in most areas of the world. In small ponds, it is almost impossible to stock the exact number of predator fish to achieve the same predator/prey balance occurring in nature. In small-scale aquaculture, predator fish are usually stocked at rates of 5 to 20 fish/100 $m^2$ of pond surface area to control reproduction of the prey species completely. Typically, the stocking rate is about 19 fish/100 $m^2$ for catla, 38 fish/100 $m^2$ and 6 fish/100 $m^2$ for mirgal (de Garaaf et al., 1996a).

Polyculture is an efficient way to maximize benefit from available natural food in a pond. However, pond management becomes more difficult when stocking fish species having specialized feeding habits in the same pond because proper fertilization and feeding practices must be followed. If inadequate fingerling supply severely limits the choice of species available for polyculture, at least one species should have general rather than specialized feeding behaviour. This will allow more of the available natural food to be utilized (Akinwole & Faturoti, 2006).

In Kenya, especially in Central Kenya and many East African countries like Tanzania some attempts have been made on polyculture farming. The polyculture potential has not been fully investigated.

## 2.6. Aquaculture production systems in Kenya

In Kenya, aquaculture culture systems are generally made up of extensive and semi-intensive systems. However, truly intensive systems exist in a relatively small number. Reports indicate that fish farmers operating at a subsistence level are turning into commercial intensive fish farming with some earning as much as US$ 11,000.00 ha−1 year−1 in gross income (Mbugua, 2008).According to FAO, more than 90% of farmers practice semi-intensive fish farming while the intensive system is practiced by only 3% due to high cost of electricity and non-availability of cheaper quality feeds (FAO, 2016). The semi-intensive systems involves fertilization of ponds with either cattle, sheep, poultry or rabbit manure and supplementary feed inform of cereal bran and low protein formulated feeds are given to supplement natural foods (Munguti et al., 2014). According to Ogello et al. (2013), most aquaculture farm systems in Kenya are integrated with either crop or livestock production. Further, crop farming is generally done at subsistence level while livestock rearing is often done for commercial purposes especially for milk and meat production (Ogello et al., 2016).

### 2.6.1. Extensive fish farming

Extensive farming is commonly conducted in dams and water reservoirs. Here, the farmed fish depend on primary productivity of the culture water and no artificial feed is provided. This system is mainly being used for raising *O. niloticus* and *C. gariepinus* which prevent breeding of mosquitoes in dams put in place for watering livestock (Opiyo et al., 2018). In Kenya, the dams used for extensive system are mainly found in Central and Rift valley region. Production from this system ranges between 500 and 1,500 kg ha$^{-1}$ year$^{-1}$, contributing 10% of farmed fishes in Kenya (Ngugi et al., 2007).

#### 2.6.2. Semi-intensive systems

This is the main system adopted in Kenya for production of *O. niloticus* and *C. gariepinus* either in monoculture or polyculture system (Opiyo et al., 2018). They consist of earthen ponds, liner ponds and concrete ponds. Ponds are fertilized using organic manures (Munguti et al., 2014). Feeding is done using supplementary feeds formulated on farm or purchased from cottage fish feed production industries. In some cases, cereal brans are used as feeds to increase pond productivity. Production from this system ranges between 1000 and 2500 kg $ha^{-1}$ $year^{-1}$ (Ngugi et al., 2007). The system is preferred by most farmers since it is less expensive in terms of feed inputs.

#### 2.6.3. Intensive systems

##### 2.6.3.1. Raceways

This system is mainly used for production of rainbow trout (Oncorhynchusmykiss) especially in Mount Kenya region. According to the Kenya's State Department of Fisheries, production of trout from the raceways in 2014 was 241 MT valued at USD 1,430,000 (SDF, 2014). The contribution of rainbow trout is therefore higher in monetary value than by weight since a kg costs between USD 3–12 (Mbugua, 2008). Production in these systems ranges between 10,000 and 80,000 kg ha−1 year−1 (FAO, 2016). However, the system requires high quality feed which are expensive and can only be afforded by a few farmers

##### 2.6.3.2. Recirculating aquaculture systems (RAS)

Recirculating aquaculture systems in Kenya are mainly tank-based systems used for culturing *O. niloticus* and C. gariepinus. Fish are reared in tanks indoors or under green houses. There exist eight farms operating recirculating systems in form of hatcheries and grow-out farms in Kenya. Fish are grown at high density ranging between 5 and 20 fish $m^{-3}$ under controlled conditions. Production from RAS is at 200 tonnes $ha^{-1}$ $year^{-1}$ (SDF, 2016.). The adoption of the system is low due to high cost of initial capital investment in tanks, greenhouses and high cost of electricity required in running the system. Investment in recirculation aquaculture systems (RAS) for Nile tilapia production and intensive catfish production is carried out in peri-urban areas near towns like Nairobi, Kiambu, Nyeri, Meru, Kisumu, Machakos, Kilifi, Homa Bay, Kakamega and Busia (SDF, 2016).

**2.6.3.3. Cages**

Cage farming is growing fast in Lake Victoria with the highest number of the cages located in Siaya County (Aura et al., 2018). Intensive cage culture started in 2013 after cage trials were conducted successfully at Dunga beach in Kisumu County by Kenya Marine and Fisheries Research Institute (KMFRI) and Dunga Beach Cooperative Society under the Association for Strengthening Agriculture Research in East and Central Africa (ASARECA) project (Aura et al., 2018; Njiru et al., 2018). Currently, cage farming is practiced in five riparian counties (Migori, Siaya, Homabay, Busia and Kisumu counties). Stocking density in the cages ranges between 60 and 250 fish $m^{-3}$ with cage sizes ranging from 8 to 125 $m^3$.

The number of cages increased from 1663 in 2016 to 3398 cages in 2017 (Njiru et al., 2018). Nile tilapia is the only fish cultured in cages producing 12 million kg of fish every cycle (about 8 months in a year) (Aura et al., 2018). The largest cage farming enterprise in Lake Victoria is Winnie’s farm in Anyanga beach which started with 60 cages in 2013 and currently owns more than 550 cages together with other groups consisting of 100 farmers (Opiyo et al., 2016). Currently, the enterprises operating cages are about 43 with over 4000 cages stocked with over 3 million individual tilapia fingerlings (Njiru et al., 2018). Cage farming has a huge potential to increase aquaculture production and support economic growth around the Lake Victoria region (Aura et al., 2018).

### 2.6.4. Ponds

Most of smallholder farmers have a minimum of 1 pond to a maximum of 60 fish ponds. The level of operations of farmers are rated as small scale, medium or large scale (Obwanga et al., 2017). Large scale operators represent pond surface area of 4000–80,000 $m^2$ and more than 13 ponds while medium scale operators represent 601–3999 $m^2$ and 5–12 ponds. Small scale farmers have less than 5 ponds and in most cases use their own individual labour to produce fish mainly for household consumption and excess fish are sold to neighbors (Ngugi et al., 2007; Obwanga et al., 2017)]. A stocking rate of 3 fish $m^{-2}$ is commonly used in ponds in Kenya to achieve yields of 1 $kgm^{-2}$. At this stocking rate daily weight gain ranges from 1.5 to 2.0 g in well managed systems. Rare cases in Kenya have stocking densities of 6 juveniles $m^{-2}$ in ponds giving a production of 3 $kgm^{-2}$ (FAO, 2016).

Most fish farmers practicing pond culture add manure or inorganic fertilizer to ponds to increase the supply of natural food organisms to fish so as to reduce production costs arising from feeds (Mbugua, 2008). The manures in use are; cow dung, sheep, poultry and rabbit manure. These manures increase the risk of introduction of pathogens into the system (Mente et al., 2011). Culture periods of 6 months or more are needed to produce fish that weigh between 250 and 300 g from the ponds. The size of fish attained at the end of the growth period depends on the climatic conditions of the area especially temperature with areas having an average temperature lower than 25°C having smaller fish at harvest. Type of feed used and management practices like water quality management, feeding regimes and stocking density also affect the growth of fish (Opiyo et al., 2018).

## 2.7. Performance and economics of *C. gariepinus* in mono and polyculture system

The poor performance of the aquaculture sector is due to a number of constraints, such as unavailability of efficient and inexpensive fish feeds for different stages of development and limited varieties of the cultured fish species and low quality seed fish (Munguti et al., 2012; Shitote et al., 2013). Due to this, studies have investigated the performance of fish on various fish feeds. A better understanding of these could lower the cost of *C. gariepinus* production on cheap feeds.

Aquaculture production can be in form of a polyculture or monoculture. Polyculture increases productivity by a more efficient utilization of the ecological resources in the pond (Lutz, 2003). In Kenya, tilapia farming is mainly carried out in monoculture systems (Opiyo et al., 2018). A survey conducted in Western Kenya targeting farmers indicated that a high proportion of farmers (74%) cultured *O. niloticus* and *C. gariepinus* in monoculture systems, while 26% of farmers carried out polyculture of the two species (Jacobi, 2013). This was attributed to inadequate knowledge of polyculture by farmers (FAO, 2016). The production of an aquaculture system depends on the type of culture system adopted. Consequently, studies have looked at the various dynamics of the mono- and polyculture systems. Several studies have evaluated the performance and economics of polyculture and/or monoculture of *C. gariepinus* and *O. niloticus* and variedly reported that polyculture systems exhibited higher growth performance and economic performance in terms of gross production per hectare (ha), cost of production among others than the monoculture systems (de Graaf et al., 1996a; Isyagi 2005; Ibrahim & Naggar, 2010;Haruna & Ipinjolu, 2013).

A study evaluated the growth performance of *C. gariepinus* fed on earthworm meal and Coppens company commercial feed for three months. The mean growth rate, weight gain, growth rate, and specific growth rate of *C. gariepinus* fed on earthworm fish meal were significantly higher than for those fed the commercial feed (Omeru & Solomon, 2016). Further, several reports showed that growth performances of hybrid catfish fry (Diyaware et al., 2009), Chrysichthysnigrodigitatus fingerlings (Adewolu et al., 2006) and in Heterobranchuslongifilis (Babalola & Apata, 2006) were influenced by the CP levels in the diets. More specifically, Diyaware et al. (2009) reported that growth rate and weight gain increased progressively with dietary protein level to a maximum of 50%. A high weight gain and SGR was observed in milkfish (Chanoschanos) fed at 40% protein level (Jana et al., 2006).

Moreover, *C. gariepinus* fed with 40% protein gave the highest growth (Alatise et al., 2005). The FCR of 0.28 obtained in this study was better than 1.28 observed in *C. gariepinus* fed with 40% protein (Sotolu, 2010). Moreover, a previous report evaluated the growth performance of *C. gariepinus* in floating net-hapa system fed on five diets: Diet 1 (40% CP), Diet 2 (42.5% CP), Diet 3 (45% CP), Diet 4 (47.5% CP) and Diet 5 (50% CP) for 24 weeks. The second lowest CP diet (42.5% protein), produced the highest mean final weight (946.89 g), specific growth rate (3.21%/day), FCR (0.27) (Effong & Esenowo, 2018). In two studies, *O. niloticus* polycultured with *C. gariepinus* attained highest growth performance than those cultured under monoculture (de Graaf et al., 1996a; Isyagi 2005). In another study, experiment was conducted to determine the performance of *C. gariepinus* and *O. niloticus* in five different stocking combinations for a period of twelve weeks. The *C. gariepinus*: *O. niloticus* ratios of 0:1, 1:0, 1:2, 1:4, and 1:6 were set up and fed at 3% body weight per day over a period of 84 days. The monoculture of the two species (Treatments 1 and 2) yielded the lowest growth indices (weight gain and SGR), while the performance of *C. gariepinus* at each of the three polyculture systems were higher than those of tilapia. *C. gariepinus* in treatment 5 (1:6) had the maximum mean length (17.92 ± 0.37 cm) while the monoculture recorded the lowest mean length of 16.60 ± 0.29. The monoculture of tilapia gave the lowest length gain (4.83 ± 0.41cm) while the highest (11.60 ± 0.51cm) for tilapia was recorded in Treatment 4 (1:4) (Haruna & Ipinjolu, 2013).

In another report by Ibrahim and Naggar (2010), evaluating the performance and economics of *O. niloticus* , and *C. gariepinus*, monoculture and polyculture across a range of stocking ratios: 100% tilapia + 0% catfish, 75% tilapia + 25% catfish, 50% tilapia + 50% catfish, and 0% tilapia +100% catfish. Net fish yields were 5.71, 9.84, 11.03, and 11.35 tones/ha corresponding with daily weight gains of 36.60, 63.08, 70.69, and 72.75 kg/ha/d in the 0% catfish, 25% catfish, 50% catfish, and 100% catfish treatments, respectively. Furthermore, net profit for both polyculture treatments was significantly higher than both monoculture treatments, although no significant differences were observed among polyculture or between the two monoculture treatments. The 25% catfish polyculture gave the highest economic returns. However, considering all the above studies, it is clear that they were not conducted in hapas and used high CP diets, hence might not give a true potential of *C. gariepinus* raised as mono- or in polyculture. A better and comprehensive understanding of the performance and economics of *C. gariepinus* raised in monoculture or polyculture is necessary and could inform on the best farming system to be adopted to maximize profits.

A study showed that *C. gariepinus* fed on diet 1 (40% CP), diet 2 (42.5% CP), diet 3 (45% CP), diet 4 (47.5% CP) and diet 5 (50% CP) were found to have almost similar percentage survival, cost of feeding and total cost of production in all the treatments. However, significant differences existed in gross profit, profit index and economic conversion ratio (Effong & Esenowo, 2018). However, the previous study evaluated high CP diets which are unlikely to reduce cost of production and may not be easily embraced by most fish farmers. Further, an on-farm fish production experiment conducted for 240 days to investigate the effect of stocking density on growth, yield and economic benefits of *O. niloticus* in monoculture and polyculture with *C. gariepinus* reported that *O. niloticus* cultured in polyculture system with *C. gariepinus* attained higher growth, yield and economic benefits than *O. niloticus* cultured under monoculture system (Shoko et al., 2016).

Taken together, the previous reports evaluated high CP levels did not compare mono or polyculture systems of rearing *C. gariepinus* with focus mainly being on the performance of

*O. niloticus*, but not *C. gariepinus* or tested the effect of stocking densities on performance of fish. Thus, there is need for studies to better understand the performance of *C. gariepinus* which may hold the promise to alleviating the food insecurity problem dominant in many countries worldwide.

### 2.8. Performance and survival of *C. gariepinus* larval/fry to fingerlings fed on different CP diets

Insufficient availability and quality of fingerlings for stocking are key constraints for the development of Kenyan aquaculture (Opiyo et al., 2018). In spite of the escalating demand for *C. gariepinus* fingerlings for stocking fish ponds, this species is also used as bait fish in capture fisheries, leading to increased demand every year (Ngugi et al., 2007). The Fisheries Department estimated that the annual demand for catfish fingerling in Lake Victoria was 10 million/year for aquaculture and 18 million/year for bait (Ngugi et al., 2007). Currently, the total demand for both catfish and tilapia fingerling is estimated at 100 million year–1 (Charo-Karisa & Gichuri, 2010; Opiyo et al., 2018). Despite governmental efforts to improve existing fish breeding centers, this huge annual demand for fingerlings cannot be attained unless further development by the private sector is realized. In addition, the quality of the fingerling supplied needs to be ensured. To achieve good quality seed fish, aquaculture experts have encouraged measures to obtain same-sex fingerlings especially for *O. niloticus* using sex reversal and hybridization techniques (Opiyo et al., 2018). However, such initiatives are still unpopular among fish farmers due to the technical knowledge and facilities required. On average, the hatcheries record a survival of 70% of the hatched crop which are sold to farmers at fry or fingerling stage (Opiyo et al., 2018). Thus, there is need for production of sufficient quality fingerlings that are affordable to farmers.

In a study by Nyonje et al. (2018), shell free/decapsulated artemia was utilized, for the first feeding of fry before weaning to dry starter diets of 40 % to 50 %. The survival of the catfish fry and fingerlings ranged from 40 % to 60 % in all the hatcheries. The study results further showed a progressive increase in the FCR, weight gain and total length of *C. gariepinus* larvae. Previously in a 2 weeks experiment, Verreth et al. (1987) also found that dry feeds enriched with an acetone extract of Artemia fed to *C. gariepinus* larvae (mean weight 2.2 ± 0.2 mg) resulted in low growth and extremely low survival rates (< 20%), compared to micro-encapsulated egg (34.4 % -50.9 % protein; high survival rates 64 % - 93 %, but low growth rates) and dried decapsulated Artemia cyst diets (53.2 % - 58.6 % protein; best growth and survival rates). Egg diets are high in fats and provide most of the essential nutrients and better growth was attained from addition of casein and vitamin/mineral mix to egg diets. The larvae hepatocyte ultrastructure indicated a nutritional deficiency (Verreth et al., 1987).

In summary, the performance of low CP in raising *C. gariepinus* fingerlings has not been fully investigated. Hence, the present study evaluated the growth performance and survival of *C. gariepinus* larvae fed on low CP diets. This information could lead to reduced cost of seeds which in turn could lead to better returns for the fish farmers.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1. Study area

The *C. gariepinus* mono- and polyculture with *O. niloticus* experiments were conducted at the KMFRI, Sangoro Center, Kenya (Latitude: 0° 21' 13" S and longitude: 34° 45' 26" E) while the larval experiments were carried out at Maseno University hatchery (0º 00' 60" N and 34º 36' 00" E) (Appendix 1).

## 3.2. Experimental design

About one thousand two hundred and sixty fingerlings of *C. gariepinus* (2.5-3.2 g) were purchased from Kibos Integrated fish farm located approximately 10 km East of Kisumu, Kenya and transported in aerated polythene bags to Kenya Marine and Fisheries Research Institute (KMFRI), Sang'oro Centre. The fish were acclimatized to the conditions at the Centre for 15 days using two large hapa nets, each measuring 4m by 6m placed in a 15 m by 10m earthen pond. During acclimatization, the fish were fed with a commercial diet of crude protein 28%. Prior to stocking, the pond was limed with agricultural lime, $CaO.Ca(OH)_2$,andfertilized at the rate of 2 g/$m^2$ CAN and 3 g/$m^2$ DAP at the beginning of the experiments. Fish were weighed individually and seventy fish (mean weight 3.0 ± 0.01 g) were equally distributed in four dietary treatment groups, T1 (25% CP diet) T2 (28% CP control diet), T3 (30% CP diet), and T4 (35% CP diet) with three replicates each and stocking density of 70 fish per 2m by 2m hapa by 1m hapaof 0.5 mm mesh size which were placed in 400$m^2$ earthen pond, in a completely randomized design. The experimental diets were formulated using Pearson Square method to give the required protein levels. The choice of the CP levels were based ontherecommendation of Hassan (2001) that freshwater carnivorous species require 40-55 percent dietary protein, while most omnivorous and herbivorousspecies require 30-40percent of their dry diet to be made up of protein. The current study tested the efficacy of the low protein feed in the range of 25 to 35% CP on *C. gariepinus* a carnivorous fish with the control being a commercial feed whose CP level was established at 28%.

Another set of twelve hapas also measuring 2m by 2m by 1m were stocked with 35 *C. gariepinus* fingerlings (average weight 3.0 ± 0.01 g) and 35 *O. niloticus* fingerlings (mean weight 10.0 ± 0.01 g), making a total of 70 fingerlings per hapa in this other set of twelve hapas. These, also in a completely randomized design were placed in the same 400 $m^2$earthen pond.The stocking rate was done according to de Graaf and Janssen (1996b) who recommend a range of rate 2 to 10 fingerlings/$m^2$ depending on the desired market size in the range of 500 and 200 g respectively after a six month rearing period. The present study stocked at 4.2fish/$m^2$.Data was presented using both descriptive and inferential statistics.

