# Growth Performance, Feed Utilization, and Biochemical Analysis of African Catfish (*Clarias gariepinus* Burchell, 1822) at Different Stocking Densities in Concrete Ponds

## MSc Thesis

By

**Duressa Wake Wanufo**

**May 2024**

**Jimma, Ethiopia**

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**A Thesis**

**Submitted to School of Graduate Studies, College of Agriculture and Veterinary Medicine, Jimma University, in Partial Fulfilment of the Requirements for the Degree of Master of Science in Animal Production**

**Major Advisor: Fikremariam Geda (PhD)**

**Co-advisor: Megerssa Endebu (PhD)**

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# DEDICATION

I dedicate this thesis to my father Wake Wanufo and my mother Ayole Oda, who have nursed me with care and affection, tirelessly labored, and sacrificed whatever they had for educating me to this level.

# STATEMENT OF AUTHORSHIP

I solemnly declare that the work in this thesis entitled "Growth Performance, Feed Utilization, and Biochemical Analysis of African Catfish (*Clarias gariepinus* Burchell, 1822) at Different Stocking Densities in Concrete Ponds" has been carried out by me in the Department of Animal Science at Jimma University. This thesis has been submitted in partial fulfilment of the requirements for MSc degree at Jimma University, College of Agriculture and Veterinary Medicine and is made available in the university library to borrowers in accordance with the library's rules and regulations.

The information derived from the literature has been duly acknowledged and cited in the text, with a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution. Requests for permission to reproduce this manuscript in the form of extended citations, in whole or in part, may be made by the Head of the Department of Animal Sciences or the Dean of the School of Graduate Studies when, in his or her judgment, the proposed use of the material is in the interest of scholarship. In all other cases, however, the author's permission must be obtained.

Name: Duressa Wake Wanufo Signature: ___________________

Place: Jimma University, College of Agriculture and Veterinary Medicine.

Date of Submission: ________________________

# BIOGRAPHICAL SKETCH

The author, Duressa Wake, was born on January 23, 1998, in Dugda district, East Shewa Zone, Oromia National Regional State. He attended his elementary education, grades 1-2, from 2006-2007, and grades 3-8 from 2008-2013, at Welda Caffe and Hara Denbel elementary schools, respectively. He then attended his secondary school at Bole secondary school from 2014 to 2015 and his preparatory school at Oda Bokota secondary and preparatory school from 2016 to 2017. After he completed the university entrance examination, he joined Injibara University in 2018 and attended his degree in Animal Science and was awarded a Bachelor of Science (BSc) degree on January 23, 2021, with great distinction

Then he was employed by Injibara University from March 2021 to August 2021, assigned to College of Agriculture, Food and Climate Science as Lecture at the Department of Animal Science as Graduate Assistant I. Thereafter, in November 2021, he joined Jimma University College of Agriculture and Veterinary Medicine, School of Graduate Studies, to pursue his MSc in Animal Production.

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AOAC | Association of Official Analytical Chemistry |
| BOD | Biological oxygen demand |
| CF | Fulton’s condition factor |
| DO | Dissolved oxygen |
| DWG | Daily weight gain |
| FAO | Food and Agriculture Organization of the United Nations |
| FCR | Feed conversion ratio |
| MWG | Mean weight gain |
| SE | Standard error |
| SGR | Specific growth rate |
| TDS | Total dissolved solid |
| TSS | Total suspended solid |
| WHO | World Health Organization |

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## *ABSTRACT*

*In the aquaculture production of African catfish, Stocking density is one of the major factors that affecting growth performance, feed utilization, welfare, and biochemical composition of the cultured fish. Fingerlings of African catfish (Clarias gariepinus) were reared at three different stocking densities in concrete ponds to evaluate the growth performance, feed utilization and biochemical analysis the fish. Three hundred thirty three fingerlings were stocked in one metre square volume concrete ponds at a density of 27, 37 and 47 fingerlings with three replications. The weight gain was recorded on monthly basis while, water quality parameters were recorded on two week basis. The mean weight gains of the fingerlings were 86.74, 74.70, and 66.47, for the treatments I, II, and III, respectively, which indicate the highest mean weight gain recorded at lower stocking densities. The specific growth rates of fingerlings for the treatments I, II and III, were 0.71, 0.64, and 0.6, respectively, with the highest mean specific growth rate at lower stocking densities. The mean feed conversion ratios of the fingerlings were 2.15, 2.47 and 2.83 for treatment I, II, and III, respectively. The highest Feed Conversion Ratio (2.83) was recorded in treatment of higher stocking densities. The water temperature of all treatments ranged from 19.8 to 23*$^{o}$*C and the pH of all treatments ranged from 8.69 to 9. The pH means recorded for the treatments I, II, and III, were 8.95, 8.91, and 8.84, respectively, the highest mean pH value (8.95) was recorded in lower stocking densities. The turbidity of the water in all treatments ranged from 2.65 to 16.53. The mean survival rate was 96.3, 84.7, and 78 for treatment I, II, and III, respectively. The highest survival rate (93.46%) was recorded in treatment with the lower stocking density. The results revealed that higher stocking densities negatively affected the mean weight gain, specific growth rate, feed efficiency, and feed conversion ratio. As a result lower stocking densities are more favourable for higher weight gain, survival rate, better feed efficiency, and feed conversion ratio of cultured fish.*

**Key words:** *Aquaculture, African catfish, stocking densities, Fingerlings.*

# 1. INTRODUCTION

## 1.1. Background and Justification

Aquaculture is the practice of raising aquatic organisms under controlled conditions for human consumption, conservation, research work, or other purposes. It entails the farming of various species of finfish, shellfish, aquatic plants, and other aquatic organisms in ponds, tanks, cages, or other water bodies. According to FAO (2007) aquaculture is the cultivation and rising of aquatic organisms in both inland and coastal settings. It is differentiated from capture fisheries in that the stock retention and there has been intentional human involvement at some point in the production cycle (Naylor *et al*., 2000).

Capture fisheries and aquaculture productions are efficient protein-producing sectors that provide several potentials for poverty, hunger, and malnutrition alleviation (FAO, 2018). Production from Aquaculture plays a vital role in improving food security and family incomes, especially in developing nations where it promotes access to high-quality nutrition and helps to poverty reduction. Additionally, it also makes optimal use of natural aquatic resources, and the aquatic environment serves as a family recreation area (Kubtiza and Ono, 2010).

World fish output (capture and aquaculture) is anticipated to increase by 14% (+1.2% p.a.) from 179 Mt (2019-2021 average) to 203 Mt by 2031. While this is a 25 Mt growth over the forecast period, it is less than the preceding decade (2011-2021), when output increased by 33 metric tons (OECD/FAO, 2022). About half of the fish produced worldwide come from aquaculture (FAO, 2018). However, it is anticipated that aquaculture output would overtake capture production in 2023 and account for about 53% of total fish production by 2031. The aquaculture sector has experienced rapid growth since the 1970s, with an annual growth rate of around 9% (FAO, 2018).

This rapid growth of Aquaculture is dependent on improving production while using limited resources (water, land, and feed) and using more ecologically friendly culture practises for aquaculture sustainability. The rise in fish output is principally driven by the on-going expansion of aquaculture production, which is predicted to expand by 20 Mt and reach 108 Mt by 2031. Despite this anticipated sustained development, it indicates a considerable slowing from the previous decade, when aquaculture production increased by 30 Mt at a rate of 3.8% per year (FAO/OECD, 2022).

The amount of food requirements will rise as the population increase. Fish, being one of the high-protein foods, may be a nutritious food source for the people; consequently, fish production must be enhanced (Basuki *et al*., 2018). Fish represents an important food source on our planet as it complements the food supply made available largely by land based agriculture. It enriches the diet with animal protein and essential amino acids. As the possibility of fish supplies from capture fisheries is fastly depleting, and improvement in fish availability could only be achieved through aquaculture (FAO, 2007).

The African catfish (*Clarias gariepinus*), is endemic to most African countries. It has been introduced and commercially grown in several of the countries in Europe, Asia, and South America (Marimuthu, 2011). It is one of the most important tropical freshwater fish species suitable for aquaculture (Dada and Wonah, 2003). Fish farmers cultivate catfish for a number of reasons, including: biological reasons those are fast in growing, easy to cultivate, easy to consume artificial food, tend to resist disease; Social reasons i.e. good market prices and physical reasons that are resistant to environmental changes **(**Jamabo and Keremah, 2009).

Stocking densities are a major factor that determines profitability from production systems, because it directly affects fish survival, growth, behaviour, health, water quality and feeding requirements (Gibtan *et al*., 2008). However stocking densities has both positive and negative effects on the overall production and productivities' of cultured fish. Hence the positive and negative relationships between stocking density and growth performance reported by (Abou *et al*., 2016; Chakraborty *et al*., 2010; Dasuki *et al*., 2013; Rahman *et al*., 2005). High stocking density is considered a potential source of stress for fish (Abou *et al*., 2016; Ellis *et al*., 2002), with a negative effect's on specific growth rate and final weight

(Abou *et al*., 2016; Ullah *et al*., 2018) as well as survival and feeding rates (Das *et al*., 2016; Rowland *et al.,* 2006). However, higher stocking densities, on the other hand could also facilitate the production of more biomass (i.e., marketable product) which could potentially have positive impacts on overall profitability within a farming system.