**3.3 Preparation and analyses of experimental diets**

The experimental feed ingredients were procured from Jubilee, the Kisumu City main market. The ingredients included, Fresh water shrimps from L. Victoria, Cotton seedcake, Soybean, Wheat pollard and vitamin and mineral premix. The experimental diets were formulated to vary in levels of CP contents following the Pearson square method. The diets were prepared as powder or pellet as described previously by Pandey (2013). The major ingredients were blended into fine powder and sieved through a fine-meshed screen (0.5mm diameter). The feed ingredients were mixed uniformly, vitamins and mineral premix added at 1%of total weight, and thoroughly mixed together. The powdered formwas used to feed the fry/larval fish. Water was added to a portion of the mixed ingredients and mixed further to make dough. Finally, the dough was pelletized using an extruder DGP 70 dry type fish feed machine (Jinan Sunward Machinery Co. Limited, China) to get uniform size pellets (2 mm) and sun dried for two hours. The dried pellets were kept in airtight sacs before use.

Proximate analyses of the feed ingredients and the experimental diets were determined by the standard methods of AOAC (1995).Briefly, the analyses involved the following nutrients: crude protein (CP), ether extract (EE), ash content, nitrogen-free extracts (NFE) and crude fiber (CF). The CP was estimated from Kjeldahl nitrogen. Crude lipid was quantified as the loss in weight after extraction of the sample with petroleum ether (40–60$^{o}$C). Ash content was determined by burning the samples in a muffle furnace at 550$^{o}$C for 4 h. CF was quantified by alkaline/acid digestion followed by ashing at 550°C in a muffle furnace for 4 h. NFE was determined by the difference method (DM-CP-EE-CF-Ash). Proximate analyses of the feeds were carried out in triplicate.

**3.4. Fish feeding**

The fish in hapa were fed at 3% of their body weight daily. Feeds were weighed, divided into three portions. Each feedportion wasadministeredat 0900 hours, 1300 hours and 1700 hours to apparent satiation, established by observation.

**3.5. Water quality analyses**

Water quality parameters were determined insitu monthly while for others; samples were taken using a 112 cm water column sampler (Boyd & Tucker, 1992). The samples were taken from experimental hapas. The analyzed water quality variables included: nitrate-nitrogen, nitrite-nitrogen, total ammonia nitrogen, total nitrogen, soluble reactive phosphorus, total phosphorus, total alkalinity, total hardness, chlorophyll a, and pH. Water quality analyses were carried out according to the methods described in American Public Health Association (APHA) (1989) and Egna et al. (1987). A glass electrode pH meter, Hi-9024 microcomputer (Hanna Instruments Ltd., Chicago, IL, USA), was used to measure pH while temperature and dissolved oxygen measurements were taken using model 57 oxygen meter (YSI Industries, Yellow Springs, OH, USA). Other environmental parameters within each hapa in earthen pond including salinity, conductivity and turbidity were also analyzed using procedures as stated in APHA (1989). All the physico-chemical parameters were measured fortnightly except for temperature, D.O, pH, conductivity, TDS, ammonia and nitrites, which were monitored four times weekly.

### 3.6. Sampling Procedure

All the fish in the hapas were sampled fortnightly. Weight and total length measurements were done for all fish from each hapa fortnightly during the study period. Live weight gain, the difference between initial and final weights recorded for the whole study period indicated the growth (productivity), and this parameter was used to determine growth, specific growth rate (SGR), and food conversion ratio (FCR) for the feed and diets used. The length weight data were used to analyze and determine the length-weight relation and condition indices.

### 3.7. Economics of mono- and poly-cultures

The economic analysis of the *C. gariepinus* monoculture and in polyculture with *O. niloticus* was performed as previously described (Shoko et al., 2016) with some modifications. Briefly, enterprise budgets were used to compare the relative profitability of monoculture and polyculture system fed on varying CP diets. Costs weredefined in terms of inputs categorized into variablecosts (expenses that vary with the level of production)and fixed costs (costs that do not vary withthe level of production). Variable costs included;costs of inputs such as prices offingerlings, feeds and fertilizer, whereas fixed costs included cost of pond hire and hapa nets and liming cost and the cost of labour. Theactual values of revenues generated after selling the fish were used in the analysis.All costs and revenues were converted to monetaryvalues, and the cost of production, profit index (PI) and economic conversion ratio were determined. The analysis was based on localmarket retail prices in Kisumu, Kenya and expressed in USD (USD1 = Ksh 100).

The cost-benefit estimation was performed using methods of Piedecausa et al. (2007) as follows:

Profit index (PI) = Value of fish /cost of feed.The higher the profit index is from 1, the better the business is, but if it is below 1, it is a loss making business.

Economic conversion ratio (ECR) = Cost of feed x FCR.The lower the economic conversion ratio is,the more acceptable is the business.

**3.8. Fry/larval to fingerling survival**

About 1200 fry/larvae of *C. gariepinus* were purchased from Kibos Integrated fish farm and transported in aerated polythene bags to Maseno University, School of Agriculture Aquaculture Laboratory. Acclimatization was done for 5 days after which 100 fry/larvae(initial mean weight of 0.03 ± 0.001 g) were randomly distributed into each of 12 glass aquaria (15 cm by 12 cm by 10 cm and filled by 15 L of water. The fish larvae were fed on 25%, 30%, and 35% experimental diet. Commercial diet with 28% CP was used as control. The experiments were done in triplicate. During the experiment, two-thirds of the culture water from each aquarium was replaced with clean water at every alternate day before feeding. Aeration was done using Resun Air pump model No. AC-9906 (Resun, China). Feaces in the containers were removed by siphoning. Any mortality was recorded and dead larvae removed in the morning and evening before feeding. Each day, the fish larvae were fed three times i.e. 8.00, 13.00 and 17.00 hrs. Feeding rate were at 20%, 15% and 10% body weight between 0-7 days, 7-21 days and 21-42 days respectively.

**3.9. Fry/larval to fingerling data collection and water quality measurement**

During initial stocking, a sub-sample of 20 individual fish larvae for each treatment were weighed (± 0.001 g) using an analytical balance (Shimadzu Analytical Balance AUW320 series) and total lengths measured (± 0.1 mm) to determine the initial size ($t_o$) and weight

($W_o$) at stocking. Total length was measured by placing a fry on a transparent petri dish placed on a 1 × 1 mm graph paper. On designated days of the week, the larvae were counted and the number recorded, to determine the survival.At the same time,a similar number of 20 fish were sampled and the individual weights ($W_i$) recorded and total lengths ($TL_i$) measured to determine the size at that time ($t_i$) and restocked. The water quality in the culture was determined by measurement of water temperature (˚C), pH, dissolved oxygen (DO $mgL^{-1}$), conductivity ($\mu Scm^{-1}$), ammonia ($NH_3$ $\mu gL^{-1}$), ammonium ($NH_4$ $\mu gL^{-1}$) and ORP (mV) using standard methods. The pH, ORP electrical conductivity and DO were determined using Hanna HI 9828pH/ORP/EC/DO meter and nitrate determined using a VIS-UV spectrophotometer. Nutrients levels were determined according to standard methods in both the reservoir tank and culture aquaria.

**3.10. Growth parameters for grow-out and larval fish**

The following formulae were used to calculate variables in this study:

$$Length\ gain = Average\ final\ length - Average\ initial\ length$$

$$Weight\ gain = Average\ final\ weight - Average\ initial\ weight$$

Biomass gain = Final weight of fish – Initial weight of fish

$$\%\ SGR\ in\ weight\ per\ day = (ln\,Wt2 - lnWt1)/t\ \times 100$$

$$\%\ SGR\ in\ length\ per\ day = (lnLt2 - lnLt1)/t\ \times 100$$

$$FCR = \frac{Total\ feed\ given\ (g)}{Body\ weight\ gain\ (g)}$$

$$\%\ Survival\ rate = \frac{Total\ number\ survived}{Total\ number\ stocked}\ \times 100$$

Where; $W_{t2}$ = final live body weight (g) at time $t_2$

$W_{t1}$ = Initial live body weight (g) at time $t_1$

$Ln_{t2}$ = Final total body length

$Ln_{t1}$ = Initial total body length

$t$ = $t_2$ - $t_1$ in days

$$FCE = \frac{Weight\ gain \times 100}{Feed\ intake}$$

### 3.11. Statistical analyses

Statistical analysis and graphs were performed using GraphPad prism software version 5.03. Data normality was verified using D'Agostino omnibus K12 test. Data are presented as mean ± standard error of mean (SEM). Statistical difference in growth parameters and survival of *C. gariepinus* raised as monoculture and fed on different CP diets was determined by analysis of variance (ANOVA) with Tukey's post-test. Similarly, statistical difference between mono- and/or polyculture systems was determined using one way-ANOVA or two-tailed Unpaired t-test. Further, the economic variables between mono- and polyculture systems were assessed using two-tailed Unpaired t-test. Lastly, statistical differences growth parameters and survival of *C. gariepinus* larvae was determined by one way ANOVA with Tukey's post-test. A difference with a p-value less than 0.05 was considered significant.

# CHAPTER FOUR

# RESULTS

## 4.1. Proximate composition of the fish diets

In this study, the effectiveness of three test diets and one control (with different crude protein levels) on grow-out of *C. gariepinus*(in mono- and polyculture) and on larvae to fingerlingssurvival were evaluated. Prior to the evaluation, the proximate contents of the diets such as crude protein, lipid, moisture and ash were analysed. Analysis of the diets showed proximate composition of 25% CP, 28% CP, 30% CP and 35% CP, and (Table 4.1).

**Table 4.1.** Proximate contents of locally formulated diets

| Proximate Content | 25% CP | 28% CP | 30% CP | 35% CP |
|---|---|---|---|---|
| CP | 25.51 ± 0.333 | 28.02 ± 0.253 | 30.78 ± 0.342 | 35.06 ± 0.258 |
| Crude fiber | 9.59 ± 0.30 | 5.53 ± 0.10 | 8.29 ± 0.136 | 6.44 ± 0.174 |
| Crude lipid | 13.48 ± 0.027 | 12.56 ± 0.047 | 10.11 ± 0.038 | 10.54 ± 0.036 |
| Ash | 7.00 ± 0.030 | 12.08 ± 0.277 | 7.47 ± 0.251 | 8.77 ± 0.059 |
| Moisture | 11.86 ± 0.232 | 10.48 ± 0.146 | 11.29 ± 0.178 | 11.72 ± 0.144 |
| Nitrogen free extract | 32.57 ± 0.704 | 31.33 ± 0.234 | 32.07 ± 0.273 | 27.46 ± 0.232 |

**Note:** Values represent meant ± SEM. There was no significant differences among and between diets with respect to crude fiber, crude lipid, ash, moisture and nitrogen free extract.

## 4.2. Physico-chemical parameters in water used for raising *C. gariepinus in* mono- and polyculture

Water quality is a key determinant of the growth performance of any fish species and can contribute to inter-pond variations in growth performance. Therefore, the physico-chemical parameters of water that are likely to affect growth of fish were monitored throughout the experimental period and recorded. The parameters were within the acceptable standard limits. No significant differences were observed in the parameters among the hapas with the CP diets in monoculture or polyculture system (Table 4.2). Taken together, the data presented show that all the fish culture conditions were not statistically different between the treatment groups ($p > 0.05$) hence the differences in growth performance are attributable to the CP level.

**Table 4.2.** The physico-chemical parameters of the water in hapas used for monoculture and polyculture experiments

| Parameters | Monoculture | Polyculture |
|---|---|---|
| Temperature (°C) | 23.54 ± 1.11 | 22.28 ± 0.93 |
| Conductivity (µS/cm) | 411.75 ± 20.99 | 425.33 ± 17.62 |
| DO (mg/L) | 5.29 ± 0.75 | 5.75 ± 0.27 |
| pH | 8.98 ± 0.51 | 9.03 ± 0.69 |
| TDS (mg/L) | 205.75 ± 10.58 | 213.00 ± 8.66 |
| Salinity(ppt) | 0.20 ± 0.00 | 0.20 ± 00 |
| ORP(mV) | 63.78 ± 20.41 | 44.97 ± 3.75 |
| Turbidity(NTU) | 325.50 ± 70.40 | 379.67 ± 85.48 |
| Nitrates($\mu gL^{-1}$) | 38.29 ± 7.44 | 37.15 ± 8.08 |
| Nitrites($\mu gL^{-1}$) | 26.17 ± 11.19 | 24.15 ± 1.73 |
| $NH_3$-N($\mu gL^{-1}$) | 25.24 ± 4.11 | 24.46 ± 4.87 |
| $NH_4$-N($\mu gL^{-1}$) | 161.36 ± 27.39 | 177.37 ± 38.49 |
| TP($\mu gL^{-1}$) | 909.82 ± 125.44 | 1041.43 ± 89.75 |
| SRP($\mu gL^{-1}$) | 281.86 ± 49.89 | 301.38 ± 57.03 |
| Silicates($mgL^{-1}$) | 20.49 ± 3.05 | 15.75 ± 1.17 |
| Alkalinity($mgL^{-1}$) | 207.50 ± 0.00 | 216.67 ± 19.43 |
| Hardness($mgL^{-1}$) | 67.00 ± 9.17 | 73.33 ± 13.01 |

**Note:** The values represent the mean ± SEM. Difference between each parameter for mono- and polyculture was not statistically different ($p > 0.05$) as determined by two-tailed Unpaired t-test. The physico-chemical parameters were measured fortnightly except for temperature, D.O, pH, conductivity, TDS, $NH_3$ and nitrites which were measured four times per week.

### 4.3. Growth performance of *C. gariepinus* fed on diets containing varying CP levels

One of the specific aims of the present study was to determine the growth performance in terms of weight and length of *C. gariepinus* fed on different CP levels formulated from freshwater shrimps (*C. nilotica*), cotton seedcake, soy bean meal and wheat pollard.

#### 4.3.1. Weights For *C. Gariepinus* in monoculture

To compare the growth performance of *C. gariepinus* raised as monoculture in hapa-in earthen pond in response to the four CP levels, the fish were fed on the diets for 182days.

There was a significant difference in the weight gains by the fish fed on the four diets (Figure 4.1; One-way-ANOVA, $p < 0.05$). Tukey's post-test revealed that *C. gariepinus* fed on 35% CP had significantly higher weight gain than those fed on 28% CP ($p < 0.05$) and 25% CP ($p < 0.05$). Further, the weight gain by fish fed on 30% CP was significantly higher than those fed 25% CP over the same duration ($p < 0.05$).However, there was no significant difference in the weight gains of fish fed 30% or 28% CP and 25% CP ($p > 0.05$) (Figure 4.1A Taken together, the results implied that 35% CP gave the highest weight gain but 25% CP was as good as the commercial feed (28% CP).

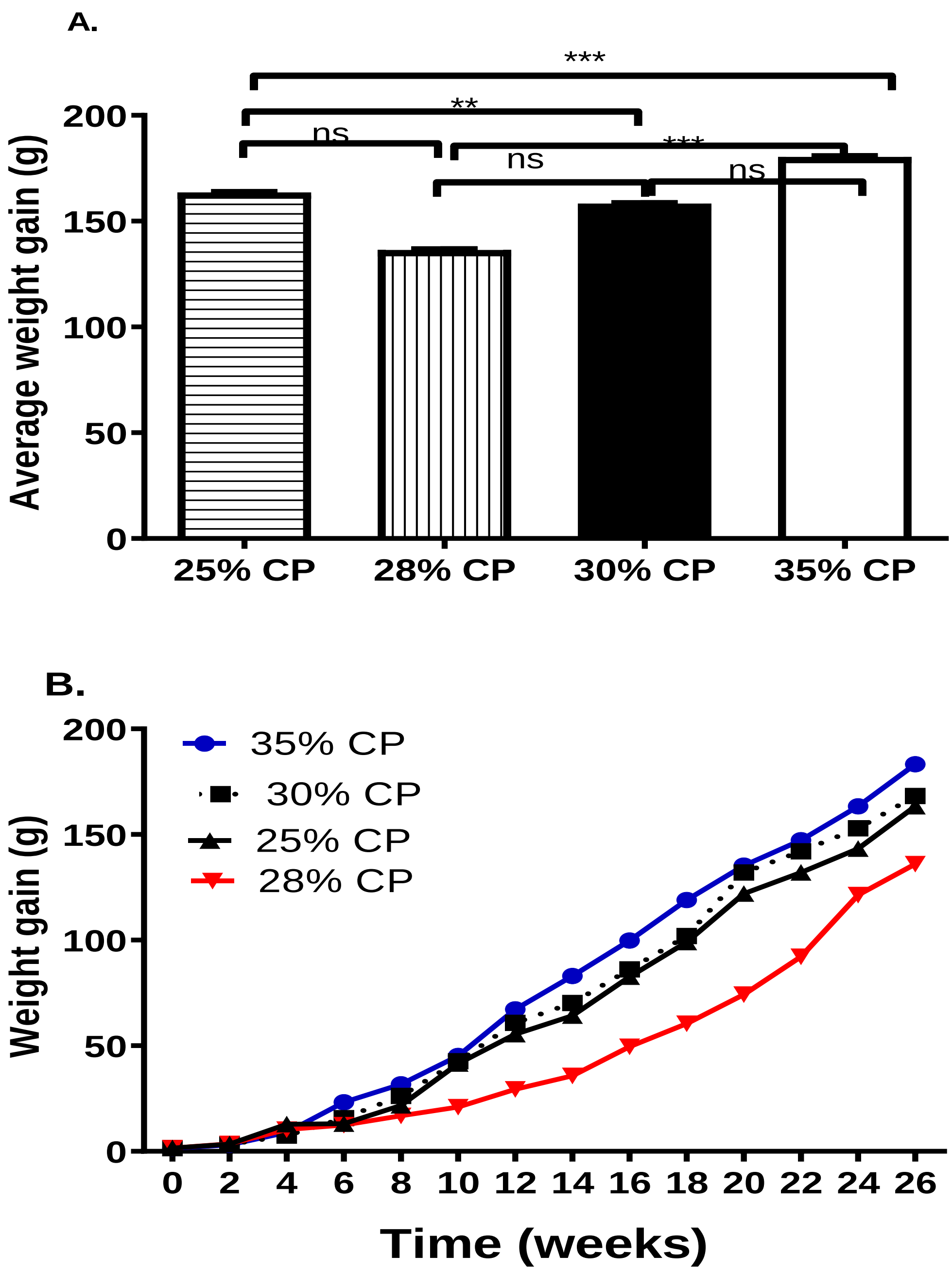


**Figure 4.1. Weight gains of *C. gariepinus* fed on different CP levels.** The comparisons of weight gains (**A**)and change of weight gain with time (**B**) for *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured. The bars and plots represent the mean ± SEM. The weights were measured in triplicates fortnightly over the 182 day period. The

statistical comparison was determined using One way-ANOVA with Tukey's post-test (ns, p > 0.05; **, p < 0.01; ***, p < 0.001).

Further, it was observed that the % SGR in weight per day was significantly different for *C. gariepinus* fed on the four diets for 182 days (Figure 4.2; One-way-ANOVA, p < 0.0001). Tukey's post-test revealed that *C. gariepinus* fed 35% CP had significantly higher % SGR in weight per day than those fed 30% CP (p < 0.001), 28% CP (p < 0.001) or 25% CP (p < 0.05). However, no significant differences in the % SGR in weight per day was observed in *C. gariepinus* fed 30%, 25% or 28% CP diets (p > 0.05). Taken together, the findings implied that 35% CP gave the best SGR in weight and that 25% CP gave similar SGR in weight just as 28% CP (commercial feed).