In this particular case, several studies have been conducted attempting to determine the optimum stocking densities of African catfish to improve the product and productivities of species culture and keep the welfare and quality of the fish. However, there is a lack of comprehensive synthesis of such studies to provide detailed knowledge and an in-depth overview of determining optimum stocking densities that maximize growth performance and feed utilization while maintaining good biochemical profiles. Further studies could explore a range of stocking densities to identify the most suitable densities for achieving optimal results.

Furthermore, studying on understanding how stocking density influences stress levels and related biochemical parameters and investigating how it affects social interactions, feeding behaviour, and overall aspects could provide insights into welfare and performance. Additionally drawing attention to the highlighting gaps in the existing literature to promote further studies that can contribute to a better understanding and advance our knowledge regarding to the interactions between stocking density, growth performance, feed utilization, and biochemical analysis in African catfish raised in concrete ponds. Also Such knowledge can guide aquaculture practices aim to improving fish welfare, production efficiency, and sustainability.

Due to this lack of information, and the major gap in existing literature regarding the interactions between stocking density, growth performance, feed utilization, biochemical composition, and profitability, it is therefore, necessary to determine the optimal stocking densities for *Clarias gariepinus* in production systems and within specific production phases, to allow efficient management and improve overall yields and profitability of the farms.

## 1.2. Objectives of the Study

### 1.2.1. General objective

The overall objective of this study was to evaluate the growth performance, feed utilization, survival rate, and biochemical analysis of African catfish at different stocking densities in concrete ponds.

### 1.2.2. Specific objectives

The following are the specific objectives of this study

- To evaluate the growth performance of African catfish *(C. gariepinus)* at different stocking densities.
- To evaluate the feed utilization potential of African catfish at different stocking densities.
- To evaluate and compare the survival rate of African catfish at different stocking densities.
- To evaluate the blood biochemistry and proximate composition of African catfish at different stocking densities.

# 2. LITERATURE REVIEW

## 2.1. Growth and Importance of World Aquaculture

Globally, aquaculture is the fastest-growing animal food production sector which now account’s over 50% of fish provided for human consumption and expected to continue to increase in the long term. Aquaculture has high potential to help meet the increasing global demand for aquatic foods created by worldwide population growth (FAO, 2021 and Stevens *et al.,* 2018). The aquaculture sector is unlike terrestrial farming, where the bulk of the production is based on a limited number of species, aquaculture produces more than 220 species (FAO, 2012). However, data from the *State of the World's Aquatic Genetic Resources for Food and Agriculture* (FAO, 2019) indicated close to 700 species are currently being cultured. A relatively small number of species predominate with 50% of aquaculture production by volume constituted by just 12 species or species items including three seaweeds, six finfish species, two mollusks species, and one crustacean species.

The contribution of aquaculture to global fish production should continue to grow (Figure 1) and surpass that of total capture fisheries (including the amount utilised for non-food uses) by 2024. By 2029, aquaculture production is projected to reach 105 Mt, 10 Mt more than the capture sector (Leach, 2017). The continuous growth in aquaculture which according to the United Nations’ Food and Agriculture Organization is responsible for 50% of all fish for human consumption (FAO, 2016), which is attributed to the improvement in the state of the fish stock and fisheries management.

Marine and coastal aquaculture represents the largest percentage of aquaculture (55.5%), with the remainder being freshwater aquaculture. Nearly all algal production, the vast majority of molluscs’ production, and more than half of crustacean production come from marine environments. Freshwater aquaculture dominates in finfish production, representing 85.0% of global totals in 2021 (FAO, 2023).

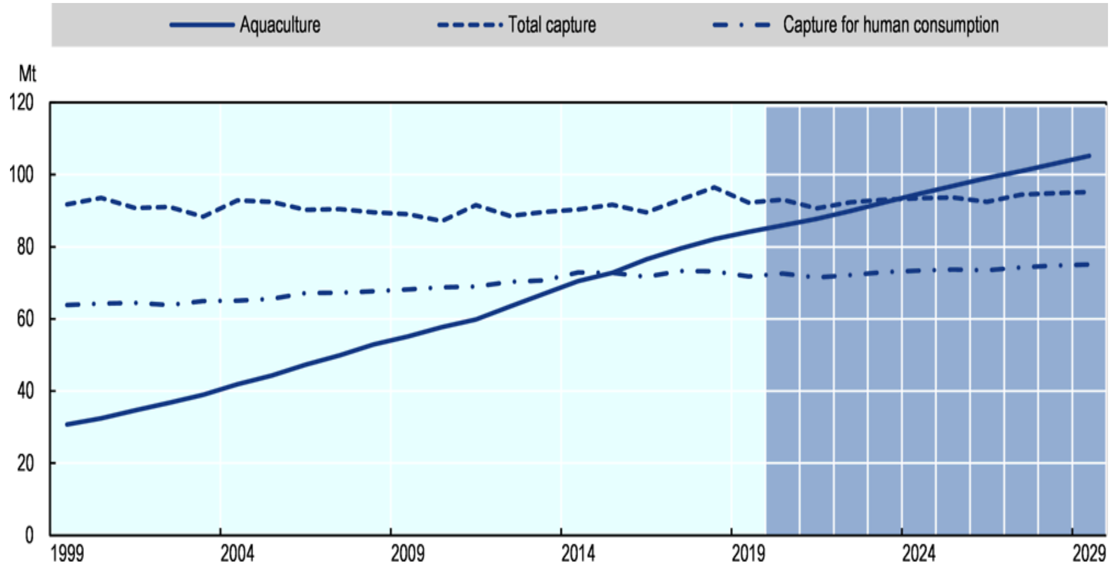

**Figure 1.**World aquaculture and capture fisheries

***Source***: FAO (2020)

From FAO (2016) report, aquaculture marginally supplied 7% of fish for human consumption in 1974, which increased to 26% in 1994, and 39% in 2004 but in 2014 the total contribution of aquaculture to total global fish production rose to 44.1%. This has been further increased to 46% in 2018 which accounted for about 18% of total fish production in Africa (FAO, 2020). The rapid increase in global population and fish demand especially from 3rd world countries has been a major boost for these improving statistics. In support of this, species with the best cultivable qualities are employed in fish farming and they possess a high proportion of these qualities including; acceptability of supplemental feed, high tolerance to fluctuating water condition, disease resistance, commanding high market value and acceptability, attaining early maturity, efficient feed converter and ability to reproduce during captivity.

Clarias species and Heterobranchus species possess a good number of these qualities and thus fit into an average fish farmer’s plan of raising marketable size fish within the shortest available time, also taking into consideration their production cycle achievable all year round (Afia *et al*., 2019 and Ekelemu and Ekokotu, 1999).

Fish farming is particularly an important aspect of aquaculture as it provides about 40% of the dietary intake of animal protein and constitutes a third world's supply of fish products; it is lower in total fat and calories than meat or poultry, making it a healthy protein choice (Gramma *et al*., 2011). It can significantly contribute vital role in the supply of food for the growing population in the world (White *et al*., 2004) and the potential to become a sustainable means to mitigate the declining fish production in capture fisheries.

The status of fisheries are in serious crisis and in a state of dramatic decline in the world (Pauly *et al*., 2002), aquaculture offers an alternative solution to meet the ever growing demand for food and nutrition (Meyers and Worm, 2003). The growth in fish production is due to increased developments in aquaculture practices. The need for aquaculture arose from a decrease in fish supply from capture fisheries due to overfishing, habitat destruction, and pollution of spawning grounds (Emmanuel *et al*., 2014).

In terms of global production volume, that of farmed fish and aquatic plants combined exceeds that of capture fisheries in 2013 (FAO, 2016). Global food fish (both finfish and shellfish) production through aquaculture has increased by almost 12 times within 20 years, during 1982 to 2012 and the global food fish production rose to 76.6 million metric tons in 2015 (FAO, 2017) on which, finfish production contributed 67.8% of this total aquaculture output. In terms of value, the 2015 produced food fish has a farm gate value of 157.9 billion USD. The world average supply of food fish for human consumption increased from 10.14 kg in 2014 to 10.42 kg in 2015 (FAO, 2017).

## 2.2. Sub-Sahara and East Africa Aquaculture Development

Africa's contribution to the global aquaculture industry has remained low due to low investment, few culture species, and poor advancements in critical aspects of aquatic animal culture like feeding and breeding technology. Moreover, some coordination and policy challenges hamper the creation of favourable environments for aquaculture development (Satia, 2011).

Aquaculture in sub-Saharan Africa (SSA) had more variable trends for the last ten years, especially when aquatic plants are included in the data. The share of aquaculture in total fisheries and aquaculture production has increased slowly, from 2% in 2000 to 8% (719,000 tonnes) in 2018. However, the average annual production growth rate, which enjoyed record highs of over 12% before 2014, has for the first time in the past two decades shown negative growth (Mapfumo, 2022). Many factor were contributed this, most importantly among them are the reduction in seaweed mainly (*Eucheuma spp*.) production in key producer countries, especially United Republic of Tanzania, Zanzibar and Madagascar (Largo, 2020).

Seaweed farming has experienced serious challenges from disease and epiphytes, attributed to climate change, with significant reductions in the seaweed trade, household incomes and livelihoods in general. Compounding the problems of seaweed disease and epiphytic infestations, there has been a reduction in African catfish (*Clarias gariepinus*) production in Nigeria, as well as overall decreases in aquaculture production from two other key producers, Uganda and Kenya, largely due to increased aquaculture costs (Kyewalyanga, 2016).

In East Africa, Aquaculture is predominantly extensively pond-based because of the lower cost of establishing infrastructure development and necessarily acquiring essential knowledge as compared to intensive systems (Hinrichsen *et al*., 2022). Some farmers and companies have embraced intensive production systems such as cages, which are profitable and have reduced capital investment per unit of fish produced (Satia, 2011). Among East African countries, Uganda has the highest number of inland cage farms at 18%, followed by Kenya, Tanzania, Rwanda, Zimbabwe, Zambia and Malawi (Musinguzi *et al*., 2019).

### 2.3. Ethiopian Aquaculture Development, and Major Bottle Neck

It is a fact that in Ethiopia, aquaculture exercise officially began after the establishment of the previous Sebeta Fish Culture Station (the contemporary National Fishery and Aquatic Life Research Center) in 1977 via the Ministry of Agriculture's monetary guide obtained from the Government of Japan's Japan International Cooperation Agency (Chimdo, 2022).

Ethiopia is a rustic country in the Horn of Africa endowed with several aquatic resources, which include over 20 natural lakes, 12 huge river basins, over 75 wetlands, and 15 reservoirs. It is also wealthy in numerous fish, water, and environmental resources; however, it's far placed at the bottom of the aquaculture producers list (Abebe, 2016). Also, in Ethiopia, current fish manufacturing is primarily based on capturing fisheries from natural lakes and rivers; artificial reservoirs additionally make a small contribution. However, the biomass and capacity yield of the natural waters cannot entertain a tremendous boom in fishing efforts, with natural fish stocks depleting from time to time (Chimdo, 2022).

Aquaculture is increasingly recognized as an alternative means of achieving food security and poverty reduction in the rural and considered as an integral part of rural and agricultural development policies and strategies of Ethiopia (Chimdo, 2022). Aquaculture policy and strategy of the country and the legal framework on fishery development are also very supportive and looking for problem solving research outputs. The Growth and Transformation Plan (GTP II) encourages the private sector to invest in aquaculture and consider it as untapped agribusiness open for domestic and foreign investors (Yalew, 2018).

The aquaculture development in Ethiopia has to become faced some challenges. These include mainly, loss of regionally selected fish seeds, lack of reasonably affordable and efficient locally available fish feeds, national regulation in the country, over-reliance and excessive dependency on capture fisheries, lack of integration between aquaculture and other farming activities, low-value aquaculture aids for rural development, loss of facilities for the multiplication of licensed fish seed and lack of institutional ability in training, research and generation transfer challenging the aquaculture development in the country (Natea, 2019).

Additionally, farmers do not get adequate academic and practical training before and after pond construction and overall management. Consequently, a few of the farmers begin fish farming without knowing anything from pond management to dish preparation and consumption of the fish (Chimdo, 2022). Moreover, the Limited availability of skilled labour is an ongoing challenge for aquaculture firms. A lack of state of the art, knowledge and agribusiness skills, including poor recordkeeping, sanitation, stocking, feeding and water management practices, stifles productivity and profits of small-scale fish-farm enterprises (Ragasa *et al*., 2022).

### 2.4. Biology and External Morphology of African Catfish

The African catfish (*Clarias gariepinus*) locally referred to as mudfish belongs to the Phylum Chordate; Class Osteichytes; Order Siluriformes; Family Clariidae and Genus Clarias. Catfish is a diverse group of ray-finned fishes representing more than 3000 species, 478 genera and 36 families (Ferarris and Pinna, 1999). The Clariid freshwater fishes belong to the order Siluriformes (ray-finned fishes) with a wide geographical distribution in Africa.

In Africa, more than one hundred different species have been identified for which about nine species features prominently in African aquatic ecology. These are the *Clarias gariepinus*, *Clarias anguillaris*, *Clarias pachynema*, *Clarias macromystax*, *Clarias agbonyiensis*, *Clarias buthupogon*, *Clarias lazera*, *Clarias macracanthus* and *Clarias tsanensis* (Graaf *et al*., 1995 and Idodo-Umeh, 2003). It consists of 13 genera and 34 species in Ethiopia and two of these species, Amphilius lampei and Chiloglanis modjensis, are endemic (Fishbase, 2014).

It is a widely distributed fish species in Africa from the Nile and Niger River system to southern Africa in the Orange-Vaal, Okavango and Cunene River systems, and East African rift valley lakes (Picker and Griffiths, 2011). Morphologically, the *Clarias gariepinus* is a scale less fish with smooth skin and soft ray fin, dorsal-ventrally flattened bony head and elongated body (Yinka *et al*., 2005 and Idodo-Umeh, 2003).

Ecologically, the Clariidae can be found in stagnant water, lake, pool, and running water body (Idodo-Umeh, 2003). They are hardy such that they can survive wide range of extreme aquatic conditions. This distinct characteristic is traced to their accessory breathing lungs that complement their gills which enable them to live several hours outside water body.

The African catfish can be raised in freshwater systems, far away from the sea, such as rivers, swamps, lakes, ponds, and streams. The spawners produce large quantities of eggs and sperm throughout the year (Yelouassi *et al*., 2018, FAO, 2014). The species tolerates high stocking densities and large environmental variation in breeding conditions (Yalcin *et al.*, 2001), which makes it the preferred model for aquaculture in tropical countries (Gaigher, 1977).

The fish is very active at night, a bottom feeder and omnivorous in its 6 feeding pattern. However, they also exhibit predatory behaviour mostly at night hence they are mostly referred to as nocturnal fish and do not reproduce in captivity. Naturally therefore, they are involved in migratory breeding during the onset of rains where they move from deep water to shallow water especially with running water. In captivity in pond, they often wriggle out of the body of water to carry out land excursion for a long distance (Idodo-Umeh, 2003).

*Clarias gariepinus* specie's are air-breathing catfishes, naturally occurring in Africa, Asia Minor (Jordan, Lebanon, Syria, Israel and Southern Turkey) and South-East Asia (Roodt-Wilding, *et al*., 2010; Shyama, 2013). African catfish is of great economic importance, as it is the most cultured catfish in Africa and the third most cultured catfish species in the world (Roodt-Wilding, *et al*., 2010). It has therefore been introduced in many parts of the World where it did not exist before such as China (Shyama, 2013), South America (Vitule, *et al*., 2006) and Europe (Gunder, 2004).

They are relatively poor swimmers and that they spend most of the time on the bottom of lakes and rivers (Gunder, 2004). The African catfish are however, able to move across land to another water source during damp conditions. They simply extend their strong pectoral fins and spines and begin crawling through shallow pathways (Islam, *et al*., 2007).

Morph histology of the internal organs of African catfish is important to understanding the fundamental of its physiological characteristics. For instance, the nature and structure of the respiratory organs of fish have a significant consequence on its ability to tolerate poor water condition. The gill of *C. gariepinus* is equipped with an air-breathing organ known as supra branchial organ (Ahmed *et al*., 2008). This pair of supra branchial chambers located in the dorsal-posterior part of the branchial cavity having extensions from the upper parts of the second and fourth gill arches, forming the arborescent organs. This structure is an air-breathing organ and allows the fish aerial breathing (Belão *et al*., 2011).

African catfish have distinctive features that are readily recognized by their cylindrical body with scale less skin, flattened bony head, small eyes, elongated spine-less dorsal fin, and four pairs of barbels around a broad mouth. According to Van Oijen (1995), the upper surface of the head is coarsely granulated in adult fish but smooth in young fish. The anal, caudal, and dorsal fins are not united. The males can be easily recognized by a distinct sexual papilla located immediately behind the anal opening. This sexual papilla is not present in female fish.

The African catfish possesses external appendages named barbels, which are accessory feeding structures that contain sensory organs and play an essential role in fish activities (Park *et al*., 2006). It undertakes lateral migration from larger water bodies, where they feed and mature, temporarily or permanent vegetated margins of streams, flood plains, lakes to breed (Gunder, 2004). These reproductive migrations take places at the onset of the rainy season. Teugels (2003) classifies them as members of the egg-scatterer reproductive guild, which awaits suitable environmental conditions before spawning.

African catfish are known for their unique reproductive strategy, called mouth brooding. The male fertilizes the eggs externally after the female lays her eggs. The male then picks up the fertilized eggs with his mouth and carries them until they hatch. The final gonad maturation in catfish is associated with raising water levels. Under ideal conditions, adult catfishes have mature gonads year round. The females may lay up 20,000 to 30,000 eggs /kg of body weight (Sheasby, 2009). The African catfish is omnivorous. Their stomach contents usually contain; insects, gastropods, crustaceans, small fish, aquatic plants and debris, larvae exclusively depend on zooplankton in the first week of exogenous feeding (Shyama, 2013).