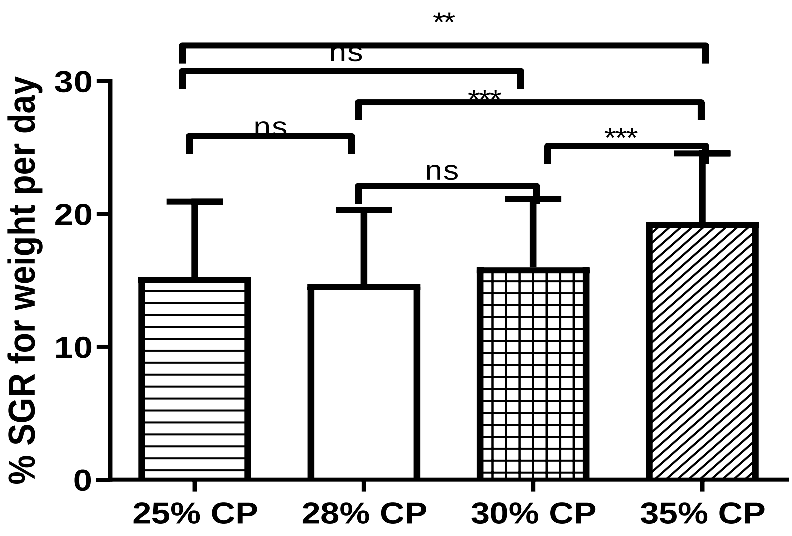


**Figure 4.2. SGR in weight of *C. gariepinus* fed different CP levels.** The percent SGR in weight of *C. gariepinus* fed **on 25% (A), 28% (B), 30% (C) or 35% (D) CP diets**were measured. The bars represent the mean ± SEM. The SGR were measured in triplicates fortnightly over the 182 day period. The statistical comparison was determined using One way-ANOVA with Tukey's post-test (ns, p > 0.05; **, p < 0.01; ***, p < 0.001).

### 4.3.2. Lengths

To compare the growth performance of C. gariepinus fed on the four CP levels, the fish were fed on the diets for 182 days. There was a significant difference in the length gains by the fish fed on the four diets (Figure 4.5; One-way-ANOVA, $p < 0.05$). Tukey's post-test revealed that C. gariepinus fed on 35% CP had significantly highest length gain followed by 30% CP ($p < 0.05$), 25% CP ($p < 0.05$) and 28% CP ($p < 0.05$) in that order. Taken together, the results indicated that 35% CP intake resulted in higher length gain and that length gain was directly dependent on the CP level fed.

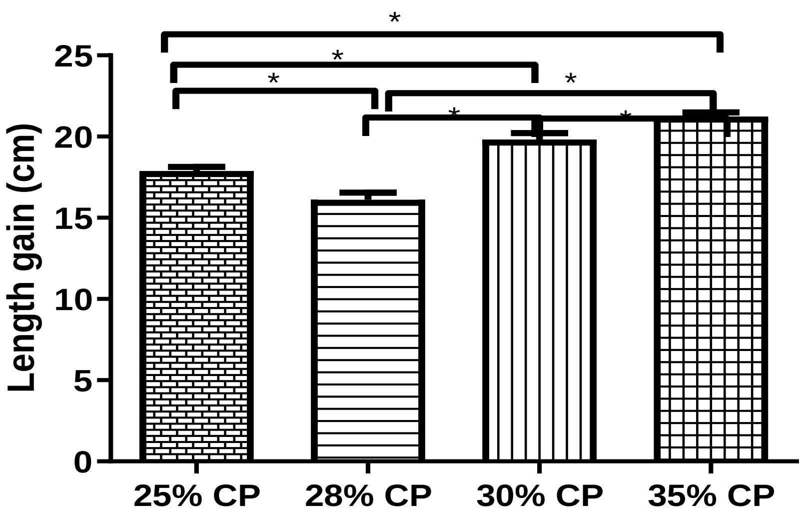


**Figure 4.3.Length gains of C. gariepinus fed on different CP levels**. The length gains by C. gariepinus fed on 25%, 28%, 30% or 35% CP diets were measured. The bars represent the mean ± SEM. The lengths were measured in triplicates fortnightly over the 182 day period. The statistical significance was determined using One way-ANOVA with Tukey's post-test (*, $p < 0.05$).

In addition, it was observed that the % SGR in length per day was significantly different for C. gariepinus fed on the four diets for 182 days (Figure 4.6; One-way-ANOVA, $p < 0.0001$). Tukey's post-test revealed that C. gariepinus fed 35% CP had significantly higher % SGR in weight per day than those fed 30% CP ($p < 0.05$), 25% CP ($p < 0.05$) or 28% CP ($p < 0.05$). Taken together, the findings implied that 35% CP had the highest percent SGR in length in comparison to the other CP levels.

### 4.3.3. Feed conversion ratios

In this study, the feed conversion into body weights were compared for the *C. gariepinus* fed on the four diets. No significant difference in the FCR of fish fed on the four diets was observed (Figure 4.3; One-way ANOVA, $p = 0.5872$). These results implied that the CP dietswere almost equally converted to body weights.

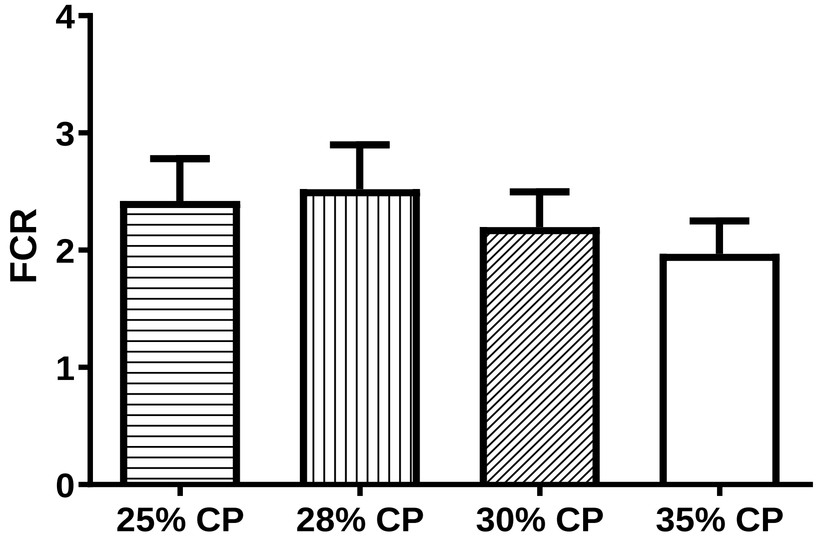


**Figure 4.4. FCR *C. gariepinus* fed on different CP levels.**

The FCR of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP dietsover a 182 day period were measured. The experiments were conducted in triplicate. Bars represent the mean ± SEM. The FCR were calculated in triplicates fortnightly over the 182 day period. The statistical comparison was determined using One way-ANOVA.

In addition, no significant difference in the FCE of *C. gariepinus* fed on the four diets was observed (Figure 4.4; One-way ANOVAwith Tukey's post-test (ns, $p > 0.05$). These results implied that the CP diets were almost equally converted to body weights.

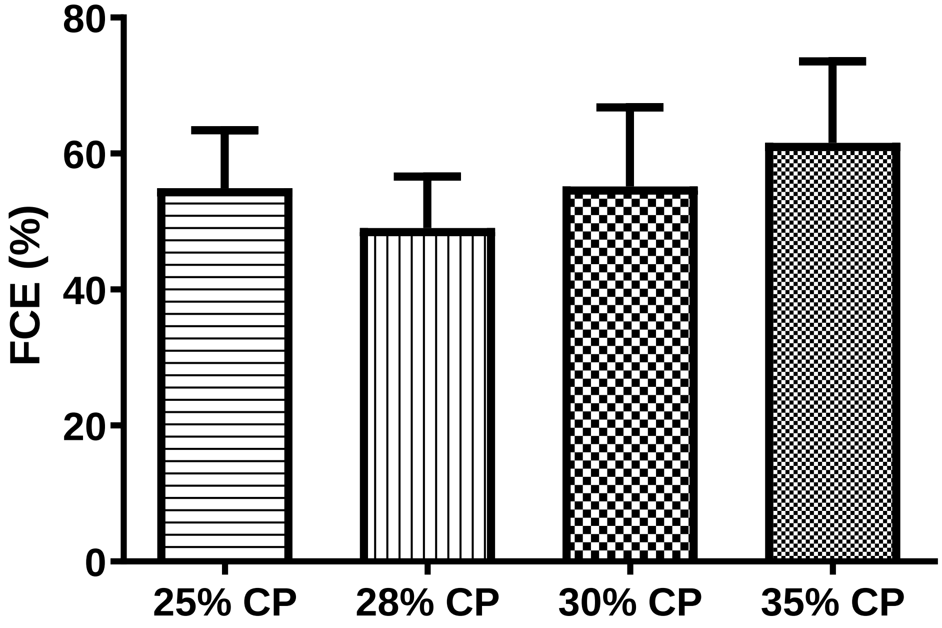


**Figure 4.5. FCE of *C. gariepinus* fed on different CP levels.** The FCE of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP dietsover a 182 day period were measured. The experiments were conducted in triplicate. Bars represent the mean ± SEM. The FCE were calculated in triplicates fortnightly over the 182 day period. The statistical comparison was determined using One way-ANOVA with Tukey's post-test (ns, $p > 0.05$).

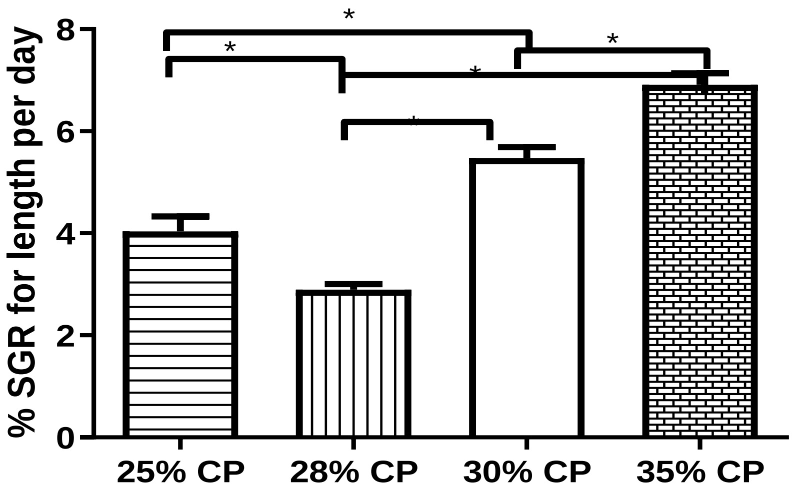


**Figure 4.6. SGR in length of *C. gariepinus* fed different CP levels.** The percent SGR in weight of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were calculated. The bars represent the mean ± SEM. The SGR were calculatedin triplicates fortnightly over the 182 day period. The statistical comparison was determined using One way-ANOVA with Tukey's post-test (**, p < 0.01; ***, p < 0.001).

### 4.3.4. Survival of *C. gariepinus* raised on different CP diets

In the present study, the survival rate of *C. gariepinus* fed on the four CP diets were assessed. No significant difference in the survival of fish fed on the four diets was observed (Figure 4.7A; One-way ANOVA, p = 0.2714). However, the survival was considerably high for fish fed on 35% CP followed by 30% CP, 28% CP and 25% CP. Further, the survival was shown to decrease gradually with time (Figure 4.7B). These results implied that the survival of *C. gariepinus* fed on the four CP diets were statistically equal.

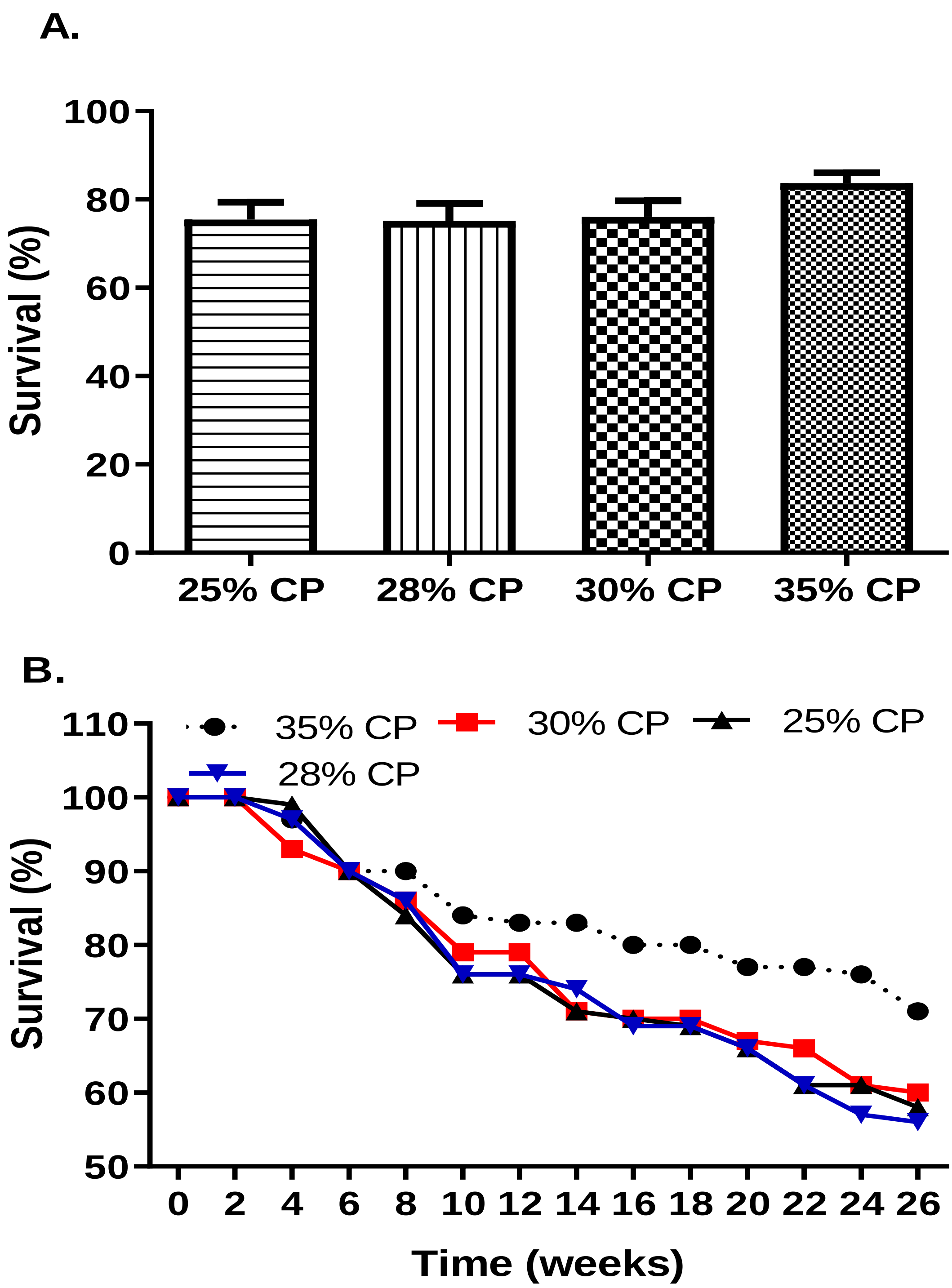


**Figure 4.7.Survival *C. gariepinus* fed on different CP diets.** The comparison of survival (**A**) and survival with time (**B**) of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP dietsover a 182 day period were measured. The experiments were conducted in triplicate. Bars or plots represent the mean ± SEM. The survival was determined in triplicates

fortnightly over the 182 day period. The statistical comparison was determined using One way-ANOVA with Tukey's post-test (ns, $p > 0.05$).

### 4.4. Growth performance of *C. gariepinus* raised in mono-and in polyculture with *O. niloticus*

The second specific aim of the present study was to compare the growth performance of *C. gariepinus* grown in monoculture and in polyculture with *O. niloticus* and fed on different CP levels.

#### 4.4.1. Weights For C. gariepinus in mono- and in polyculture

The study determined the growth performance of *C. gariepinus* in response to the four CP levels when raised both in mono- and in polyculture with *O. niloticus* in earthen ponds in hapas for 182 days. There was a significant difference in the weight gains by the *C. gariepinus* fed on the four diets in polycultures with *O. niloticus* (One-way-ANOVA, $p = 0.05$). Tukey's post-test revealed that *C. gariepinus* fed on 35% CP had significantly higher weight gain than those fed on 25% CP and 28% CP ($p < 0.05$). Further, the weight gain by fish fed on 30% CP was significantly higher than those fed on 28% CP ($p < 0.05$). However, there was no significant difference in the weight gains of fish fed 30% and 25% CP ($p > 0.05$). Similarly, no significant difference was observed between fish fed on 25% and 28% CP (Figure 4.9A).The weight gains of *C. gariepinus* in polyculture were observed to be increasing gradually over time (Figure 4.9B). These results showed that 35% CP had thehighest weight gain by C. gariepinus. Clarias gariepinus raised in polyculture and fed on 25% CP was as good as the commercial feed (28% CP).

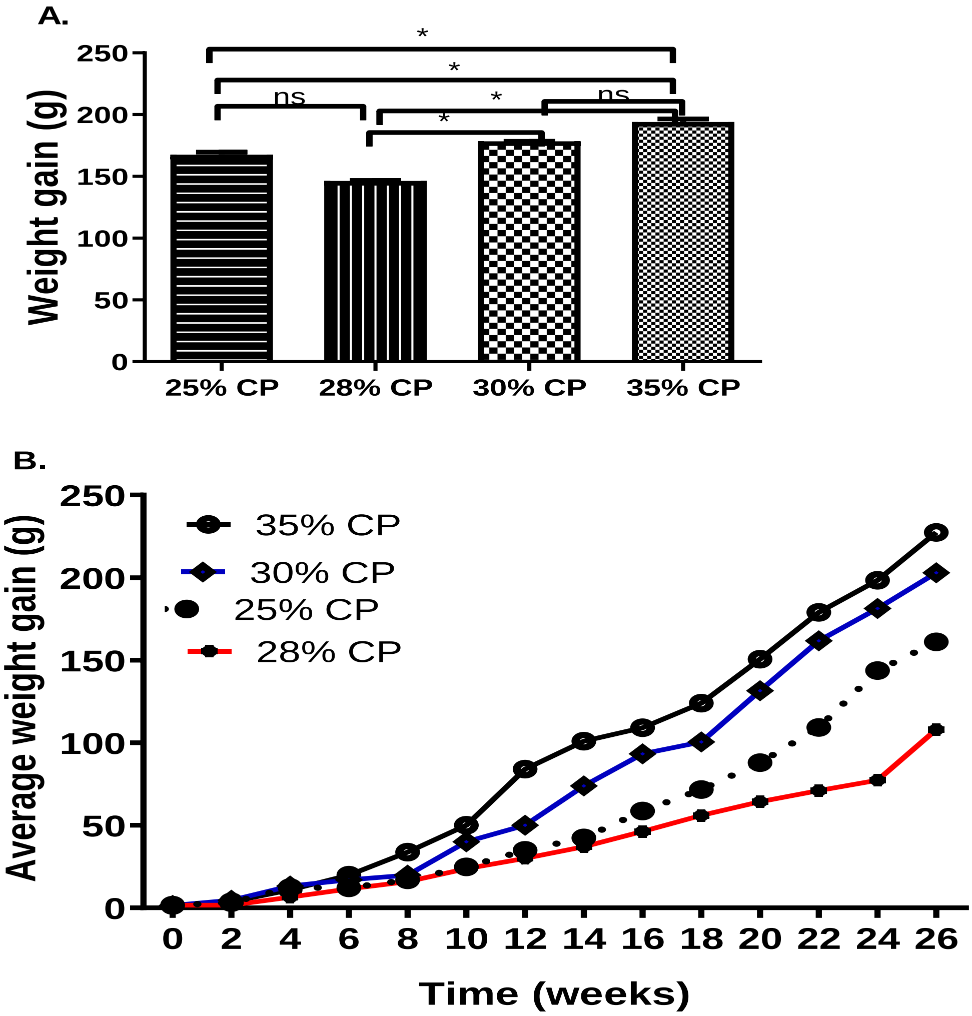


**Figure 4.8. Growth of *C. gariepinus* in polycultures with *O. niloticus* and fed on different CP diets over time.** The comparisons of weight gains (**A**) and change of weight gain with time (**B**) for *C. gariepinus* fed on 25% (A), 28% (B), 30% (C) or 35% (D) CP diets were measured. The bars and plots represent the mean ± SEM. The weights were measured in triplicates fortnightly over the 182 day period. The statistical comparison was determined using One way-ANOVA with Tukey's post-test (ns, $p > 0.05$; **, $p < 0.01$).