## 2.5. Feeding Habits and Feed Utilization of African Catfish

Feeding is a complex behavior of animals, including fish in natural habitat and aquaculture. Different fish species have different ways of feeding. The effective management and knowledge of food items and feeding habits of freshwater fish species, specially, African catfish, is an important area of consideration and needs ongoing research. This is because it serves as the basis for the development of a successful management program on fish capture and culture (Shalloof and Khalifa, 2009).

Feeding behaviour of fish is influenced by several factors, including environmental factors and habitat. The two environmental factors that affect the feeding habits of fish are Temperature and photoperiod, and they are frequently related to the reproductive season. For instance, certain temperate zone fish have been seen to cease feeding as winter approaches, with shortening photoperiods and decreasing water temperatures presumably serving as environmental signals (Hart, 1993). Along with physiological and feed factors, the feeding habits of fish have also been affected by environmental factors.

According to Helene and Richard (2006), fish feeding habit is greatly influenced by different environmental factors such as physicochemical parameters of the water including the nature of the habitat (natural captivity), stocking density, and the environmental photoperiod. Salinity also affects Feeding habits and macronutrient selection in fish (Rubio *et al*., 2004). Although feeding habits are undoubtedly important for growth, research suggests that in fish, food intake is set-point-regulated to support growth (Peter, 1979).

Characteristically, the African catfish is an aquatic predatory omnivorous that hunts at night using non-visual primary sense organs, especially the senses of touch through the barbells and tactile organs found on the mouth and skin (Bruton, 1996). The omnivorous diet of African catfish allows the species to eat almost anything, including a variety of cheap artificial foods, which contributes to its easy breeding (Baßmann *et al*., 2017).

Dadebo (2009) stated that African catfish possess long, numerous, and compact gill rakers to filter large amounts of zooplankton. Such morphological adaptation is important to shift from one kind of feeding habit to the other, which depends on the availability of food items in the water bodies as well as zooplankton production, which depends on water productivity and temperature. The fish has morphological adaptations for piscivorous feeding habit like big mouth, marginal and pharyngeal teeth, tough and muscular stomach with high acidity, and short intestine.

Various authors have studied the feeding habits of African catfish in Ethiopian water bodies (Alemayehu, 2009; Demeke *et al*., 2015; Dadebo *et al*., 2014; Dadebo, 2009; Dadebo, 2000; Teka, 2001; Tugie and Taye, 2004). According to those authors the African catfish feed on a variety of foods based on their living condition in their habitat. The omnivorous and opportunistic feeding habit of African catfish helps it to consume a wide variety of feeds, such as algae, macrophytes, zooplankton, insects, fish prey, detritus, amphibians, and sand grains (Abera, 2007; Demeke *et al*., 2015).

In aquaculture activities, feed is one of the important components that support the growth and survival of farmed fish. Feed used in cultivation activities is generally artificial feed, which accounts about 60 –70% of the total production costs incurred (Suprayudi, 2010).

African catfish feed utilization was evaluated by Fauji *et al*. (2018) in order to determine the effects of different stocking density on feed utilization of the fish. The fish has the ability to utilize and switch efficiently between alternative food sources such as plants and detritus when prey animals become rare and scarce (Cyrino *et al*., 2008). Food type and availability and feeding method can mitigate agonistic behaviour and cannibalism in larvae and early juveniles (Almazan *et al*., 2004).

In Africa, the primary constraint for expansion and development of aquaculture sector is soaring cost of formulated fish feeds (Hecht, 2007), and this has promoted to look for suitable alternative feed ingredients. The main obstacle facing fish culturists is the need to seek a balance between rapid fish growth and optimizing the utilization of supplied feed (Gokcek *et al*., 2008).

There is also a need to establish the consequence of feeding frequencies on feed management, nutrient utilization and fish performance. Since the feed cost accounts a proportion of 40 to 60% of the total operating costs in intensive culture systems (Agung, 2004), due to this reason the economic feasibility of the fish farming operation depends on the feed type and feeding frequency.

## 2.6. Stocking Densities of African Catfish

Stocking density is normally referred to as the weight of fish per unit volume in unit time of water flow through the holding environment (Ashley, 2007). According to Ellis *et al*. (2002), "stocking density" refers to the initial population of fish placed into a system of production.

In finfish aquaculture, stocking density is a pivotal factor and a source of chronic stress, which can lead to long-term stress that might alter physiological and biological processes such as stress responses, growth reduction, and health impairment (Carbonara *et al*., 2020). Based on these conditions, fish well-being can decrease (Oké and Goosen, 2019).  Stocking densities in fish farming have been identified as an important area of animal welfare issues, Similar to concerns about the intensity of terrestrial or temporal livestock production. These concerns are generally associated with problems such as decreased feed conversion efficiency, condition factor, and growth at increasing densities (Ellis *et al*., 2002; Lymbery, 2002).

Stocking density is essential to determining the potential for yield productivity and profitability of aquaculture. Conversely, increased stocking density cause stress to reduce fish robustness, and more susceptible to diseases (Yadata *et al*., 2020). As such, social interaction and water quality play a major mediating role in the relationships between stocking densities and fish welfare. Fish growth and behavior are influenced drastically by stocking density which is governed by different factors, such as fish species, size, and environment of production. Unlike other terrestrial Animals, fish require a three dimensional media in order to satisfy their behavioural and physiological needs such as oxygen supply, and dilution of metabolic waste products (Ellis *et al*., 2002).

The most common method used under farm condition to increase production is increasing stocking density. Fish growth and survival are known to be significantly impacted by stocking density, even though high densities may be profitable to the farms. (Hecht and Appelbaum, 1988; Haylor 1991, 1993; Siddiqui *et al*., 1993; Kaiser *et al*., 1995; Khwuanjai *et al*., 1997; Hossain *et al*., 1998).

Stocking density is a main factor significantly affecting the growth, feed utilization (FCR) and survival rate (SR) of the catfish fingerlings (Rahman *et al*., 2005). High stocking densities act as stressors, fish aggregate for the same amount of feed and some of them can't eat resulting in growth retardation and/or decrease of feed utilization.

Standardizing the ideal stocking density in an intensive culture system is essential to achieve appropriate goals for production. Stocking density has a considerable impact on fish growth and development as well as the stress of transporting fish in aquaculture water. Therefore, establishing the optimal density is essential to guarantee economically viable fish production (Yarahmadi *et al*., 2015). It has been demonstrated that different stocking levels have both positive and negative effects on the growth of several fish species (Qi *et al*., 2016).

## 2.7. Growth Performance of African Catfish

African catfish growth performance especially when reared in concrete ponds can be influenced by several factors including water quality, stocking density, feeding regime, and environmental conditions. African catfish is important species due to its high growth rates, tolerance to a wide range of temperature and DO levels, good palatability and high fecundity (Hecht 1996; Rad *et al*., 2004; Soltan and Tharwat, 2006; Amisah *et al*., 2009). The species has a very fast growth of up to 5g per day, and reaches sexual maturity within 3 to 6 months (Dadebo *et al*., 2014). Its fillets are highly appreciated by the majority of the African population, which makes the species commercially more valuable (Rad *et al*., 2004). African catfish has higher commercial value even when their fillet is processed (Olaleye, 2005). Generally, African catfish are known for their rapid growth rate and ability to adapt to various environmental conditions.

Increasing the stocking density of farmed fish to optimum stocking rates is an important strategy to increase the productivity as well as profitability of fish production (Fauji *et al*., 2018). Protein quality and quantity determine the growths of larvae (Giri *et al*., 2003). If the crude protein content of the feed has a big difference, the larvae show likewise differences in their growth performances. It is important to monitor and maintain optimal water quality parameters in the concrete ponds to ensure the health and growth of the African catfish. Additionally, providing a balanced and nutritious diet, regular feeding schedules, and proper management practices can also contribute to the growth performance of the fish (Furuya *et al*., 2004, Owodeinde and Ndimele, 2011).

African catfish is an excellent model for fish farming in tropical and sub-tropical regions because it can grow and reproduce in a wide range of environmental conditions (FAO, 2014). The species is a very hardy that tolerates stress induced by handling (Manuel *et al*., 2014).

## 2.8. Water Quality Requirements of African Catfish

Water quality plays an essential role in the growth performance of African catfish. Fish growth and survival at different stages are influenced by Water quality parameters, Therefore determining the optimal water quality determinants becomes crucial for any aquaculture farming (Marimuthu *et al*,. 2019). Optimal water temperature, dissolved oxygen levels, pH, and water turbidity are important for the overall health and growth of the fish. Consequently, Poor water quality can elicit a stress response, reduced growth rates, and have negative impacts on their overall health and well-being (Conte, 2004).

African catfish has several adaptation mechanisms for low oxygen level due to the arborescent organ enabling the fish to obtain oxygen from the atmosphere (Hecht, 1996). These organs above gill arches is an accessory air-breathing organs functioning like a lung and render them to be capable of aerial respiration and thus able to get 80–90% of the dissolved oxygen requirements (Moreau, 1988).

The African catfish is an easily cultivable fish because of its resilience and high tolerance level for environmental conditions below their optimal requirements, e.g., high ammonium and nitrite concentrations (Ip *et al.,* 2004; Schram *et al.,* 2014). According to FAO (1996) reports that toxicity tolerable levels of ammonia depend on individual species; however, toxicity level below 0.02 ppm is generally considered as non-detrimental.

Catfishes are an example of a warm water species, with a temperature range suitable for growth between 20 and 30°C. A temperature of 28°C is generally considered as optimum temperature for the growth of catfishes. The acceptable optimum pH range in fish culture is between pH of 6.0 to 9.0 for fresh water species (Boyd, 1979). Fish growth depends greatly on the quality of the water used in the pond and the quality of the water depends upon where it comes from and what kind of soil it travels over. Testing the water quality means making sure that all the factors which related to water are at their appropriate requirements for the fish to enhance maximum growth and yield. These are chemical factors such as dissolved oxygen concentration, pH, total dissolved solids, carbon dioxide, and alkalinity, and physical factors such as temperature, turbidity, light penetration, water colour, and plankton's concentration.

Water temperature is one of the major environmental factors that affects and controls food utilization at all levels and stages of fish growth (Kaushik, 1986). It is one of the most important factors to be considered when selecting a particular species for pond culture because the body temperature, of fish varies with, and is almost the same as that of their environment. The intensive application of commercial feed in aquaculture causes environmental pollution and increases the possibility of disease outbreaks. Therefore, water quality management is crucial in the aquaculture system (Asaduzzaman *et al*., 2008 and De Schryver *et al*., 2008). The objective of water quality management is to provide the comfortable environment and meet the optimum requirements for cultured organisms (Nurhatijah *et al*., 2016).

Fish generally experience stress and disease breakout when temperature is chronically near the maximum tolerance or fluctuates suddenly. Warm water holds less dissolved oxygen than cool water. This is because every 10°C rise in temperature doubles the rate of metabolism, chemical reactions, and oxygen consumption in general (Boyd, 1979).

Turbidity and colour of water are closely related. High turbidity, one of the major factors that impede light penetration, could be due to presence of planktonic organisms or clay particles (Chukwuma and Ezeanya *et al*., 2015)

**Table 1.** Standard water quality requirements for fish farming

| S.N | Water quality parameter | Recommended requirement | Source |
|---|---|---|---|
| 1 | pH | 6.6 – 8.5 (saline)<br>6.0 – 9.0 (fresh) | Davis (1993) |
| 2 | BOD | 3 – 20 mg/l | Boyd (2003) |
| 3 | Temperature | $25^0$C – $30^0$C | FAO (2006) |
| 4 | TSS | 10 – 20 mg/l | Davis (1993) |
| 5 | TDS | 0.13 mg/l | Davis (1993) |
| 6 | $N_{O3}$=N | 16.9 mg/l | Boyd and Schwartz (1994) |
| 7 | Total hardness | 50 – 100 mg/l | WHO (2003) |

***Source*****:** Chukwuma, Ezeanya *et al*. 2015

## 2.9. Welfare of African Catfish

The ‘’Five Freedoms’’ framework identified by (FAWC, 1996) is defined as ideal states rather than specific levels of acceptable welfare. Freedom from hunger and thirst, discomfort, pain, injury, disease, fear, and distress, as well as the freedom to express normal behavior, allow us logical approaches with which to assess welfare issues.

Being physically health is the most universally accepted measure of welfare and is undoubtedly a necessary requirement for good welfare. Nevertheless, for many, good animal welfare goes beyond just physical health and also involves a lack of mental suffering. This aspect of welfare hence seeks to better understand subjective experiences of non-human animals and proposes the conscious experience of suffering in these animals (Broom, 1991).

The welfare of fingerlings of African catfish is crucial for their survival and growth. To ensure their welfare, it is important to provide suitable water conditions, adequate nutrition, a stress-free environment, and proper stocking densities (Stevens *et al*., 2017). The stocking densities applied in fish farming have been highlighted as an important area of welfare concern, generally associated with problems as reductions in feed conversion efficiency, condition factor and growth at increasing density (Ellis *et al*., 2002).

Well managed water quality is essential for the welfare of fingerlings. This includes maintaining the right temperature, pH levels, oxygen demands, and water clarity in the water (Dey, 2022). Poor water quality can lead to stress and disease in the fingerlings, and Stress during fish culture can impact growth, physiology and fillet quality (Ciaramella, 2015). Proper nutrition is essential for the growth and development of the fish, and understanding their nutritional requirements is critical for producing healthy and high-quality fish (Langi, Maulu *et al.*, 2024).

Increasing fish density may compromise the animal welfare, which ultimately reduces the survival and growth (Fauji *et al.,* 2018). Overall, ensuring the welfare of African catfish fingerlings involves providing them with a suitable environment, proper nutrition, and ideal stocking densities and minimizing stress factors (Gizaw, 2017).

## 2.10. Blood Biochemical and Proximate Composition of African Catfish Fillets

Hemato-biochemical investigations provide valuable diagnostics to predict the well-being status of cultured fish species (Fazio, 2019). Especially, the blood indices are considered to be the vital physiological markers for examining the stress responses in fish (Seibel *et al*., 2021) due to disease (Clauss *et al*., 2008), toxicants (Groff and Zinkl, 1999), nutrient deficiency (Khan and Khan, 2021), environmental stressors (Parrino *et al*., 2018), inappropriate stocking density (Refaey *et al*., 2018).

Analyses of serum biochemical constituents give useful information for detecting and diagnosing metabolic disturbances and diseases in fishes (Ferrari, 2007). Serum total protein concentration provides critical information on the functional status of various organs and systems (Adeyemo *et al*., 2022). Serum, rather than plasma was used for blood chemistry analysis to avoid possible interference of fibrinogen. The samples for each fish was analysed for the following analytes:  blood glucose (GLU), total protein (TP) and total cholesterol (CHOL) (Nabi *et al*., 2022).

Fish is highly nutritious, palatable with tender fillets hence easily digestible (Effiong and Fakunle, 2011). Their fillet contains four basic ingredients in varying proportions: water, protein, fat, and minerals. Fillets from healthy fish contain 60–84% water, 15– 24% protein, and 0.1–22% fat, mineral usually constitutes 1–2% (Clucas and Ward, 1996).

Analyses of proximate composition of fish products are sometimes essential to meet the requirements of food regulations or commercial specifications (Murray and Burt, 1983). In industrial processing of fish, knowledge of the composition of fish is important in several ways. Such information will be useful in prescribing the diets for health conscious people and those with certain medical conditions to change to poly-unsaturated fatty acids (Namaga *et al*., 2020).

# 3. MATERIALS AND METHODS

## 3.1. Description of Experimental Station

The experiment was conducted for 120 days in concrete ponds at the experimental station of Batu Fish and Other Aquatic Life Research Centre, Batu town, East Shewa Zone, Oromia National Regional State, Ethiopia (Figure 2). Batu town is found in Adami Tullu Jido Kombolcha district, which is a part of Rift Valley that lies 165 km south of Addis Ababa. The district is located between 38°20’ and 38.5°5’ E and 7°35’and 8°05’ N. Geographically, the area is located at an altitude of 1500 to 2000 meters above sea level. It receives mean annual rainfall of 760–1000 mm. The average annual temperature ranges from 22–28ºC and relative humidity of 60%. The agro-ecological zone of the district is semi-arid and sub-humid in which 90% of the area is lowland while the remaining 10% is intermediate (Kebede, 2010).