Further The analysis showed that monocultured *C. gariepinus* fed on 35%, 30%, 28% or 25% CP for 182 days had significantly lower weight gains than those polycultured with *O.*

*niloticus* (Figure 4.10A-D; Unpaired t test, $p < 0.05$). These implied that polyculture comparatively led to better weight gain of C. gariepinus.

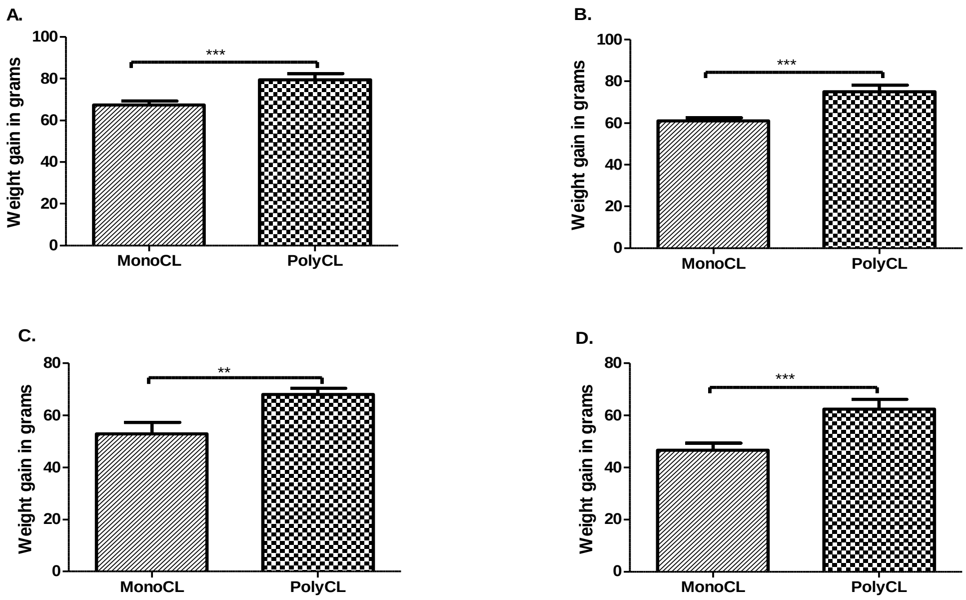


**Figure 4.9.Weight gains by*C. gariepinus* monoculture or polyculture with *O. niloticus* fed on different CP diets.** The fish were fed on 25% CP (**A**), 28% CP (**B**), 30% CP (**C**) or 35% CP (**D**) for 182 days.The bars represent the mean ± SEM. The weights were measured in triplicates fortnightly over the 182 day period. Statistical differences was determined using Unpaired t-test (**, $p < 0.01$; ***, $p < 0.001$).

Further, the weight gain by *C. gariepinus* was significantly higher than *O. niloticus* fed on the four CP diets (Figure 4.11; Unpaired t test, $p < 0.05$).

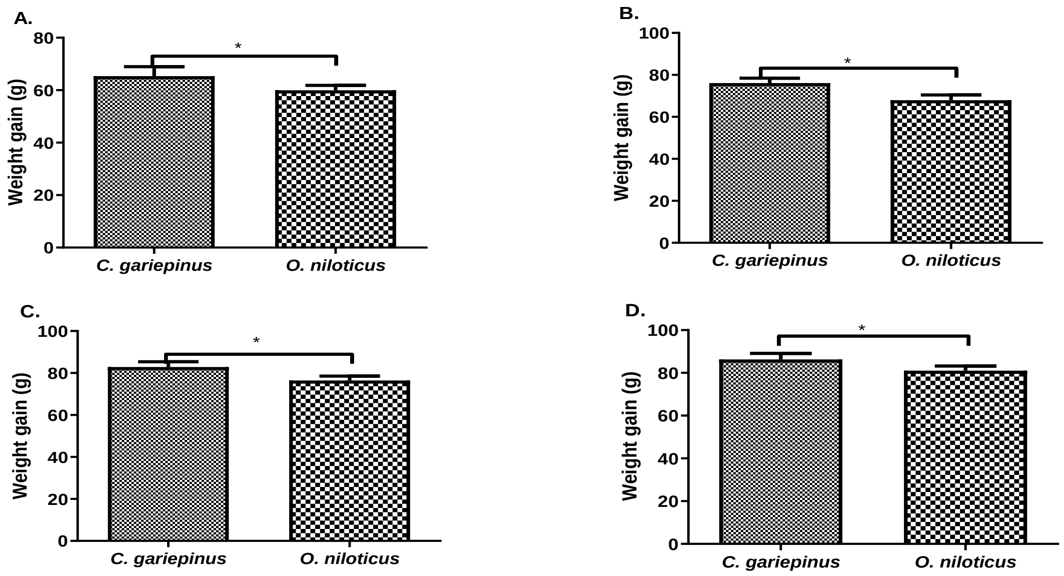


**Figure 4.10Weight gain by*C. gariepinus* and *O. niloticus* raised in polyculture and fed on different CP diets.**The weight gains of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured. The bars represent the mean ± SEM. The weight gains were calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (ns, $p > 0.05$; $p < 0.05$).

Further, the biomass gain by polyculture fed on 35%, 30%,25% CP were significantly higher than that of monoculture (Figure 12A-C; Unpaired t test, $p < 0.05$). Conversely, the biomass gains by monoculture and polyculture systems fed on 28% CP were not significantly different (Figure 12D; Unpaired t test, $p > 0.05$).

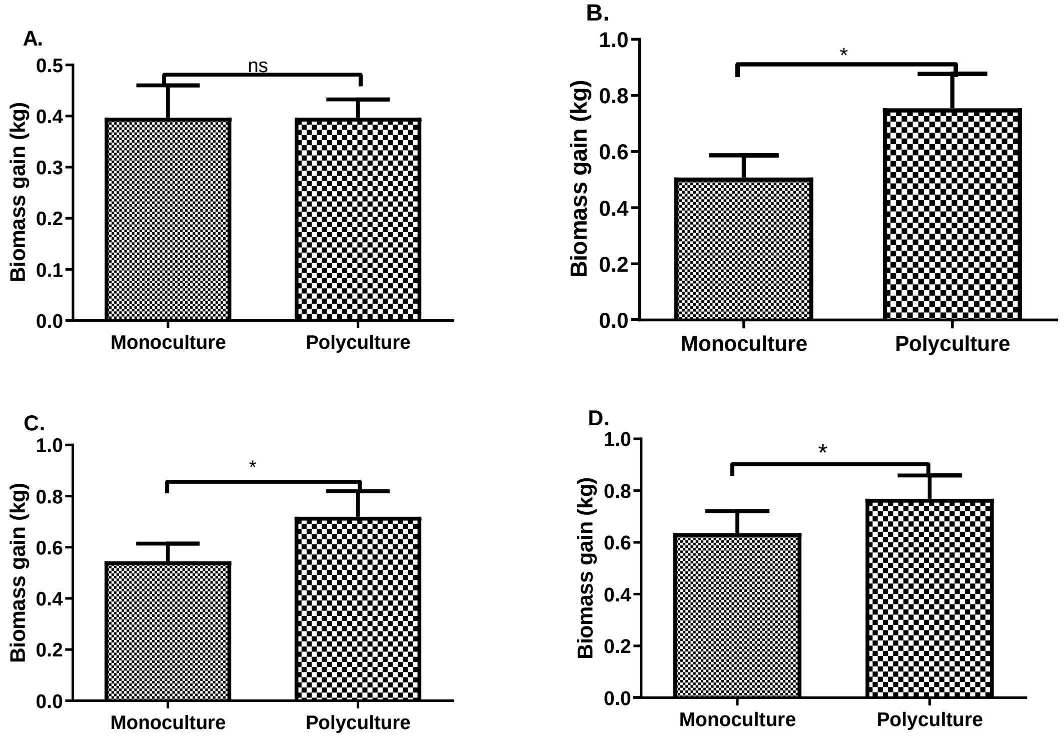


**Figure 4.11 Biomass gain by mono- and polyculture system fed on different CP diets.**The biomass gains of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The biomass gains were calculated in triplicates fortnightlyover the 182 day period. Statistical difference was determined using Unpaired t-test (ns, $p > 0.05$).

Further analysis revealed that monocultured *C. gariepinus* fed on 35%, 30%, 28% or 25% CP for 182 days had significantly lower % SGR in weight than those polycultured with *O. niloticus* (Figure 4.13A-D; Unpaired t test, $p < 0.05$). These data implied that polyculture comparatively gave better SGR in weight of C. gariepinus.

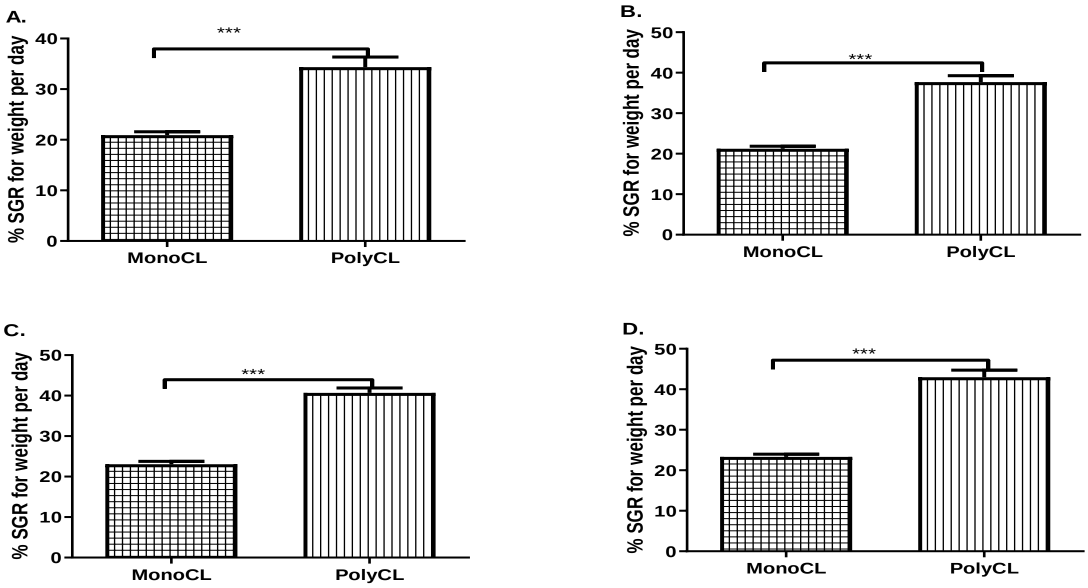


**Figure 4.12 SGR in weight of*C. gariepinus* monoculture and in polyculture with *O. niloticus* and fed on different CP diets.** The percent SGR in weight of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The SGR were measured in triplicates fortnightly over the 182 day period. Statistical differences was determined using Unpaired t-test (***, $p < 0.001$).

Further, the % SGR in weight for *C. gariepinus* was significantly higher than for O niloticus fed on 35%, 30% or 25% CP (Figure 4.14A-C; Unpaired t test; $p < 0.05$). However, no significant difference in % SGR per weight was observed between *C. gariepinus* and *O. niloticus* fed on 28% CP (Figure 4.14D; Unpaired t test; $p > 0.05$).

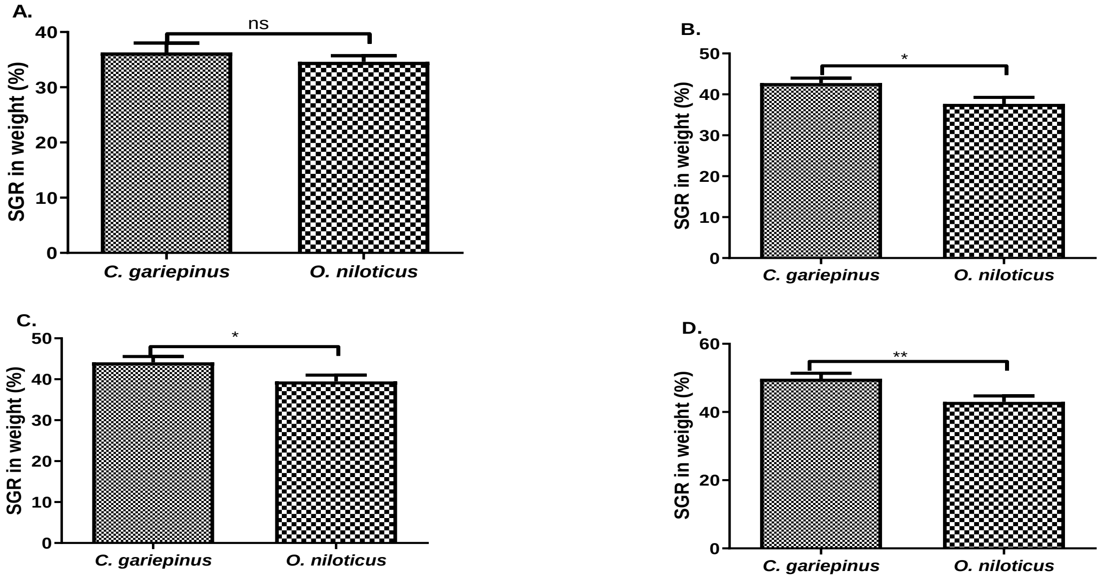


**Figure 4.13SGR in weight of *C. gariepinus* and *O. niloticus r*aised in polyculture and fed on different CP diets.**The percent SGR in weight of *C. gariepinus* fed on 25% (A), 28% (B), 30% (C) or 35% (D) CP diets were measured. The bars represent the mean ± SEM. The SGR in weight were calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (ns, p > 0.05; *, p < 0.05).

### 4.4.2 Feed conversion ratio

In this study, the FCR for the *C. gariepinus* in polyculture with *O. niloticus* fed on the four diets was assessed. The FCR of*C. gariepinus* raised either as monoculture or in polyculture with *O. niloticus* and fed on 25%, 28%,30% or 35%, CP for 182 days was not significantly different (Figure 4.15; Unpaired t test, p > 0.05). These data implied that the conversion of the CP diets by *C. gariepinus* was not affected by the rearing method.

In addition, the FCR of *C. gariepinus* and *O. niloticus* fed on 35%, 30%, 28% or 25% CP for 182 days were not significantly different (Figure 4.16; Unpaired t test, p > 0.05).

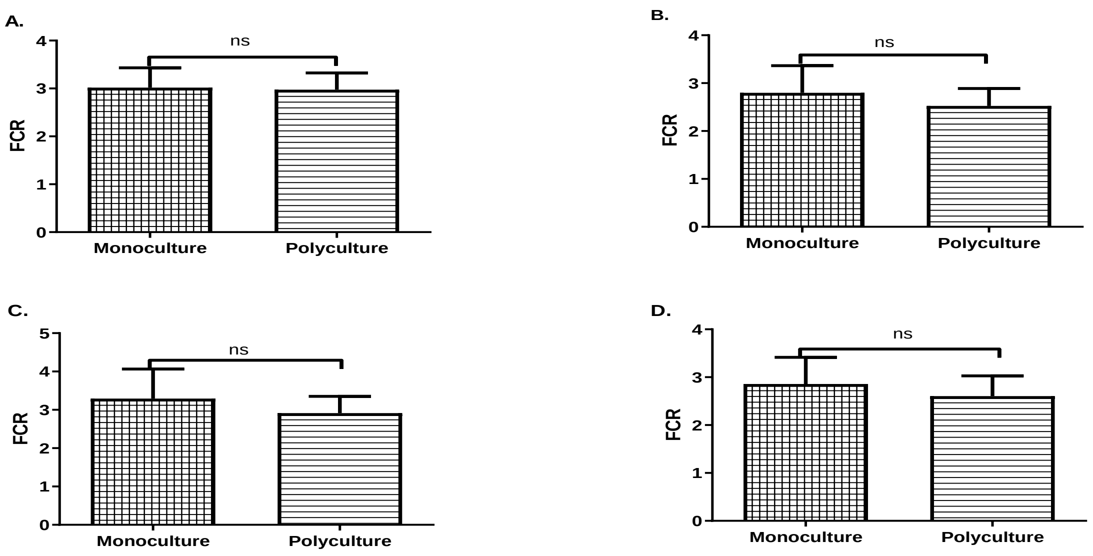


**Figure 4.14 FCR of mono- and polyculture systemsfed on different CP diets.** The FCR of fish fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The FCR were measured in triplicates fortnightly over the 182 day period. Statistical differences were determined using Unpaired t-test (ns, $p > 0.05$).

The FCR of *C. gariepinus* raised as either monoculture or in polyculture with *O. niloticus* fed on **25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**)** CP for 182 days was not significantly different (Figure 4.16; Unpaired t test, p > 0.05).

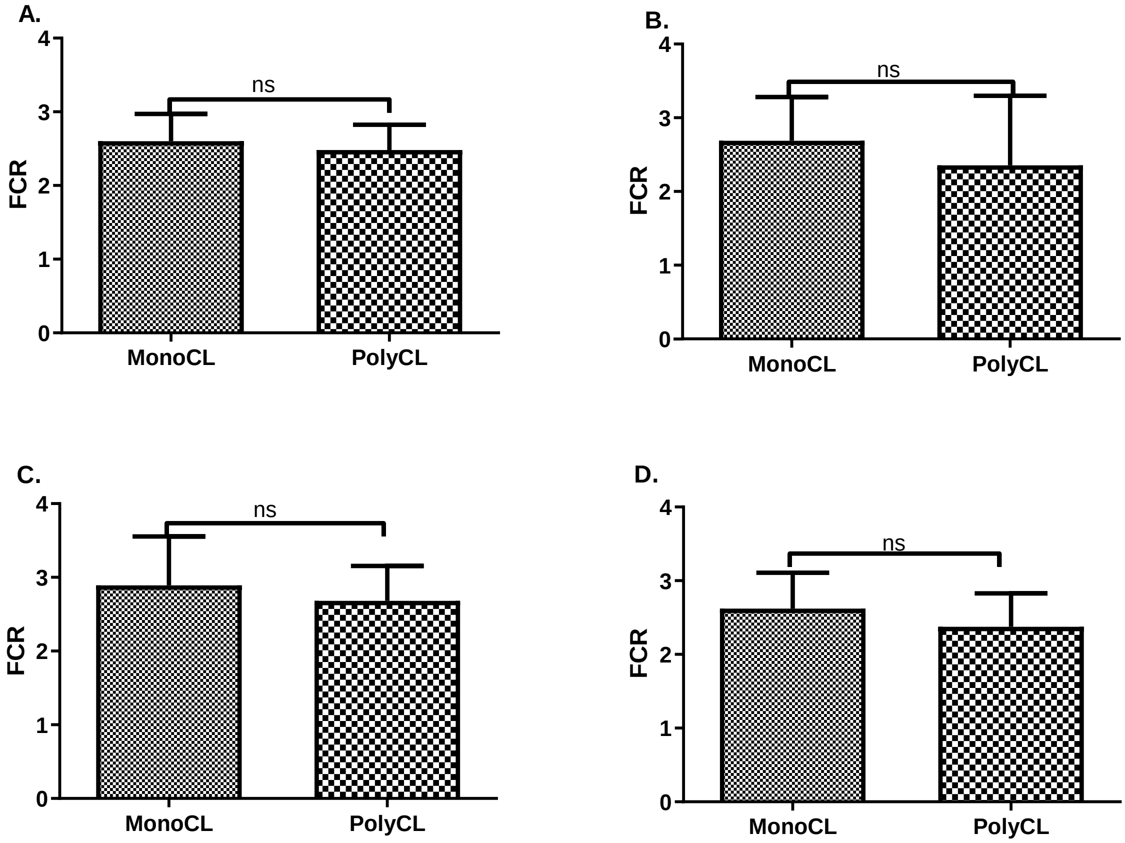


**Figure 4.15FCR of *C. gariepinus* in monoculture and in polyculture systems and fed on different CP diets.** The FCR of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The FCR were measured in triplicates fortnightly over the 182 day period. Statistical differences were determined using Unpaired t-test (ns, p > 0.05).

#### 4.4.2.1 Food Conversion Efficiency

In the present study, the FCE were also compared for different fish species or rearing systems. There was no significant difference in the percent FCE of fish raised under polyculture and monoculture systems (Figure 4.17; Unpaired t test, p > 0.05). Similarly, no significant differences in percent FCE were observed between *C. gariepinus* raised as monoculture or in polyculture with *O. niloticus* (Figure 4.19; Unpaired t test, p > 0.05). However, data revealed a significant difference in percent FCE of *C. gariepinus* and *O. niloticus* raised as polyculture system (Figure 4.20; Unpaired t test, p <0.05).

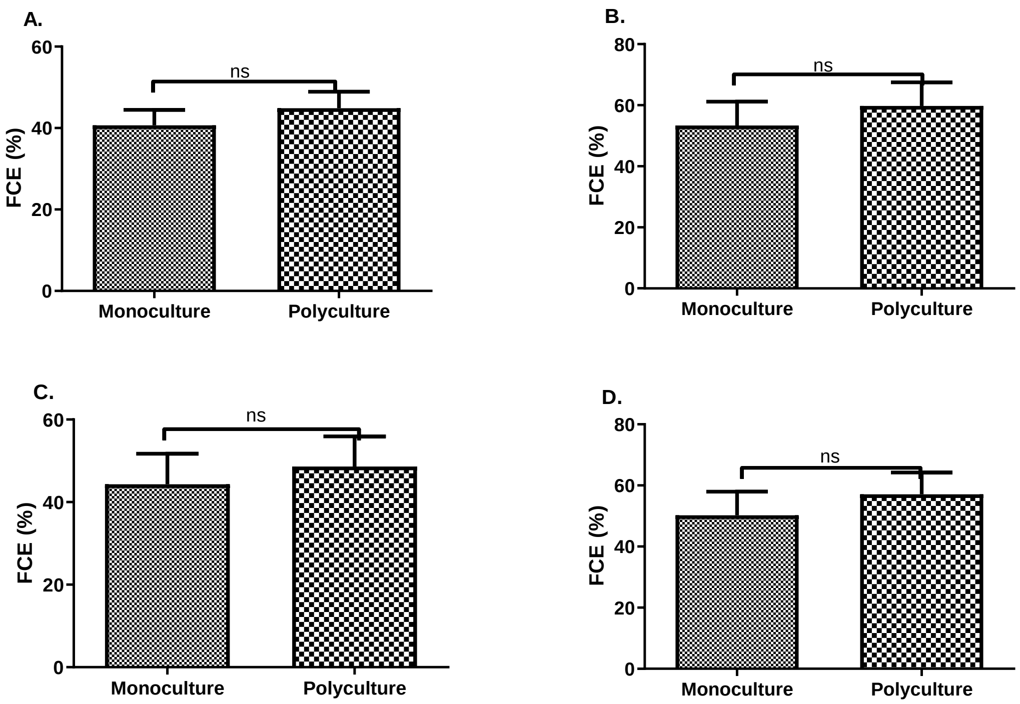


**Figure 4.16FCE of mono- and polyculture systems fed on different CP diets.** The FCR of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**)CP diets were measured.The bars represent the mean ± SEM. The FCE were measured in triplicates fortnightly over the 182 day period. Statistical differences were determined using Unpaired t-test (ns, p < 0.05).

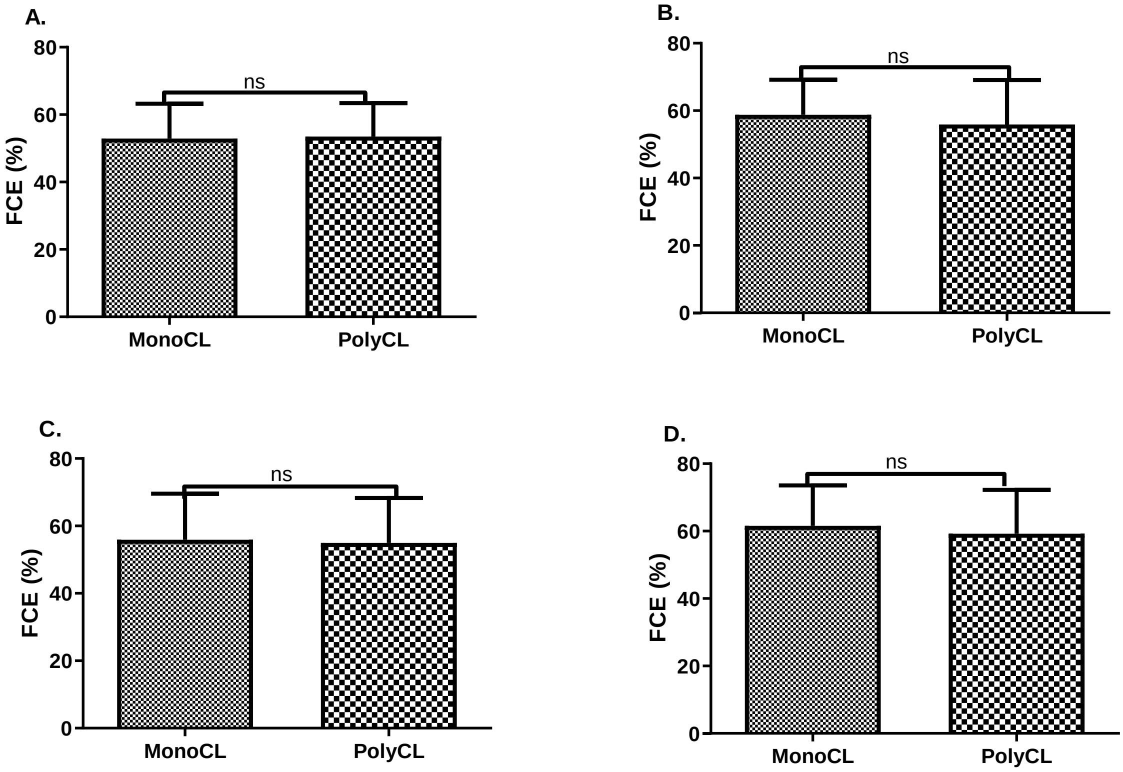


**Figure 4.17FCE of *C. gariepinus* in monoculture and in polyculture and fed on different CP diets.** The FCE of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**)CP diets were measured.The bars represent the mean ± SEM. The FCE were measured in triplicates fortnightly over the 182 day period. Statistical differences were determined using Unpaired t-test (ns, $p > 0.05$).

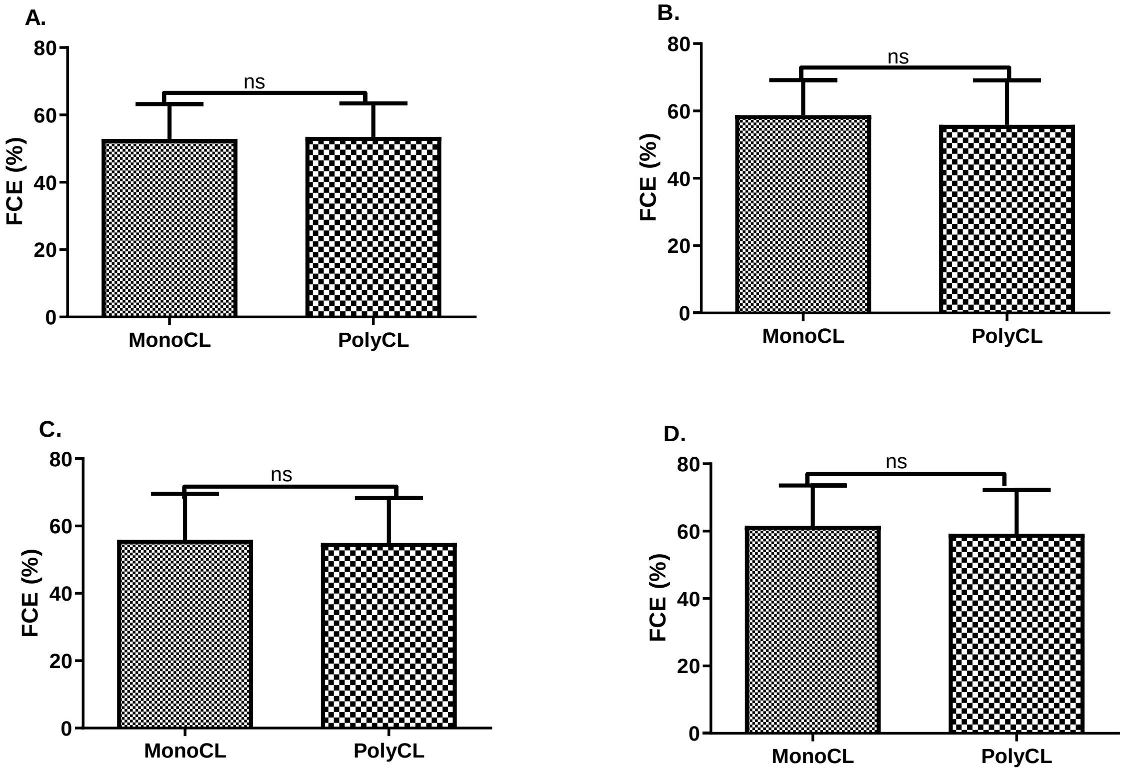


**Figure 4.18FCE of *C. gariepinus* and *O. niloticus*raised in polyculture and fed on different CP diets.** The FCE of *C. gariepinus* or *O. niloticus fed* on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The FCE were calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (*, $p < 0.05$).

### 4.4.3. Survival of fish in monoculture and in polyculture when fed on different CP diets

In present study, the survivals were compared for the mono- and polycultures fed on the four CP diets for 182 days. The analysis showed that the survival of monoculture on 35%, 30%, 28% or 25% CP is statistically similar to that of polyculture system (Figure 4.21; Unpaired t test, $p > 0.05$).

Moreover, no significant differences in percent survivals were observed between *C. gariepinus* raised as monoculture or in polyculture with *O. niloticus* (Figure 4.22; Unpaired t test, $p > 0.05$). Data further revealed that there is no significant difference in percent survivals of *C. gariepinus* and *O. niloticus* raised as polyculture system (Figure 4.23; Unpaired t test, $p > 0.05$).These data implied that the survival of monoculture or polyculture is on the four diets is comparably similar.

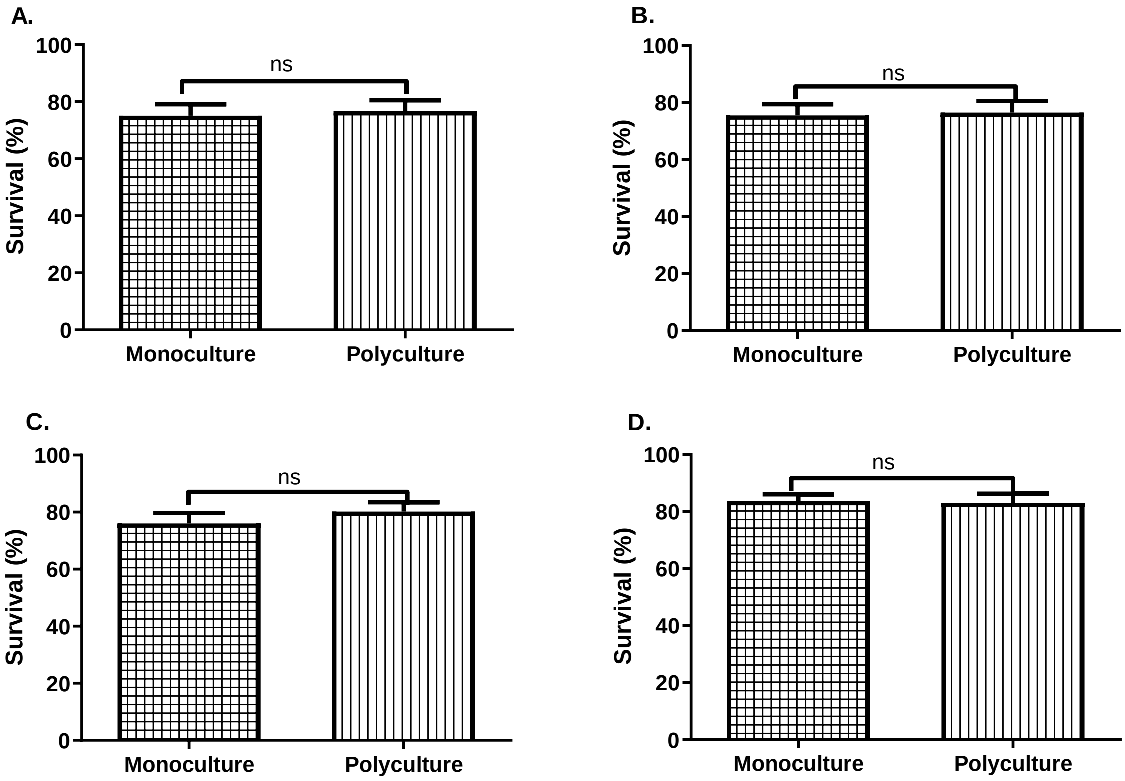


**Figure 4.19Survival of fish raised in mono- and polyculture and fed on different CP diets.** The percent survivals of fish fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**)CP diets were computed. The bars represent the mean ± SEM. The survivals were calculated in triplicates bi-weekly over the 182 day period. Statistical differences were determined using Unpaired t-test (ns, $p > 0.05$).

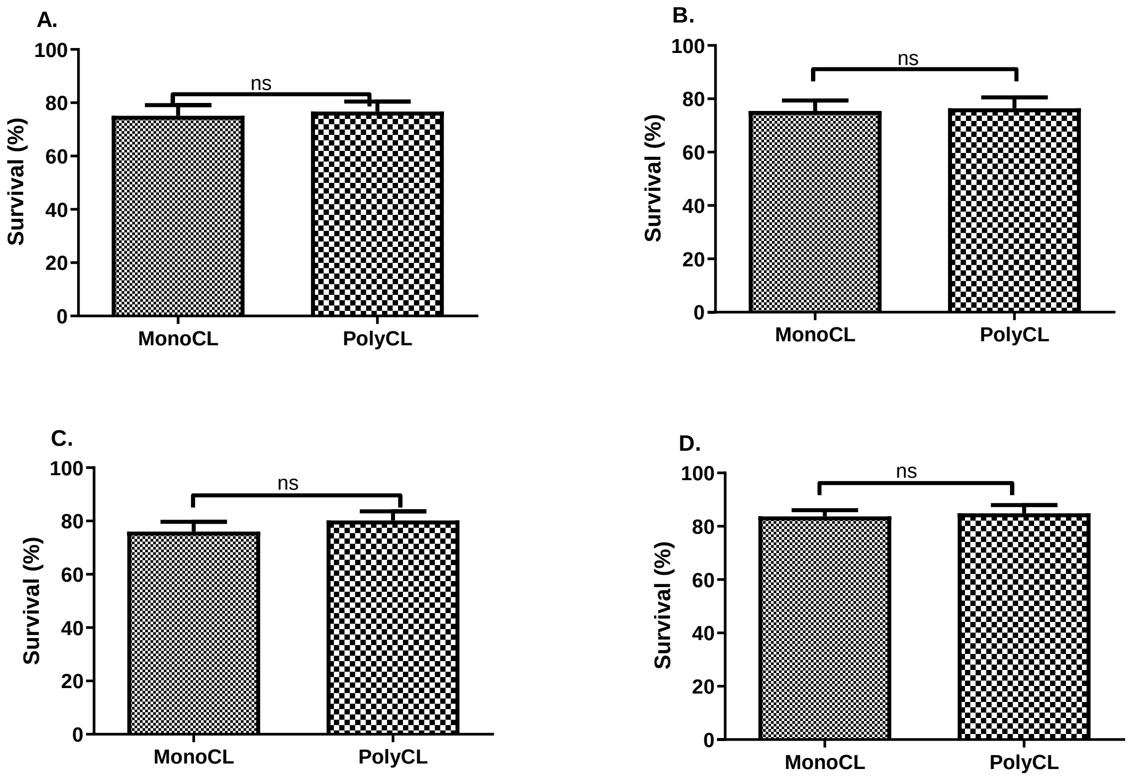


**Figure 4.20 Percent survivals of *C. gariepinus* raised in mono- and polyculture and different CP diets.** The percent survivals of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The percent survivals were calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (ns, $p > 0.05$).

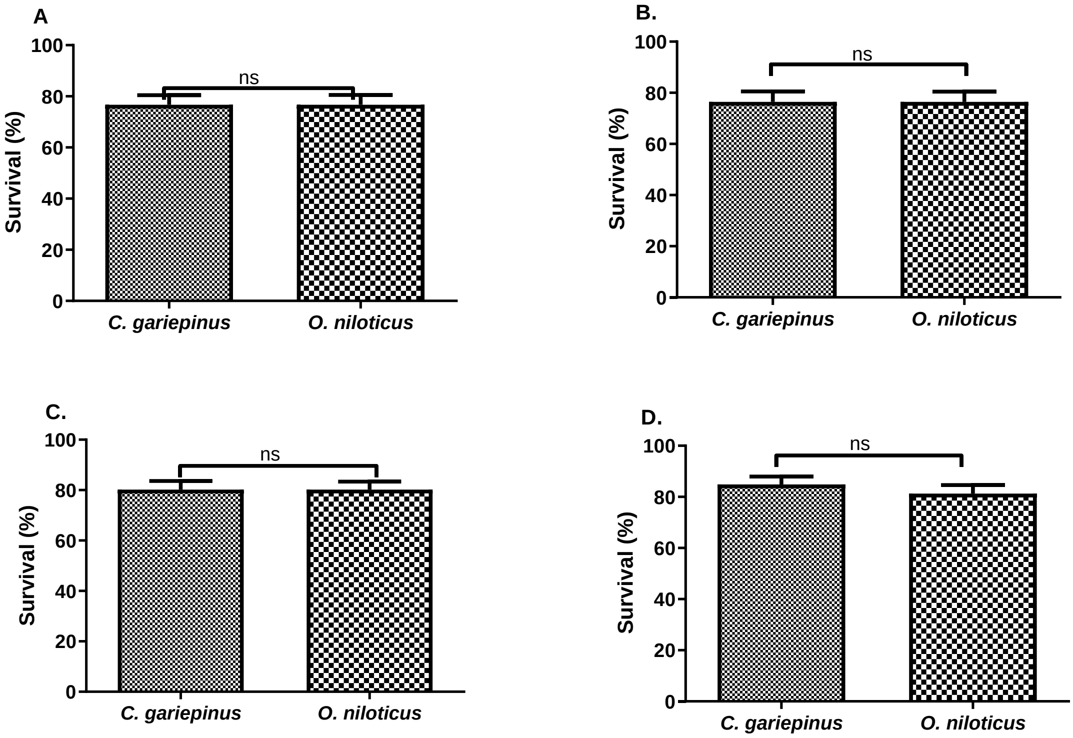


**Figure 4.21Percent survivals of *C. gariepinus* and *O. niloticus*raised in polyculture and fed on different CP diets.** The percent survivals of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The percent survivals were calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (ns, $p > 0.05$).

## 4.5. Economics of *C. gariepinus* culture under mono- and polyculture with *O. niloticus* farming systems in earthen pond

The third specific aim of the present study was to analyze the economics of raising *C. gariepinus* as monoculture or in polyculture with *O. niloticus* and fed on diets of different CP levels. Based on the price of each feed ingredient and the quantities that were required to make the different diets, the cost for one kilogram of each diet was calculated (Table 4.3). The feed ingredientprices used were the actual prices in open air market in Kisumu, Kenya.

**Table 4.3. Prices of ingredients used for formulating fish feeds for this study**

| Ingredients | Market price/kg | 25% CP | 30% CP | 35% CP |
|---|---|---|---|---|
| C. nilotica | 1.10 | 0.132 | 0.232 | 0.332 |
| Soy bean meal | 1.50 | 0.384 | 0.304 | 0.224 |
| Cotton seedcake | 0.80 | 0.084 | 0.148 | 0.212 |
| Wheat pollard | 0.25 | 0.408 | 0.320 | 0.272 |
| Vitamin and mineral premix | 6.00 | 0.06 | 0.06 | 0.06 |
| Cost of processing/kg | 0.10 | 0.10 | 0.10 | 0.10 |
| **Total cost of feed/kg** | | **0.840** | **0.960** | **1.083** |

**Note:** Prices are provided in USD.

Vitamin and mineral premix was added at 1% of the formulated feed.