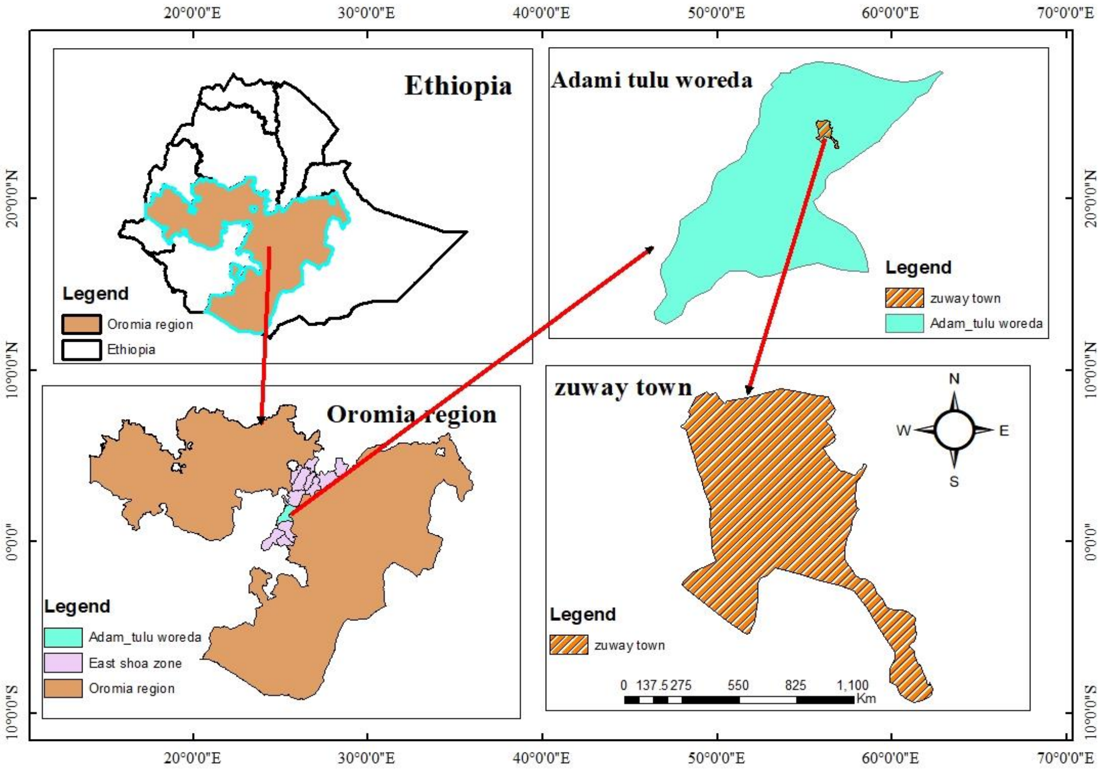

**Figure 2.** Map of study area.

### 3.2. Experimental Animals and Design

The experiment was carried out using a total of nine concrete ponds, where three experimental groups in three replication were randomly distributed over the ponds (Figure 3). A completely randomized experimental design with three treatments was applied in the present study. The treatments consisted of concrete pond with different fish densities and a control system at optimum stocking density. The experiment had three treatments with stocking densities of $T_I$= 27fish/m$^2$, $T_{II}$ = 37fish/m$^2$ and $T_{III}$ = 47fish/m$^2$. Each of the three treatments consisted of three replications.

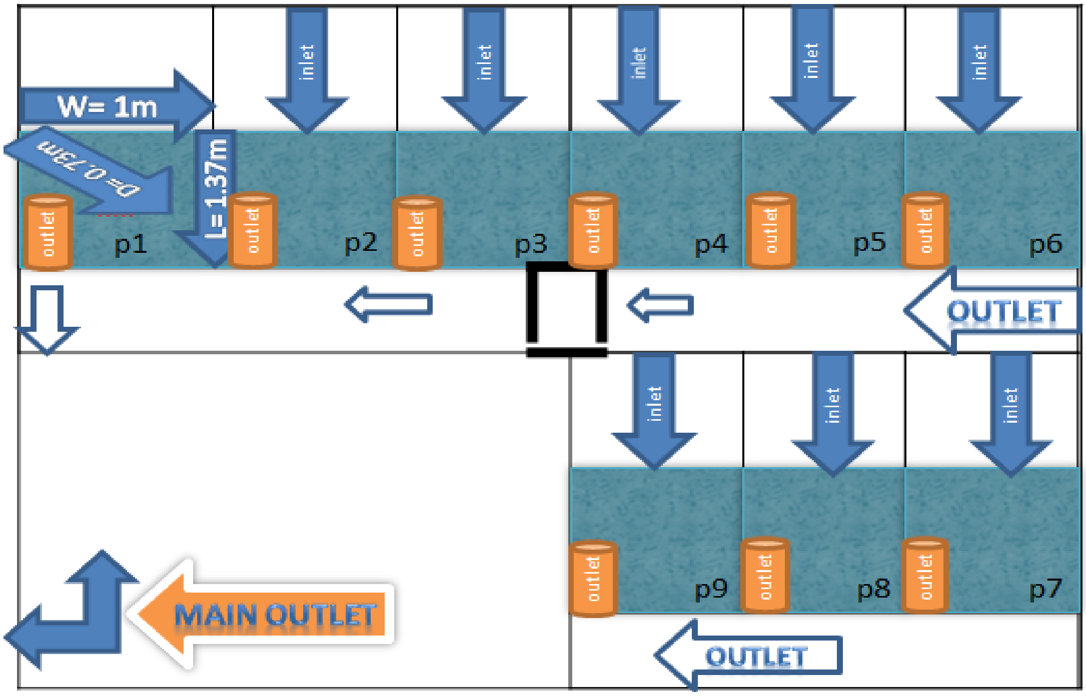

**Figure 3.** Outline of experimental Ponds

### 3.3. Collection of Experimental Fish

Accordingly, a total of 333 African catfish (*Clarias gariepinus*) juveniles were used in this experiment, which were collected from Koka reservoir. The juvenile African catfish collected from wild were adapted to the concrete pond environment and fed the artificial feed for two weeks before the commence of the experiment. These adapted juvenile fish were randomly distributed to the replications of treatments in the experimental ponds.

### 3.4. Feeding of Experimental Fish

The experimental fish were fed based on their body weight twice a day at 10:00 AM and 4:00 PM (Figure 4). The proportion of feeding was 40% during the morning and 60% during the afternoon, for a total of 120 days. The feed used during the experimental period was pelletized and floating, which consisted of 30% CP.

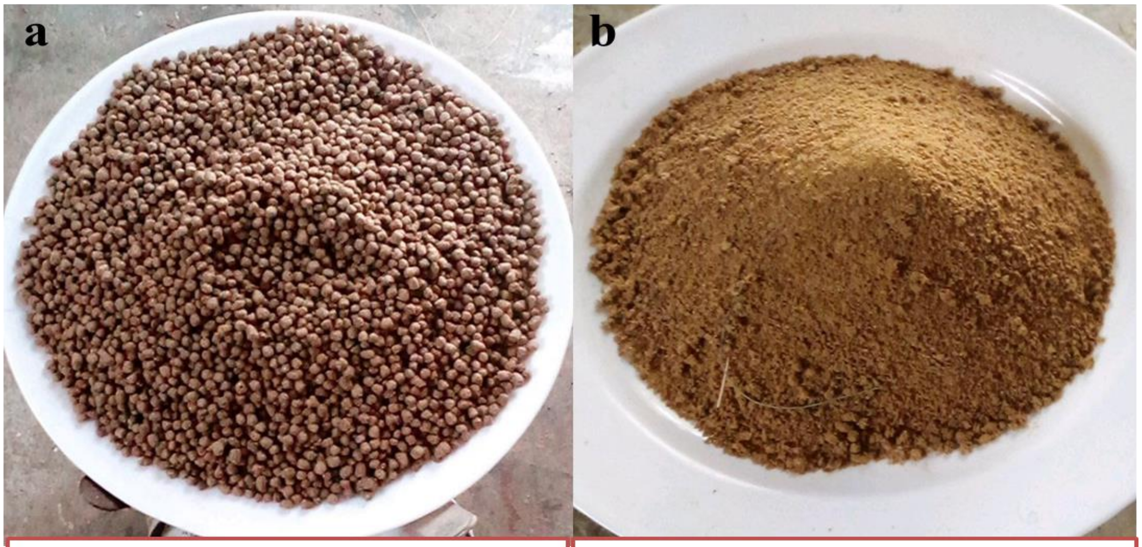

Fig. a. indicates that the completed feed with a 3mm pellet size floats over the water for a minimum of 2 minutes, which is used throughout the experimental period.

Fig. b. indicates that the completed feed had a pellet size of 1mm and was used as a starter meal for the fingerling just for two weeks of the experiments.

**Figure 4.** Type of feed used during experimental period.

### 3.5. Growth Performance and Feed Utilization

After stocking, African catfish were randomly sampled and their individual total weights (g) and total lengths (cm) recorded by using a sensitive weighing balance and measuring boards, respectively. Before weighing, the specimens were blot-dried to ensure accuracy (ElNaggar 2008). Every month, 15 fish were randomly sampled from each of the nine concrete ponds for weight and length measurements using a scoop net. The experimental fish were ethically treated in a humane way, per the guidelines for animal experiments and in consultation with experts working on animal welfare at the experimental station. Feeding was calculated and adjusted on a monthly basis, in accordance with the average weight of the sampled fish.

Parameters evaluated during fish culture included growth performance, specific growth rate, and survival rate, feed utilization as well as water quality. Fish sampled from each pond were measured for their length and weight and the data were recorded in the prepared data sheet. Sampling of fish was done once in a month. After the data was collected the growth performance and feed utilization of experimental fish determined by using those parameters: specific growth rate (SGR), weight gain (WG %), daily weight gain (DWG), feed efficiency, feed conversion ratio (FCR) and mean weight gain (MWG) by using the following equations:

$$\text{Specific growth rate (\%)} = \frac{\text{Ln Final weight(g)} - \text{Ln initial weight(g)}}{\text{feeding period(day)}} * 100$$

Mean weight gain (MWG) = WF – WI

Where WF is the mean final weight and WI the initial weight.