#### 4.5.1. Cost benefit evaluation of monoculture and polyculture systems

In this study, cost-benefit analysis of each CP diet was analysed for monoculture and polyculture systems. The cost of production of a kg of *C. gariepinus* raised in monoculture was lowest for 35% followed by 30%, 25% and finally 28% CP diets (Table 4.4). The cost of production of a kg of *C. gariepinus* or *O. niloticus* was lowest for 35% followed by 30%, 25% and finally 28% CP diets (Table 4.4). A similar pattern was observed in polyculture system (Table 4.5). The polyculture system was more profitable compared to the monoculture system fed on the four CP diet levels.

**Table 4.4. A summary of cost benefit evaluation results of CP diets fed to monoculture system.**

| Parameter | 35% CP | 30% CP | 25% CP | 28% CP |
|---|---|---|---|---|
| Production period (days) | 182 | 182 | 182 | 182 |
| Stocking density (pieces) | 210 | 210 | 210 | 210 |
| Net production (Kg/182days) | 24.42 | 21.48 | 17.10 | 12.69 |
| Value of fish @ 3.5 USD/kg | 85.47 | 75.18 | 59.85 | 44.42 |
| Feed Input (Kg) | 16.36 | 14.39 | 11.46 | 8.50 |
| Cost of feed used | 17.72 | 13.81 | 9.63 | 8.50 |
| Cost of fingerling | 10.5 | 10.5 | 10.5 | 10.5 |
| Cost of hapa per cycle | 9.00 | 9.00 | 9.00 | 9.00 |
| Cost of pond hire & liming costs per kg of fish | 0.08 | 0.08 | 0.08 | 0.08 |
| Cost of fertilizer per kg of fish | 0.17 | 0.17 | 0.17 | 0.17 |
| Cost of labour | 52.5 | 52.5 | 52.5 | 52.5 |
| Total cost of production | 89.33 | 84.92 | 81.23 | 80.25 |
| Cost of production per kg | 3.66 | 3.95 | 4.75 | 6.32 |
| Gross profit | -3.86 | -8.74 | -20.38 | -35.83 |

**Notes**: The costs are presented in USD.

Fertilizer was applied at the rate of 2 g/m$^2$ CAN and 3 g/m$^2$ DAP at the beginning of the experiments.Gross profit is highly affected by the labour cost on fish feeding which was paid at the rate of USD 70 per month distributed across the production streams of mono and polyculture each of which had four treatments. This rate however was too high for the level of production under the current study thus resulted in negative gross profit.This can be dealt with by either adopting an economy of scale approach or family members doing the fish feeding, especially when the level of production remains low.

**Table 4.5. A summary of cost benefit evaluation results of CP diets fed to polyoculture system.**

| Parameter | 35% CP | 30% CP | 25% CP | 28% CP |
|---|---|---|---|---|
| Production period (days) | 182 | 182 | 182 | 182 |
| Stocking density (pieces) | 210 | 210 | 210 | 210 |
| Net production (Kg/182days) | 29.74 | 25.97 | 21.08 | 18.7 |
| Value of fish @ 3.5 USD/kg | 104.09 | 90.90 | 73.78 | 65.45 |
| Feed Input (Kg) | 19.92 | 17.53 | 14.12 | 12.54 |
| Cost of feed used | 21.57 | 16.83 | 11.86 | 12.54 |
| Cost of fingerling | 10.5 | 10.5 | 10.5 | 10.5 |
| Cost of hapa per cycle | 9.00 | 9.00 | 9.00 | 9.00 |
| Cost of pond hire & liming costs per kg of fish | 0.08 | 0.08 | 0.08 | 0.08 |
| Cost of fertilizer per kg of fish | 0.17 | 0.17 | 0.17 | 0.17 |
| Cost of labour | 52.5 | 52.5 | 52.5 | 52.5 |
| Total cost of production | 93.85 | 88.05 | 83.45 | 84.54 |
| Cost of production per kg | 3.16 | 3.39 | 3.96 | 4.52 |
| Gross profit | 14.24 | 3.85 | -8.67 | -19.09 |

**Notes**: The costs are presented in USD.

Fertilizer was applied at the rate of 2 g/m$^2$ CAN and 3 g/m$^2$ DAP at the beginning of the experiments.

Further, two other key economic parameters, namely profit index (PI) and economic conversion ratio (ECR) were evaluated.

### 4.5.2. Profit index (PI)

The PI was compared for the monoculture or polyculture fed on the four CP diets for 182 days.At a selling price of 3.5 USD per kilogram of fish, the analysis showed that the PI of polyculture is significantly higher than monoculture irrespective of the CP level of the diets

(Figure 4.26; p < 0.05). These data implied that feeding polyculture with25%CP, 28% CP 30%CP, or 35%CP, is more profitable than themonoculture.

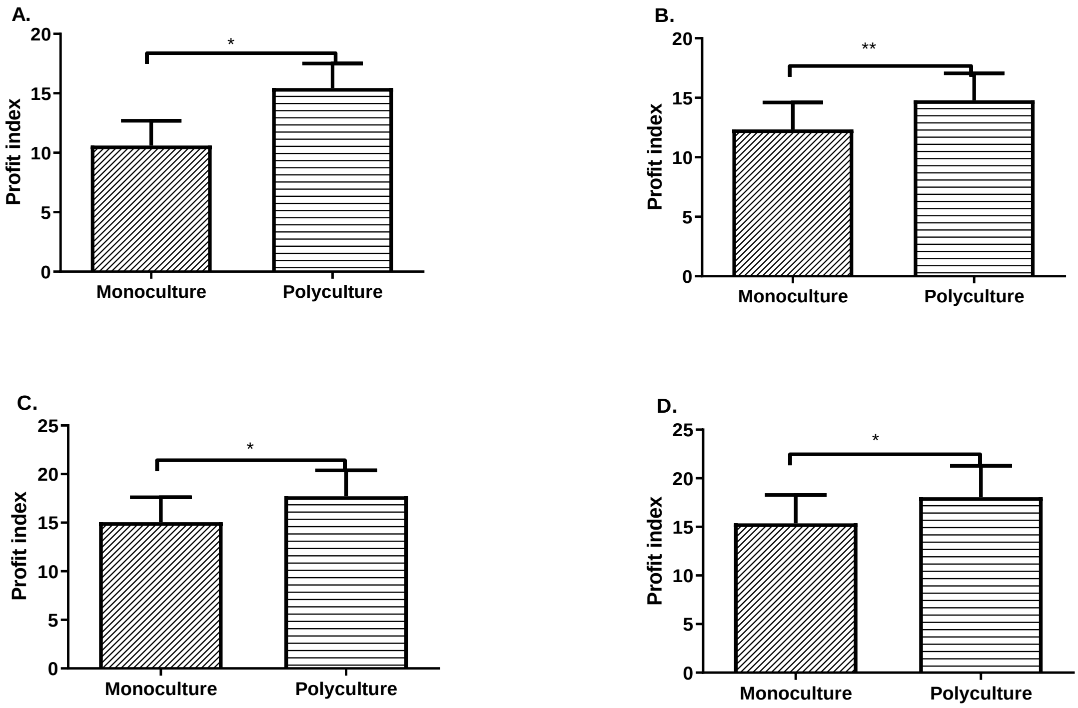


**Figure 4.22Profit index of mono- (C. gariepinus) and polyculture (*C. gariepinus* + *O. niloticus*) fed on varying CP diets.**The PI of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP dietsin mono- and polyculture with *O. niloticus* production were compared.The bars represent the mean ± SEM. The PI was calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (*, p< 0.05; **, p < 0.01).

The results further showed that *C. gariepinus* raised under polyculture and fed on 25% (A), 28% (B), 30% (C) or 35% CP (D)diets hadsignificantly higher PI than those raised in monoculture (Figure 24; Unpaired t test, p < 0.05).

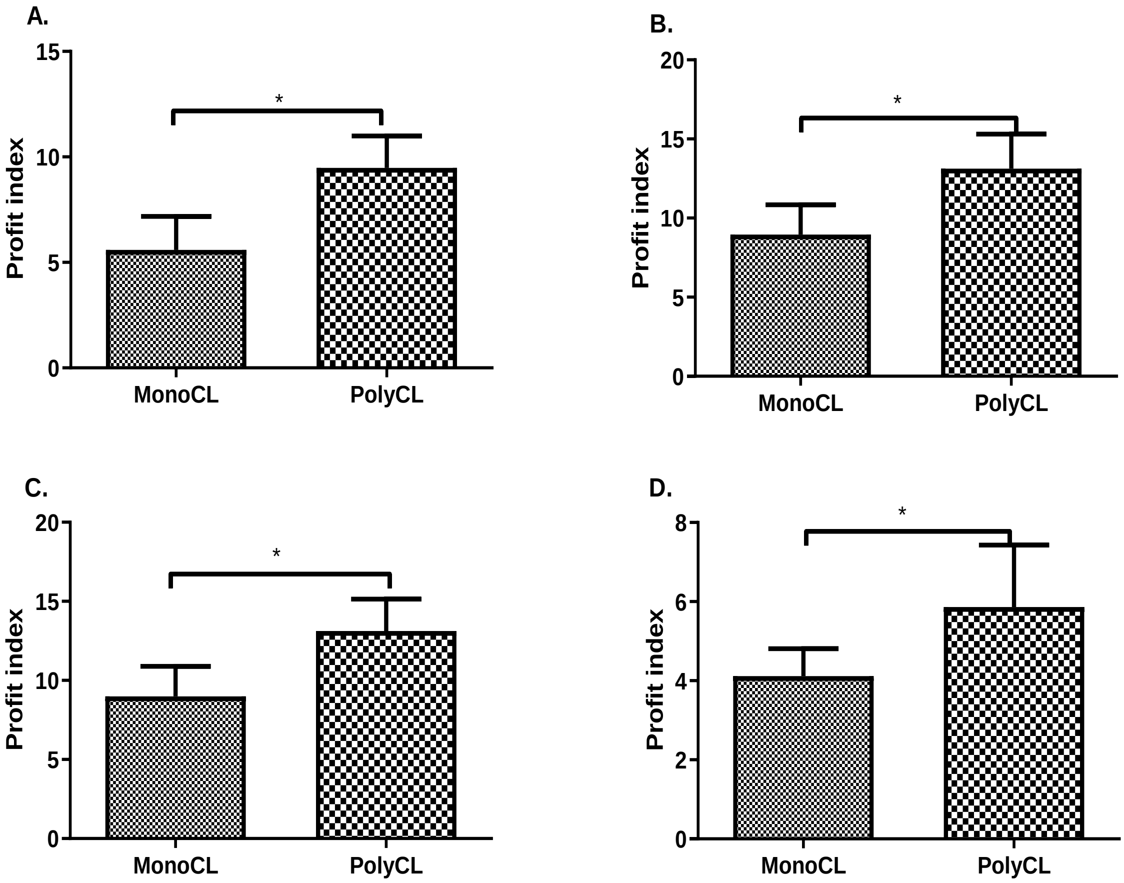


**Figure 4.23Profit index of *C. gariepinus* raised in mono- and in polyculture fed on different CP diets.** The PI of *C. gariepinus* in mono- and polyculture production fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**)CP diets were measured.The bars represent the mean ± SEM. The PI was calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (*, $p < 0.05$).

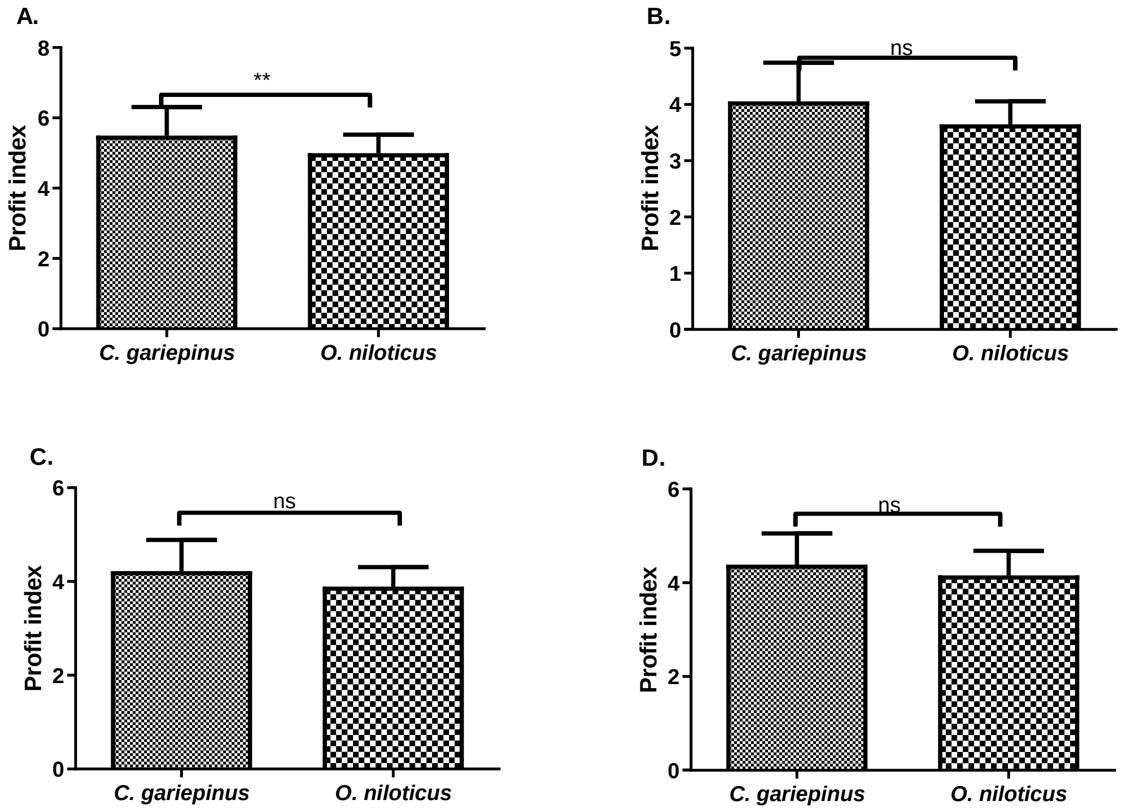


**Figure 4.24Profit index of *C. gariepinus* and *O. niloticus:*all produced in polyculture and fed on different CP diets.** The PI of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets were measured.The bars represent the mean ± SEM. The PI was calculated in triplicates bi-weekly over the 182 day period. Statistical difference was determined using Unpaired t-test (ns, $p > 0.05$; **, $p < 0.05$).

### 4.5.3. Economic conversion ratio (ECR)

The ECR were compared for the monoculture or polyculture fed on the four CP diets for 182 days.The analysis showed that the ECR for monoculture was significantly higher than that ofpolyculturefed on 25%, 28%, 30% or 35%CPfor 182 days (Figure 4.29; Unpaired t test, $p < 0.05$). These data implied that the ECR of monoculture of was higher than for polyculture regardless of the CP level of the diet. The higher ECR implies higher costs of production and therefore

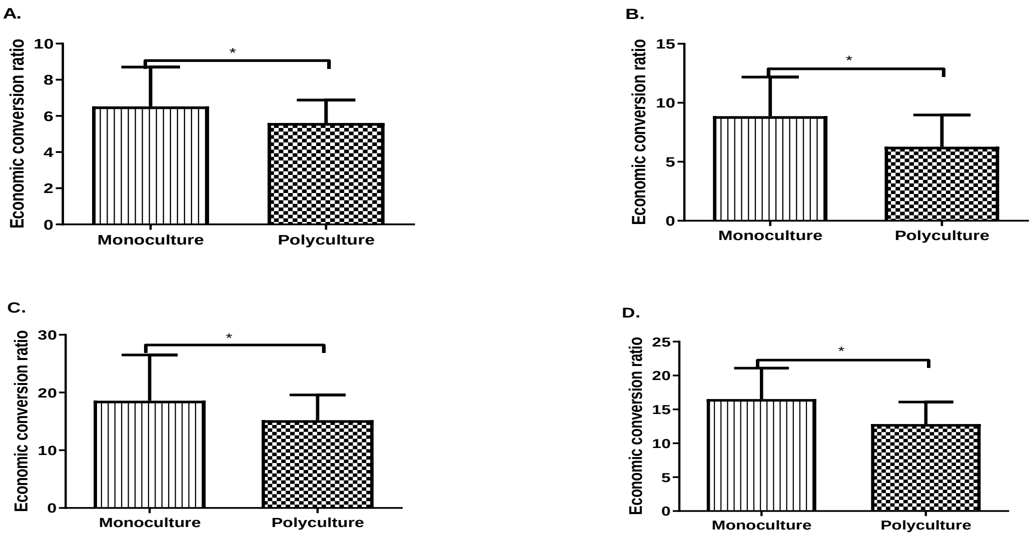


**Figure 4.25ECR of mono- (*C. gariepinus*) and polyculture (*C. gariepinus* + *O. niloticus* ) fed on different CP diets.** The ECR of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**) CP diets for mono- and total polyculture productions werecompared.The bars represent the mean ± SEM. The ECR was calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (ns, $p > 0.05$).

Further, the results showed that *C. gariepinus* raised as monocultures and fed on 35%, 30%, 25% or 28% CP had a significantly higher ECR than those raised in polyculture with *O. niloticus* (Figure 4.30; Unpaired t test, $p<0.05$). Further, the *O. niloticus* raised as fed on 35%, 30% 25% or 28% CP had a significantly higher ECR than *C. garipinus* (Figure 4.31; Unpaired t test, $p <0.05$). Taken together, these results indicated that it is cheaper and more profitable to raise *C. garipinus*in polyculture than in a monoculture system.

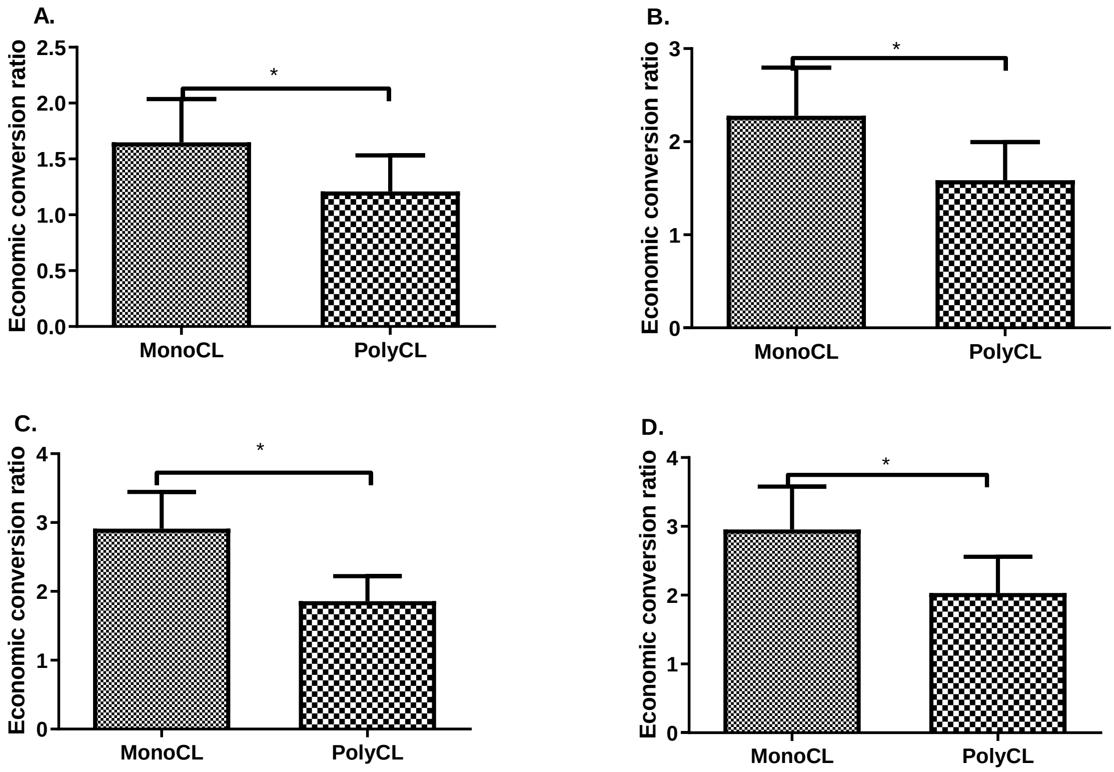


**Figure 4.26ECR of *C. gariepinus* raised in mono- and polyculture fed on different CP diets.** The ECR of *C. gariepinus* in mono- and in polyculture fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**)CP diets were measured.The bars represent the mean ± SEM. The ECR were calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (*, $p < 0.05$).

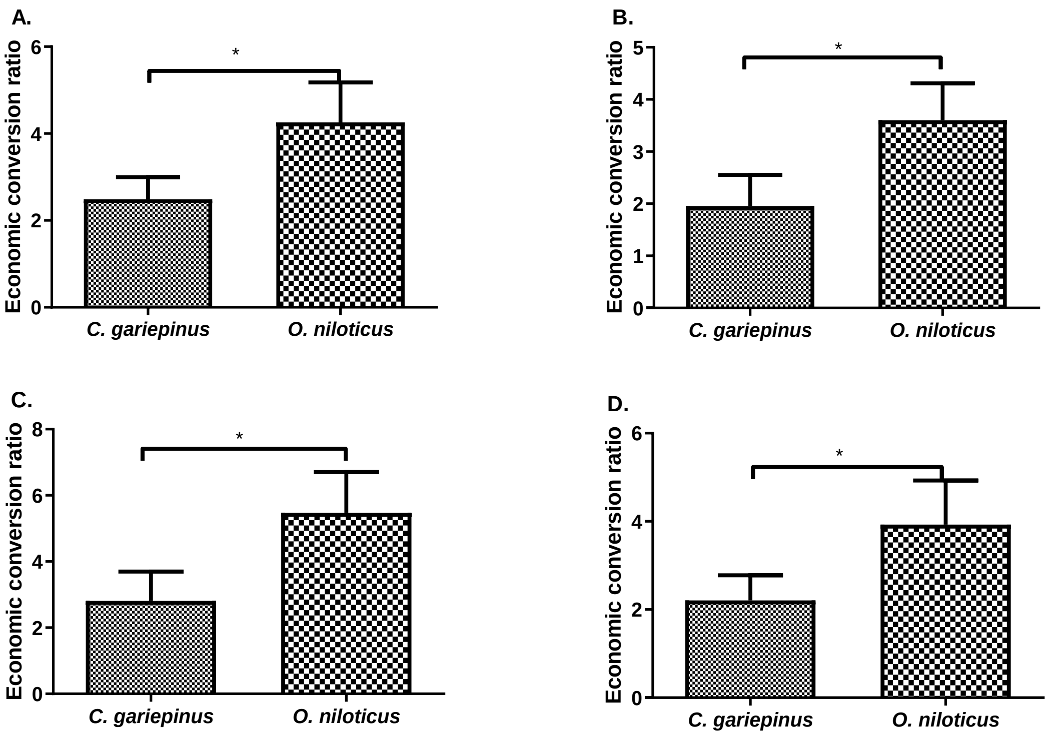


**Figure 4.27ECR of *C. gariepinus* and *O. niloticus* raised in polyculture and fed on different CP diets.** The ECR of *C. gariepinus* fed on 25% (**A**), 28% (**B**), 30% (**C**) or 35% (**D**)CP diets were measured.The bars represent the mean ± SEM. The ECR were calculated in triplicates fortnightly over the 182 day period. Statistical difference was determined using Unpaired t-test (*, $p < 0.05$).

### 4.6. Low protein level in*C. gariepinus* fry/larval to fingerling survival

The fourth aim of the present study was to determine the CP level that can contribute to better growth performance and survival of *C. gariepinus* fry/larvae to fingerlings.

#### 4.6.1 Physico-chemical parameters of water used for raising *C. gariepinus* tofingerlings

There was no significant difference in the physico-chemical parameters of the culture conditions among the four treatment groups at the beginning and end of the experiments (Table 4.6; Unpaired t test, $p > 0.05$). Of note, the parameters were within the acceptable standard limits. Taken together, the data presented show that all the larval culture conditions were similar and that only CP level was the independent variable.

**Table 4.6. The physico-chemical parameters of the treatment groups**

| Parameters | 25% CP | 28% CP | 30% CP | 35% CP |
|---|---|---|---|---|
| Temp (˚C) | 18.8±2.9 | 19.2±2.6 | 18.8±2.7 | 18.9±2.6 |
| DO ($mgL^{-1}$) | 6.3±0.8 | 5.8±0.7 | 5.8±0.8 | 6.2±0.9 |
| Cond.($\mu gcm^{-1}$) | 306.5±7.5 | 308.4±3.2 | 316.7±7.2 | 360.2±36.7 |
| TDS ($mgcm^{-1}$) | 61.1±5.2 | 55.7±0.5 | 56.3±5.0 | 55.1±8.7 |
| $NH_4$ ($\mu gL^{-1}$) | 302.5±56.9 | 305.5±92.8 | 325.8±31.9 | 308.6±51.3 |
| $NH_3$ ($\mu gL^{-1}$) | 41.3±6.9 | 38.1±4.4 | 42.2±6.7 | 45.8±4.4 |
| Nitrates ($\mu gL^{-}$) | 143.5±12.1 | 160.6±11.2 | 173.4±26.8 | 178.7±8.6 |
| Nitrites ($\mu gL^{-}$) | 92.1±6.3 | 92.6±4.5 | 89.5±3.5 | 87.2±2.2 |
| TP ($\mu gL^{-1}$) | 420.9±38.5 | 464.1±36.6 | 421.1±24.2 | 483.2±43.7 |
| Silicates ($mgL^{-1}$) | 4.3±0.3 | 3.9±0.2 | 4.2±0.4 | 5.3±1.4 |

**Note:** The values represent the mean ± SD taken during the experimental period.

### 4.6.2. Growth performance of larvae

The length gain of the fish larvae grown under different diets were significantly different (Figure 4.32A; One-way ANOVA; $p < 0.05$). Tukey's post-test revealed that larvae fed on 35% CP had the highest length gain (Figure 4.32A; $p < 0.05$). The mean length gain per day by fish larvae fed on the four diets followed a similar pattern (Table 4.7). Conversely, the weight gain of the fish larvae fed on the four diets was not significantly different (Figure 4.32B; $p > 0.05$). However, we observed that larvae fed on 35% CP showed significantly highest weight gain per day compared to the rest (Table 4.7; $p < 0.05$).

In the present study, no significant difference in SGR was observed among the fish larvae fed on the four diets (Figure 4.32C; $p < 0.05$). Further, throughout the study, the highest SGR was observed in larvae fed 35% CP (Figure 4.32D). Considered together, the findings implied that formulated feeds particularly 35% CP, contributed better to *C. gariepinus* larval growth than the commercial feeds.

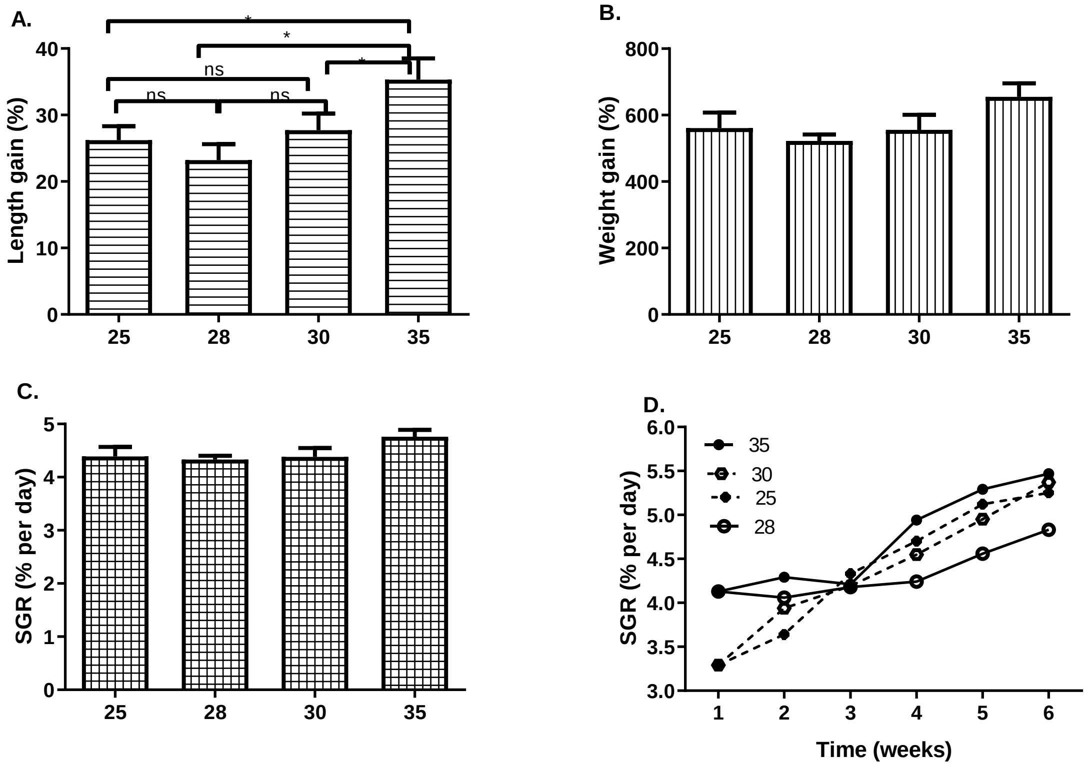


**Figure 4.28 Growth performance of *C. gariepinus* larvae fed on different CP contents.** The percent length gain (**A**), weight gain (**B**) and SGR (per day) (**C**) of larvae and SGR over the time (**D**) fed on diets containing 25, 28, 30 and 35%CP over a six-week period. Bars/plots represent mean ± SEM. The measurements were taken in triplicate every week. Statistical differences was determined using One way-ANOVA with Tukey's post-test (ns, $p > 0.05$; *, $p < 0.05$).

**Table 4.7.** The daily growth performance of fish larvae fed on different diets

| **Parameter** | 25% CP | *28% CP | 30% CP | 35% CP |
|---|---|---|---|---|
| Daily length gain (mm/day) | $0.15 \pm 0.01^{a}$ | $0.15 \pm 0.01^{a}$ | $0.17 \pm 0.01^{a}$ | $0.23 \pm 0.01^{b}$ |
| Daily weight gain (g/day) | $0.005 \pm 0.00^{a}$ | $0.005 \pm 0.00^{a}$ | $0.006 \pm 0.00^{a}$ | $0.006 \pm 0.00^{b}$ |
| Survival rate (%) | $75.00 \pm 1.40^{c}$ | $75.00 \pm 1.40^{c}$ | $80 \pm 1.60^{b}$ | $70.00 \pm 1.60^{a}$ |
| FCR | $0.823 \pm 0.05^{a}$ | $0.823 \pm 0.05^{a}$ | $0.830 \pm 0.05^{a}$ | $0.706 \pm 0.05^{a}$ |

*28% CP: commercial and control diet

**Note:**Different letters per row represent statistically significant difference between the different diets as determined by one-way ANOVA with Tukey's post-test ($p < 0.05$).

### 4.6.3. Feed utilization and survival rate of larvae

In the present study, feed utilization by the fish larvae was quantified in terms of the FCR. There was no significant difference in the FCR of larvae fed on the four diets (Table 4.7; One way-ANOVA, $p > 0.05$). However, the FCR increased gradually over the six-week period for the fish larvae fed on the four diets with 35% CP showing a considerably higher FCR (Figure 4.33).

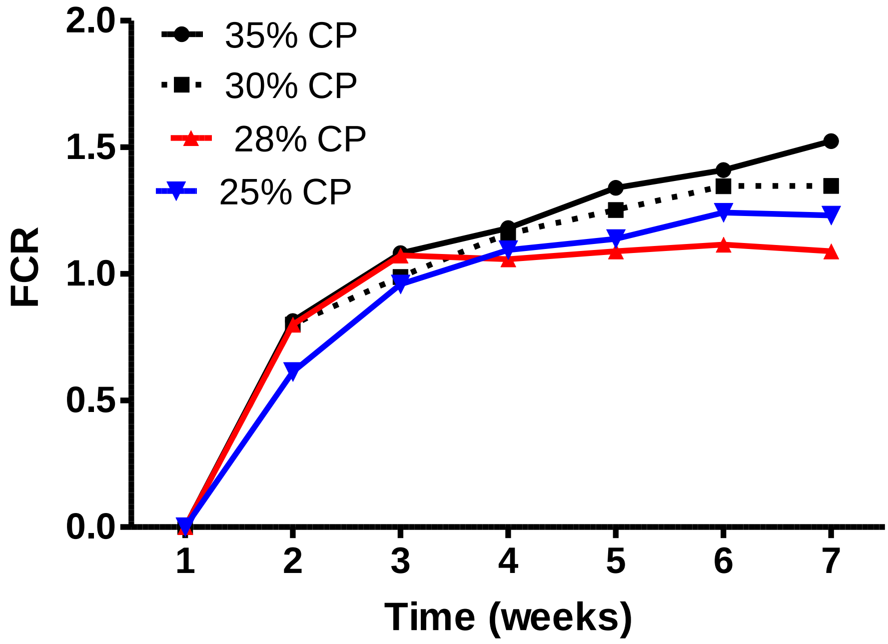


**Figure 4.29 The FCR of *C. gariepinus* larvae fed on four diets.**The FCR of *C. gariepinus* larvae fed on 25%, 28%, 30% or 35%CP over a six-week period were calculated. The FCR were calculated in triplicates weekly over a six-week period. The experiments were conducted in triplicate. Each plot represents the mean ± SEM.

The survival rate of the fish larvae grown under different diets were significantly different (Table 4.7; One way-ANOVA, $p < 0.05$). A post hoc analysis revealed that larvae fed on 35% CP had the highest length gain ($p < 0.05$), followed by 30% CP, 25% CP and 28% CP in that order ($p < 0.05$; Table 4.7). However, the mean survival rate per week was considerably highest for 35% CP (Figure 4.34). These findings implied that the survival rate is not dependent on the level of CP.

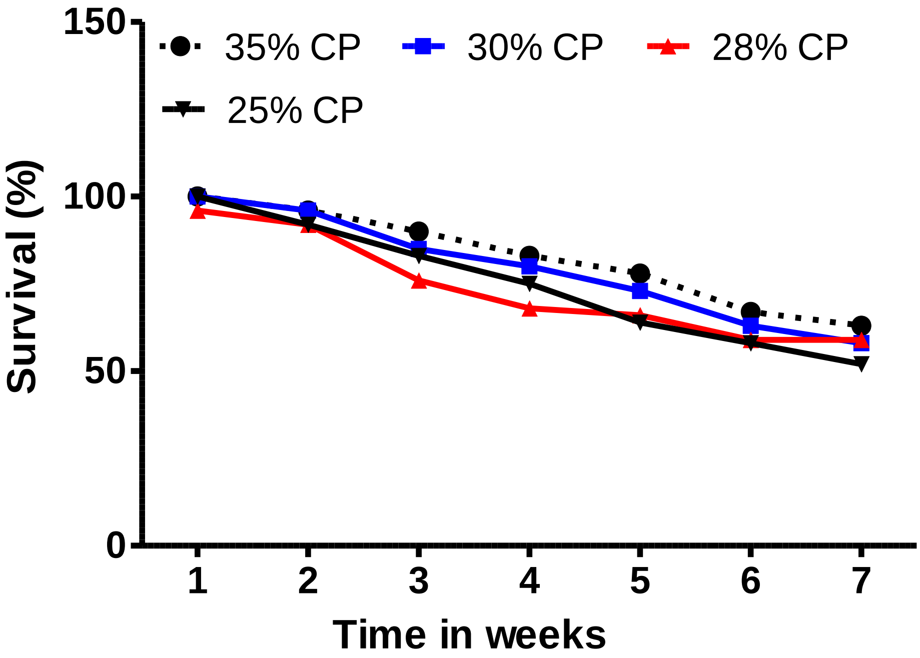


**Figure 4.30Survival rate of *C. gariepinus* larvae fed on different diets.**The percent survival of fish fed on 25% CP, 28% CP, 30% CP or 35% CPwas calculated weekly. The experiments were conducted in triplicate. Each plot represents the mean ± SEM.

# CHAPTER FIVE

# DISCUSSION

## 5.1. Water quality parameters

### 5.1.1. Water quality parameters in hapas-in-earthen pond

Water quality is of prime importance in fish culture systems for optimal growth, survival and reproduction. Thus, any evaluation of the growth performance, survival or reproduction of fish must take a record of water quality data in the experimental set ups. Several water quality parameters were monitored fortnightly over the entire growth period of *C. gariepinus* in hapas. There were no significant differences between the physic-chemical parameters for the hapas used for mono- and polyculture experiments regardless of the CP levels. These physico-chemical parameters of water met the standards required for the growth of *C. gariepinus*, i.e. atemperature between 17°C and 32°C (Hecht et al., 1988); pH between 6.5-9.0 (Hepher & Pruginin, 1981); dissolved oxygen content ≥ 3 mg/L(Viveen et al., 1985); nitrite content <250 mg/L (Viveen et al., 1985), followed by a nitrate content of 0.2-10 mg/L (Boyd, 1998). The ammonium content in that study washigher than the norm of 0.05 mg/L(Viveen et al., 1985). Edea et al. (2018) conducted a similar study on growth performance of *C. gariepinus* in tanks and cages fed on commercial feeds. All water parameters were within acceptable range except t for ammonium, nitrate and nitrates which were higher than the normal ranges. This was due to the use of high crude protein levels (45%) in the feeds. The present study did not suffer from the high nitrogenous species products since the aim of the study was to go low on protein.According to Cao et al. (2007) ammonia is the main nitrogenous waste produced by aquatic animals, via metabolism, and is excreted through the gills, hence is affected by the higher protein content in the diet.

### 5.1.2. Water quality parameters in aquarium tanks

There were no significant differences between the physic-chemical parameters for the hapas used for mono- and polyculture experiments regardless of the CP levels. The present findings suggest that water quality is not affected by the diets used. Further, the fish excreta after feeding on this diet did not affect the water quality. These physico-chemical parameters of water met the standards required for the growth of *C. gariepinus*, temperature is the most important variable affecting the growth of larvae and early juveniles (Ajiboiye et al., 2015). However the experimental temperature was below the range and must have affected growth,it fell between 17°C and 32°C (Hecht et al., 1988); pH between 6.5-9.0 (Hepher & Pruginin, 1981); dissolved oxygen content ≥ 3 mg/L (Viveen et al., 1985); nitrite content <250 mg/L (Viveen et al., 1985), followed by a nitrate content of 0.2-10 mg/L (Boyd, 1998). The ammonium content in the present study was higher than the norm of 0.05 mg/L (Viveen et al., 1985). The present findings are consistent with a report from Edea et al. (2018) except for ammonium, nitrate and nitrates which were higher than the normal ranges. The discrepancy between the present study and that of Edea et al. (2018) could be due to the high CP diets of 45% that was used. According to Cao et al. (2007) ammonia is the main nitrogenous waste produced by aquatic animals, via metabolism, and is excreted through the gills, hence is affected by the higher protein content in the diet.

However, fish are sensitive to unionized ammonia and the optimum range is 0.02 mg/L to 0.05 mg/L in the pond water. The water DO and pH are important factors in water quality with influence over other nutrients. In indoor culture, high feeding rates may contribute to increase of uneaten feed and together with fish wastes can cause a significant deterioration in water quality. This could be the reason for high nitrogen and phosphorus elements measured. However, the frequent cleaning of the containers and the replacement of water ensured maintenance of good water quality.