Mean length gain (MLG) = MFL – MIL (Oscar *et al*., 2013)

$$\text{Feed efficiency (\%)} = \frac{\text{Weight gain(g)}}{\text{feed fed(g)}} * 100$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{feed intake (dry weight in g)}}{\text{Fish wet weight gain (g)}}$$

Survival Rate (SR) were calculated according to Pangni *et al*., (2008)

$$\text{\% SR} = \frac{\text{Total number of fish harvest}}{\text{Total number of fish stocked}} *100$$

Fulton’s condition factor calculated according to the formula indicated bellow

$$\text{FC} = \frac{W}{L^3} *100$$

Where FC is Fulton’s condition factor

*W* is body weight the fish

*L* is body length of the fish

### 3.6. Water Quality Analysis

The water sample was taken every two weeks for analysis of the water quality of cultured ponds of different stocking densities. The water temperature of the ponds was measured using a mercury-in-glass thermometer. The thermometer was placed into pond water at about 15cm below water for two minutes and quickly removed, and the readings were then recorded. The pH of the water samples was determined by using a digital pH meter. Water samples were collected from the experimental ponds and sent to the laboratory for analysis. The pH meter was dipped into the water samples, and after stabilizing, the readings were then recorded. The turbidity of water was measured using a turbid meter. After carefully taking the water sample from the pond, then placed it into the turbid meter and the results were recorded.

### 3.7. Blood Sampling and Serum Biochemical Analysis

The blood serum biochemistry analysis was done at Meki Hospital in human clinical laboratory to test total protein, glucose and cholesterol levels of the sampled blood by using cobas modular analyser machine.

For gentle handling and for safety reasons, fish was sedated prior to and during blood sampling to minimize pain or discomfort and to prevent defensive or flight reactions and subsequent injuries. A loss of consciousness, therefore, were ensures the welfare of the fish during blood collection (Seibel *et al*., 2021).

Blood samples were collected via dorsal puncture with a hypodermic needle inserted to a plastic syringe and 3ml of blood was extracted from sampled fish. The site chosen for puncture was wiped dry with tissue paper to avoid contamination with mucus. The blood samples were rocked gently in the tubes to allow thorough mixing of its contents with the anticoagulant.

After collection of the whole blood, allow the blood to clot (incubation period) by leaving it undisturbed at room temperature. This usually takes 15-30 minutes. Remove the clot by centrifuging at 1,000-2,000 x g for 10 minutes in a refrigerated centrifuge. The resulting supernatant is designated serum. Following centrifugation, it is important to immediately transfer the liquid component (serum) into a clean microcentrifuge tube using a pipette (Figure 5).

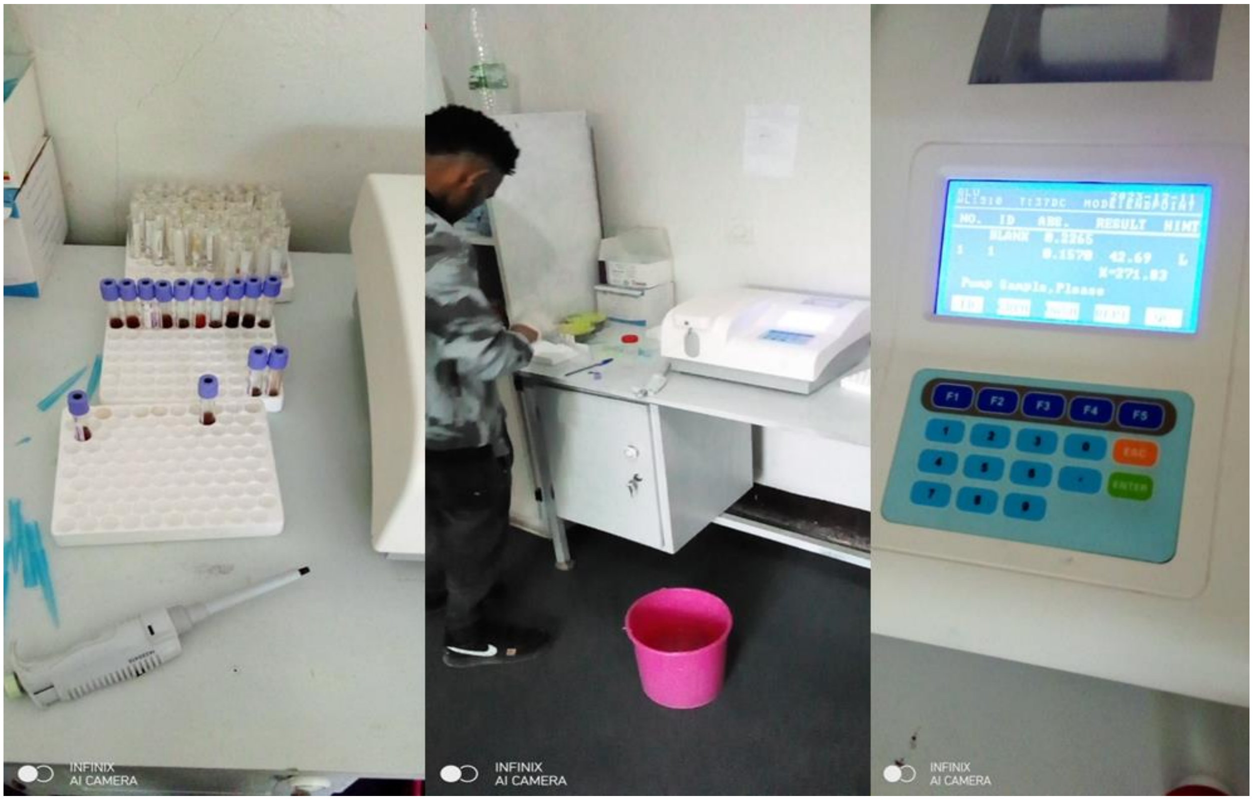

**Figure 5.** Blood sample preparation and analysis.

### 3.8. Sample Preparation and Proximate Analysis of Fish Fillets

The fish for fillets sample was taken from ponds randomly using the same procedure as sampling for blood biochemistry analysis used to determine the moisture content, crude protein, crude fat, and ash content by the methods of AOAC (2005). The sample was dried in a drying oven at 65$^{o}$C for 72 hours at the Batu Fish and Other Aquatic Life Research Centre General Laboratory, and the overall analysis was conducted at Jimma University College of Agriculture and Veterinary Medicine, Nutrition Laboratory.

### 3.8.1. Determination of moisture contents

The estimation of moisture content in fish fillets tissue sample used for the study were determined by applying oven drying method as specified by ASABE (2011). Before analysing, the fresh samples were weighted in grams and records the measures. After weighing the sample were put into an oven for drying at about 65°C for almost 72 hours. After being dry the samples were then immediately cooled by using desiccators, and weighted again and the weight were recorded. At the point that it stops changing, the difference between the initial weight and the final weight expresses the moisture content that is the weight loss. In the last the moisture content estimation was obtained by applying the following equation:

$$\text{Moisture content (\%)} = \frac{\mathrm{M1}-\mathrm{M2}}{\mathrm{M1}} * 100$$

Where *M1* is the initial weight of the sample or fresh weight in gram

*M2* is the final weight of the sample or dried weight of the sample in gram

### 3.8.2. Determination of crude protein percentage

The estimation of protein contents of the samples was made by total nitrogen estimated using the Kjeldahl method with standard method AOAC (2005). It involves the complete digestion of dried samples at first place. Then the liberated ammonia is distilled in to 2% boric acid through distillation process by using bromocresol green methyl red as indicator. Thus the nitrogen amount obtained was changed to percentage protein with multiplying total protein by factor 6.25 using the following formula:

$$\text{Crude Protein (\%)} = \text{N\%} * 6.25$$

### 3.8.3. Determination of fat contents

Fat contents of already homogenized samples were determined by using Soxhlet's method for almost 6 hours at 65°C. The evaporation of solvent contents as followed as fat contents was drawn-out. Finally, the drawn-out material was weighted and calculated (Adewumi *et al*., 2014).

$$\text{Crude fat (\%)} = \frac{W1-W2}{W3} * 100$$

Where ***W1*** is weight of beaker and fat residue in grams

***W2*** is tare weight of the beaker in gram

***W3*** is initial weight of dried sample in gram

### 3.8.4. Determination of total ash contents

The ash content is an indicator of product quality and the nutritional value of food products. The ash contents of fish sample was determined possible by igniting the sample in a hot muffle furnace at about 550°C for 5-6 hours until the sample was completely free from carbon particles. After burning in furnace the sample were set on desiccators until properly cooled then weighted again based on the standard procedure method AOAC (2005). The percentage of ash contents of samples were calculated as follow:

$$\text{Ash (\%)} = \frac{W1-W2}{W3-W2} * 100$$

Where *W1* is dry weight of crucible and ash in gram

*W2* is tare weight of the crucible in gram

*W3* is initial weight of crucible and dried sample in gram

### 3.9. Statistical Analysis

Microsoft Excel 2010 was used to record data, and made comparison graphs. Data of length and weight measurements at specific intervals was statistically analysed by using the statistical Analysis software (SAS) programme. To compare the different means and make an ANOVA to test the significance, and statistical analysis software (SAS) of version 9.3 was employed.