When concentrations of ammonia and nitrite exceed the recommended guidelines, toxicity effects can affect growth rates (Bitz & Hechts, 1987). In the present study the rate of pollution due to the burden of crude protein was minimized by aeration and use of low crude protein feed. Lack of uptake of available soluble P may result in high concentration in indoor setup, but often much high nitrogen and phosphorus in outdoor ponds results from application of fertilization and manure. The formulated feeds were nutrient – dense in order to reduce the output of solid, phosphorus and nitrogen waste (Wanatabe, 2002) as this also contributes to improved water quality in fish culture systems.

### 5.2. Growth performance of *C. gariepinus* fed on different CP diets

In the present study, growth performance of *C. gariepinus* fed on theexperimental diets,weresignificantly higher than those fed on the control feed containing 28% CP. For instance weight gain at 30 and 35% CP were significantly higher ($p < 0.001$). In regard to SGR, 35% CP diet performed significantly higher ($p < 0.001$) than the commercial diet. Moreover in terms of length gain, 30 and 35% CP performed significantly better ($p < 0.001$) than control diet.The feed conversion was found **not**to be significantly different among the CP diets. The present findings suggest that the formulated diets contain suitable amounts of nutrients required by *C. gariepinus* to grow than the commercial feed used in the study. It is possible that the amount and ratios of the ingredients used in the commercial feed are not optimal resulting in the poor performance. The present findings concur with a previous report on growth performance of *C. gariepinus* fed on different CP diets(Omeru & Solomon, 2016), but not on the feed conversion efficiency. The present observation that growth performances of *C. gariepinus* were influenced by the CP levels is consistent with several previous reports on*C. gariepinus* (Mwangi et al. 2018; Yakubu et el. 2015). More specifically, Diyaware et al. (2009) reported that growth rate and weight gain increased progressivelywith dietaryprotein level to a maximum of 50%. However Diyaware et al. (2009) worked with hybrid catfish fry and therefore the result of the present study should be taken with caution since the genetic background of the broodstock species were not determined. Moreover, the present study contradicts a previous report, which showed that *C. gariepinus* fed on different CP levels had no significant difference in growth performance (Effong & Esenowo, 2018). The discrepancy between the present and previous outcomes could have arisen from the possibility that the CP level were above the upper thresh hold (40 -50%) acceptable for fish growth.The use ofhigh CP levels may be too costly to farmers thus not easily embraced.In thepresent study, the most significant growth performance wasobserved in fish fed 35% CP. Further, the differences observed between the present findings and the previous could be explained by the intraspecific differences, the varieties of methodology, such as feedformulation and feeding rate tests,or culturesystem used in individual experiment.

The present study showed that the survival of *C. gariepinus* is not dependent on the CP level of the diet within the working CP range. The survival rates were within the 70% survival commonly registered in many hatcheries in Kenya (Opiyo et al., 2018). Survival of fingerlings is a function of acclimatization, stocking densities, genetics, predation **and geographical issues**. Considering that most of these factors were similar to what exist in most hatcheries in Kenya, the higher values recorded in this study could be attributed to the quality of the CP diets used in this study. The survival percentages of the present study are comparable to those of Opiyo et al. (2015) working on Indonesian strain of *C. gariepinus*.However the same study involved two other strains of *C. gariepinus*, Dutch and Kenyan with survival rates of 36.22 and 23.28% respectively fed on commercial catfish starter feed 45 % crude protein in a hatchery tank environment.

In thisstudy,the grow out survival was not significantly different between treatments indicating that low CP of 25% could be used to achieve similar survival rates at much lower production cost as depicted in Table 4.3.

### 5.3. Growth performance and survival of*C. gariepinus* in monoculture or in polyculture with *O. niloticus*

The *C. gariepinus* in polyculture with *O. niloticus* had better growth performance or biomass than those raised as monocultures irrespective of the CP levels of the diets.The higher performance of polyculture system could be explained in relation to the fact thatuse of polyculture system maximizes production of fish from different levels of the food chain (Akpaniteaku et al., 2005). The technology also enhances nutrient utilization efficiency in the culture unit with consequent maximum fish growth and yields (Lin et al., 1997).The present finding concurs with a previous report in which the growth performance polyculture (*C. gariepinus* and *O. niloticus*) was found to be higher than the monoculture (Shoko et al., 2014). The present findings are also comparable to previously reported findings in which polyculture was found to perform better than the monoculture system (de Graaf et al., 1996a; Isyagi 2005). Furthermore, the present findings are in agreement with two previous report in which monoculture of the *C. gariepinus* or *O. niloticus* species yielded the lowest growth indices (weight gain and SGR), while the performance of *C. gariepinus* in the polyculture systems were higher than those of tilapia (Haruna & Ipinjolu, 2013). However, the previous reports utilized male and female tilapia which might have boosted the yield of *C. gariepinus* which fed on the tilapia fingerlings. Moreover, theprevious report also evaluated effect of different stocking ratios on the growth performance but not the feed content. The present study used a stocking ratio of 1:1 as opposed to the recommended 1:3 for *C. gariepinus* to *O. niloticus* . The 1:3 is recommended for mixed sex *O. niloticus* culture. The present study has demonstrated that a stocking ratio of 1:1 it is possible for mono-sex *O. niloticus* in a polyculture fed on low CP diets to yield good results. Considering that most aquaculture ventures in Kenya mostly involve mono-sex tilapia, the previous studies may not fully inform on the performance of polycultures. In many experimental set-ups polyculture of *C. gariepinus* involves mixed sex tilapia, hence the growth performance of *C. gariepinus* is often associated with their feeding on the tilapia fingerlings. In the present study, mono-sex tilapias were used yet the polyculture system was still higher. The present findings strongly suggest that the low CP diet is capable of giving favourable yield. Taken together, the present findings suggested that *C. gariepinus* has a capacity to accept and utilize low protein diets formulated from available materials to perform optimally in a polyculture system.

### 5.4. Economics of raising *C. gariepinus* in monoculture or in polyculture with *O. niloticus*

Aquaculture as a farming enterprise requires inputs e.g. feeds, fingerlings, water, labour, technical skills, land space. The products may be for subsistence or commercial use. Good returns may be realized through economy of scale.

In all CP levels tested, economic indices including PI and ECR and cost-benefit analyses were significantly higher for polyculture than for themonoculture system. Higher economic benefits from polyculture can be attributed to niche partitioning, which allows for coexistence of the two species and hence increase in the feed utilization. In addition, dead, weak or small *O. niloticus* are consumed by catfish thus increasing the biomass of the latter, which contribute into the combined yield of *O. niloticus* and *C. gariepinus*. In a polyculture, the loss of *O. niloticus* biomass is replaced by more or equal biomass of *C. gariepinus* which feed on them (de Graaf et al., 1996a).In the present study, negative or marginal gross profits were realized but with lower values for the polyculture system. A plausible explanation for the marginal profits or losses is that the venture performed economic analysis for the initial cycle of production. Initial cycle is generally expensive due to high capital involved e.g. in purchasing the hapa nets. In a multiple cycle economic analysis the current setup would show significantprofitability. The present findings are consistent with a previous report in which *C. gariepinus* fed on diet 1 (40% CP), diet 2 (42.5% CP), diet 3 (45% CP), diet 4 (47.5% CP) and diet 5 (50% CP)were found to have similar economic indices (Effong & Esenowo, 2018). Further, the present findings on higher economic performance for polyculture of *C. gariepinus* with *O. niloticus* than the monoculture are consistent with previous reports (Shoko et al., 2016). However, the previous reports by Effong and Esenowo (2018) and Shoko et al. (2014) evaluated high CP levels or did not compare mono or polyculture systems of rearing *C. gariepinus*. The low magnitude of the economic indices of the present study in comparison to the two previous studies could be explained by the differences in the ingredients, cost of the ingredients in the countries where the studies were conducted or feeding rate. The observed lower ECR of fish in polyculture fed on the four CP diets probably pointed that these dietary protein levels may be suitable in economic terms for polyculture than monoculture. Of note, the significantly higher PI of polyculture fed on four CP diets than monoculture suggests that lower CP diets are more profitable in polyculture systems. Whereas polyculture is more profitable than the monoculture, majority of fish farmers in Kenya and other East African countries such as Tanzania practice monoculture (Shoko et al. 2005, 2011). The results of this study suggest that farmers can maximize profit from fish farming by adopting polyculture systems.

### 5.5. Low protein level in*C. gariepinus* fry/larval to fingerling survival

In this study *C. gariepinus* larvae weight and total length significantly increased during the six weeks experimental period with the highest mean weight gain observed on fry feed on CP 35%. The high growth rate could be attributed to the high nutritional composition of the feed meal with 35% crude protein. However the experimental indoor temperature in the present study was not within the optimal temperature range of 26 – 33$^{\circ}$C. In general, rearing of *C.*

*gariepinus* larvae during 42 days in this experimental study setup, exhibited growth of between 55.6% and 67.2% of the length and weight respectively. *C. gariepinus* larvae under the 35% CP diets exhibited positive allometric growth compared to the rest of the treatments. The larvae fed the experimental diets recorded better SGR than those fed the control diet. Larvae fed the highest 35% CP diet recorded the highest survival rate and considerably high FCR.

Good quality fish feeds are necessary aquaculture inputs to address the challenges of lack of efficient and inexpensive farm made feeds for different stages of fish development. The most commonly used feed ingredients are C. nilotica and R. argentea, with wheat or rice bran, sunflower or cotton seed cake and cassava as binders (Boyd, 1998). The major ingredients (sunflower seed cake, cotton seed cake, C. nilotica, wheat pollard) CP content ranged from 14 % to 60 % (with a high dry matter of 91 % to 94 % content) (Boyd, 1998), as found in this study's proximate analysis. Evaluation of some of the most commonly used sources of protein for culture of *C. gariepinus* and *O. niloticus* , shows that crude fiber (CF) is generally higher on feed ingredients of plant origin and range between 55 g/Kg - 368 g/Kg dry matter while nitrogen free extracts (NFE) and ash content are higher in the feedstuffs of plant origin with an exception of maize bran which have the lowest value (Munguti et al., 2014). Cotton (Gossypium sp) and sunflower (Helianthus annuus) seed cakes provided the best option as source of processed plant based protein in the present study (Munguti et al., 2014).

Fish may adapt their metabolic functions to the dietary substrates, through a regulation in enzyme secretion, in order to improve the utilization of feed ingredients (Munguti et al., 2012). Although not provided, such specific information could provide more explanation on the feed conversion rate of uptake for larvae growth. Fish meal has traditionally been used as the major protein source for formulated fish feeds due to the high protein content, balanced amino acid profile, high digestibility, palatability, and as a source of essential n-3 polyenoic fatty acids (Caruso et al., 2009). However, many experimental studies have formulated relatively cheap mixed plant based dietary protein sources for the Nile tilapia, and there is a growing need for feeds to cater for the larval stage of *C. gariepinus*. Studies have suggested C. nilotica to replace fishmeal in the early feeding stage of *C. gariepinus* (Chepkirui-Boit et al., 2011).

The study results showed a progressive increase in the FCR, weight gain and total length of *C. gariepinus* larvae. This finding is related to the fact that the formulated diets used in this study had all the essential nutrients required by the *C. gariepinus* larvae to grow and have a resistant body against the environmental changes which have a negative effect on the survival of fingerlings. The present findings are comparable to those of Nyonje et al. (2018), which ranged from 40 % to 60 % for *C. gariepinus* fingerlings fed on 40-50% CP.The present study are also comparable to survival rates reported by Verreth et al. (1987) while feeding *C. gariepinus* larvae on high CP diets i.e.53.2 % - 58.6 % CP.Considered together, the present study results contribute towards the success and realization of the improved production of key candidate fish culture species, and improved hatchery management practices by adopting the use of cheap but efficient CP diets.

# CHAPTER SIX

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 6.1. Summary

In summary, the present study demonstrated that *C. gariepinus* fed on formulated diets, especially 35% CP, exhibited higher growth performance in terms of the parameters evaluated compared to those fed on commercial feed. In addition, the findings of the present study showed that *C. gariepinus* in polyculture with *O. niloticus* had higher biomass than those raised as monocultures irrespective of the CP levels of the diets. There was significantly higher economic performance of raising *C. gariepinus* in polyculture with *O. niloticus* irrespective of the CP level in the diets. Lastly, although the larvae fed the highest CP diet (35 % CP) had the highest growth performance, there was almost similar growth performance and survival between larvae fed on 25% CP and 28% CP (control commercial feed).

## 6.2. Conclusions and implications

Based on the results presented, the following conclusions can be drawn:

1. The *C. gariepinus* fed on 35% CPfarm formulated diets, exhibited higher growth performance compared to those fed on commercial feed. Thus, the farm formulated feed with about 25-35% CP could potentially be used as an alternative replacement to the commercial feed in *C. gariepinus* farming.
2. The *C. gariepinus* raised in polyculture with *O. niloticus* exhibited higher growth performance than those reared as monocultures. Thus, polyculture of *C. gariepinus* should be embraced to guarantee better production.
3. The economics of raising *C. gariepinus* in polyculture with *O. niloticus* were higher than monocultures. Thus, farmers can adopt polyculture with cheaper and low CP diets to maximize profits.

4. The *C. gariepinus* larvae fed on low CP level had a growth performance and survival similar to those fed on 28% CP (commercial control diet). Therefore, the study supports the strategies towards ensuring maximum farmer profits by utilization of less expensive protein sources.

### 6.3. Recommendations

#### 6.3.1. Recommendations for the present study

1. The study recommends the adoption of farm formulated diets with the crude protein range 25% to 35% made from the ingredients soybean, Caridina nilotica, wheat pollard and cotton seedcake in grow-out system with hapa-in-pond.

2. The study further recommends the adoption of polyculture as opposed to monoculture using the diet recommended in (1) above, given that polyculture has better returns over monoculture.

3. In order to produce quality seed that can boost C. gariepinus production, it is recommended that fry be fed on low protein freshly formulated diets from soybean, Caridina nilotica, wheat pollard and cotton seedcake

#### 6.3.2. Suggestions for further research

1. Future studies should consider working with fish species whose broodstock genetic background is well known in a bid to boost the genetic fitness of fry.
2. There is need for evaluating the performance of several hapa stocking densities and ratios of *C. gariepinus*and *O. niloticus*to establish the one with optimum yield.
3. Future studies should test on various species of fish other than *O. niloticus* e.g. *O. esculentus* in combination with *C. gariepinus* to determine its full polycultural potential.
4. Further large scale and multiple cycle economic analysis should be conducted to determine the full economic potential of *C. gariepinus* polyculture system.

**5.** Further studies should focus on a wide array of feed ingredients to develop a cheap and effective diet for raising *C. gariepinus* larvae/fry.

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# APPENDICES

## Appendix 1. Map of Kenya showing positions of KMFRI Sangoro Research Center and Maseno University

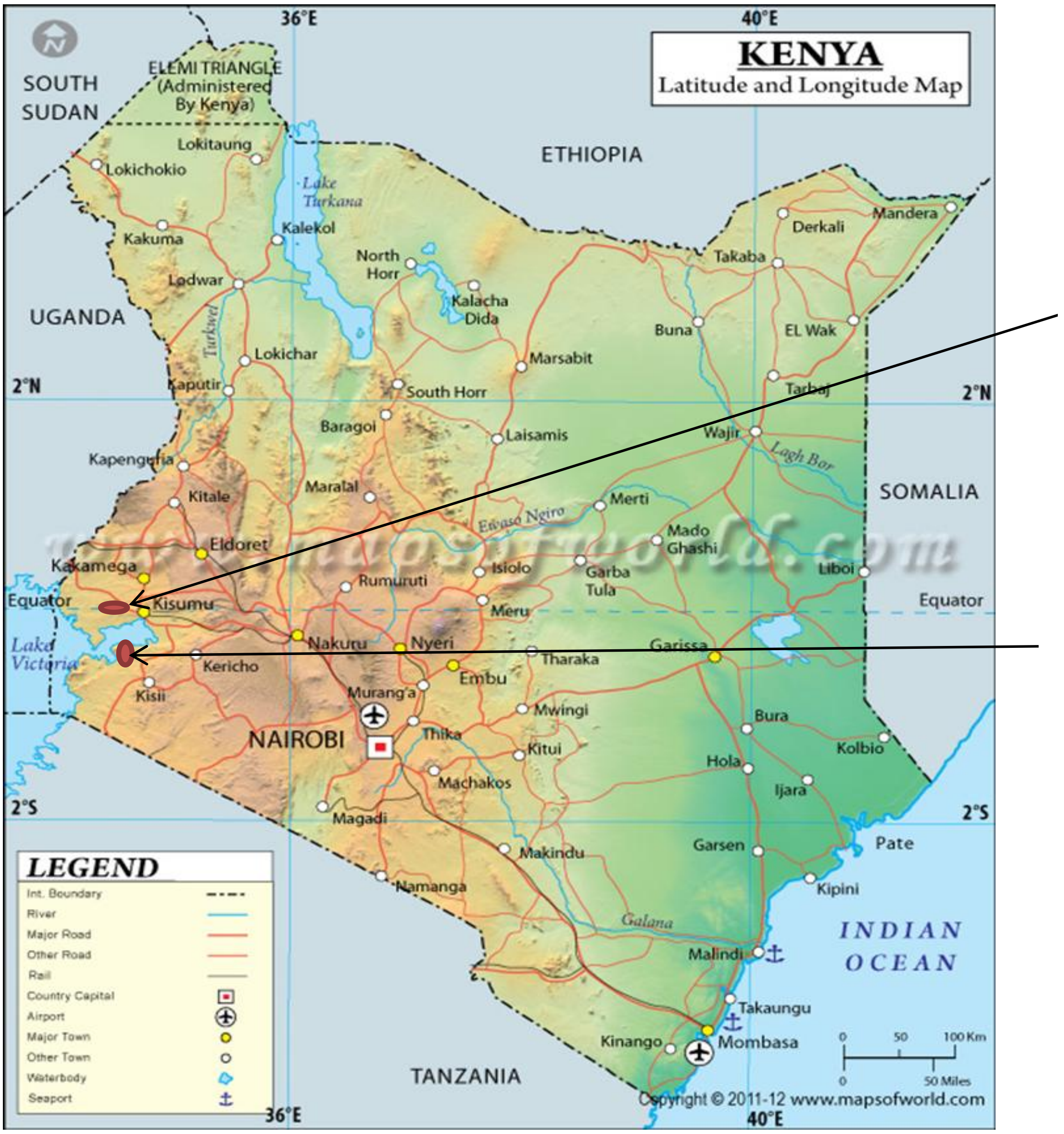


**Figure 3**. Map showing the study areas (Adapted from Adapted from Mapsofworld, 2011).

**Appendix 2. Arrangement of hapas in the earthen pond**

| | | |
|---|---|---|
| **APOLY 3** | **DPOLY 2** | **APCL 2** |
| **DPCL1** | **BPCL3** | **BPOLY2** |
| **CPOLY1** | **DPCL2** | **CPOLY3** |
| **CPCL1** | **APOLY3** | **CPCL3** |
| **DPOLY1** | **BPCL2** | **APCL3** |
| **APOLY2** | **APCL1** | **DPCL3** |
| **CPOLY2** | **CPCL2** | **BPOLY3** |
| **BPOLY1** | **BPCL1** | **DPOLY3** |

**Note:**

A: Hapas fed on 35% CP

B: Hapas fed on 30% CP

C: Hapas fed on 25% CP

D: Hapas fed on 28% CP

PCL: *C. gariepinus* raised in monoculture system

POLY: Polyculture of *C. gariepinus* and *O. niloticus*

1, 2, 3: Replicate experiment (hapas)

All the hapas were placed in an earthen pond as shown in the arrangement above.

**Appendix 3. Arrangement of aquaria for *C. gariepinus* fry/larval to fingerling survival experiments**

| | | |
|---|---|---|
| **T1A** | **T2B** | **T4A** |
| **T4C** | **T3B** | **T1C** |
| **T3A** | **T1B** | **T2C** |
| **T2A** | **T3A** | **T4B** |

**Note:**

T1: treatment 1 (25% CP)

T2: treatment 2 (28% CP; commercial control diets)

T3: treatment 3 (30% CP)

T4: treatment 4 (35% CP)

A, B and C: Replicate aquaria for each treatment