# 4. RESULTS AND DISCUSSION

## 4.1. Growth Performance and Feed Utilisation of African Catfish

Table 2 demonstrate that the growth performance and feed utilization results of fingerling of Claries gariepinus reared in a concrete pond at different stocking densities. The results show that, with the exception of mean length gain, stocking densities had a significant impact on mean weight gain, specific growth rate, feed efficiency, and feed conversion ratio.

**Table 2.** Growth performance and feed utilisation of fish (Mean±SE)

| | **Stocking densities (Fish $m^{-2}$)** | | |
|---|---|---|---|
| **Parameters** | **$T_I$** | **$T_{II}$** | **$T_{III}$** |
| Culturing period | 120 | 120 | 120 |
| Initial weight(g/fish) | 65.07±1.13 | 65.30±1.14 | 61.96±1.08 |
| Initial length(cm) | 18.10±0.43 | 18.04±0.43 | 17.72±0.42 |
| Final weight(g/fish) | $151.81\pm1.93^{a}$ | $140.00\pm1.78^{b}$ | $128.43\pm1.63^{c}$ |
| Final length(cm) | $27.16\pm0.32^{a}$ | $26.63\pm0.32^{a}$ | $25.63\pm0.30^{b}$ |
| MWG(g/fish) | $86.74\pm2.87^{a}$ | $74.70\pm2.47^{b}$ | $66.47\pm2.19^{b}$ |
| MLG(cm) | 9.18±0.35 | 8.59±0.33 | 7.91±0.29 |
| SGR(% per day) | $0.71\pm0.02^{a}$ | $0.64\pm0.02^{ab}$ | $0.6\pm0.01^{b}$ |
| FE | $0.46\pm0.01^{a}$ | $0.40\pm0.01^{b}$ | $0.35\pm0.01^{c}$ |
| FCR | $2.15\pm0.04^{c}$ | $2.47\pm0.05^{b}$ | $2.83\pm0.05^{a}$ |

Means with the same superscript within the same raw are not statistically different at *($p<0.05$)*; *MWG*= mean weight gain, *SGR*= specific growth rate, *FCR*= feed conversion ratio, *FE*= feed efficiency, *T*= treatment, *SE*= Standard error.

### 4.1.1. Weight and length gain of African catfish

The mean final weight of the fish was 151.81g, 140.00g, and 128.43g recorded for treatment I, II, and III respectively. The highest mean final weight (151.81g) was recorded in treatment I (lower stocking densities), however the lowest mean final weight (128.43g) was obtained in treatment III (higher stocking densities). Based on ANOVA analysis there is significant difference among all treatments at ($p<0.05$).

The fish weight gain is an important consideration in aquaculture, since it directly impacts the growth and productivity of the fish. In an aquatic environment, Growth is the principal key to energy loss or gains; which can be measured mostly by determining the weight gain (Magouz *et al*., 2019). The highest mean weight gain (86.74 g) was obtained in treatment I, however the lowest weight gain (66.47 g) was obtained in treatment III, which was significantly different at ($p<0.05$) based on ANOVA analysis. The results showed that lower stocking densities are more favourable for higher weight gain in the fish when fed the same feed in concrete ponds. This could be attributed to reduced competition for food and space, which allows the fish to feed more efficiently and to grow better. According to related study reported by Kareem and Olanrewaju (2015) revealed that fish in treatment LD had the highest mean final weight gain (2.42 g) followed by fish in treatment MD (1.94 g), and treatment HD (1.35 g), respectively. However the current results higher than the results of Kareem and Olanrewaju (2015), this might be due to rearing period and age of the fingerling at first stocking.

The mean final length recorded for treatment I, II, and III were 27.16cm, 26.63cm, and 25.63cm respectively. The highest mean final length (27.16cm) was recorded in treatment I, however the lowest mean final length (25.63cm) was obtained in treatment III. There is significant difference among higher and lower stocking densities treatments at ($p<0.05$).

The mean length gain recorded for treatment I, II, and III were 9.18 cm, 8.59 cm, and 7.91cm respectively. However there is no significant difference among all treatments of the experimental group.

### 4.1.2. Specific growth rate

The specific growth rate of catfish, on 120 days of experimental period in concrete ponds recorded for treatments I, II, and III were 0.71 g, 0.64 g, and 0.6 g respectively (Table 2). The treatment I with lower stocking densities had highest average of SGR (0.71 g). Stocking densities have been shown to affect Catfish growth and performance. High stocking densities have resulted in stress and subsequently, negative impacts on fish growth and health (Langi *et al*., 2024).

The specific growth rate can decrease at higher stocking densities due to increased competition for resources such as food and space. Consequently, the specific growth rate was lower at higher stocking densities when compared to lower stocking densities. Hitzfelder *et al*. (2006) reported similar effects of high stocking densities on growth and SGR. These results also agreed with the finding of Mohammed. (2001), who mentioned that the specific growth rate decreased from 0.87 g to 0.46 g by increasing the stocking rate from 5 to 10fish/m$^3$. Kareem and Olanrewaju (2015) also report that the specific growth rates were significantly different amongst treatments at ($p<0.05$). Treatment LD with the least stocking density fish had an SGR of 0.95 g while, treatment HD stocking density had the least specific growth rate of 0.66 g.

### 4.1.3. Feed conversion ratio and feed efficiency

Understanding the results of the feed conversion ratio (FCR) of the fish indicated in Table 2 showed an increasing trend with increasing stocking densities from 2.15 for lower stocking densities (27 fish/m$^2$) followed by medium stocking densities (37 fish/m$^2$) which are 2.47, and reach 2.83 for highest stocking densities treatment (47 fish/m$^2$). The mean Feed conversion ratio of the fingerlings were significantly different among all treatments at ($p<0.05$) based on ANOVA analysis. This increment may be due to competition on feed as a result of increasing fish stocking densities. The results correlated with the finding of Mohammed (2001) who revealed that feed conversion ratio increased from 3.14 (for stocking 5 fish/m$^3$) to reach 7.01 in the highest stocking density treatment (10 fish/m$^3$). However, the results contradict with the finding of Gizaw (2017) who revealed that in the present study FCR decreased as stocking density increased. The feed conversion ratio results of current study were lower than finding of Mohammed (2001). This may be due to the quality of feed used during experimental period.

The mean feed efficiency of the fingerlings was 0.46, 0.40, and 0.35 for treatments I, II, and III, respectively (Table 2). The highest Feed efficiency (0.46) was recorded in treatment I followed by II (0.40). However, the lowest Feed efficiency (0.35) was recorded in treatment III which was stocked with 47fish/m$^2$. The recorded mean Feed efficiency of the fingerlings indicates that there is a significant difference among all treatments at ($p<0.05$) based on ANOVA analysis. The results showed that Feed efficiency was decreased with increasing stocking densities (Oké and Goosen, 2019).

### 4.2. Survival Rate and Welfare of Fingerlings

#### 4.2.1 Survival rate

The adapted fish are placed in the cultivation pond once it has been properly prepared, and the cultivation stage is then initiated. Following their initial month of culture in a healthy state, some fish in $P_2$ as much as one fish and $P_4$ and $P_9$ up to two fish from each pond died during the first month of cultivation. There were two dead fish in $P_3$ and one dead fish in each of $P_8$ and $P_9$ in the second month, along with the only two dead fish found in $P_3$ during the third month of culturing period.

**Table 3.** Survival rate of African catfish under different Stocking densities (Mean ± SE)

| | **Stocking densities (Fish m$^{-2}$)** | | |
|---|---|---|---|
| **Parameters** | **$T_I$** | **$T_{II}$** | **$T_{III}$** |
| Culturing period | 120 | 120 | 120 |
| Number of fish stocked | 81 | 111 | 141 |
| Number of fish harvested | 78 | 94 | 110 |
| SR | $96.3 \pm 3.39^a$ | $84.7 \pm 3.39^{ab}$ | $78 \pm 3.39^b$ |
| CF | 0.76±0.03 | 0.73±0.02 | 0.75±0.02 |

Means with the same superscript within the same raw are not statistically significantly different at ($p<0.05$); *SR*= survival rate, *CF*= Condition factor, *T*= treatment, *SE*= Standard error.

After 120 day of culturing period the survival rate (SR) of the cultured fish was measured (Table 3). The survival rate recorded for the treatments I, II, and III, were 96.3%, 84.7%, and 78% respectively (Table 3). The highest SR (96.3%) was recorded for treatment I followed by treatment II, SR (84.7%), while the lowest SR (78%) was recorded for treatment III with a high stocking density of 47fish/m$^2$. The survival rate was significantly different among the lowest and highest stocking densities treatments at ($p<0.05$) based on ANOVA analysis (Rahman *et al*., 2005). Survival rates of African catfish in concrete ponds are shown to be highly affected by stocking densities that can reduce the survival rate of cultured fish. If environmental variables and husbandry necessities in the rearing environment remain constant, survival rate and growth are directly proportional to each other (North *et al*., 2006). The current results of survival rate were opposed with the finding of Gizaw (2017) who has been emphasised that the survival rate recorded in this study was generally high and were not density dependent. This might be as a result of management condition.

### 4.2.2. Welfare and condition factor of fish

The condition factor results obtained in the current study for treatment I, II, and III were 0.76, 0.73, and 0.75 respectively, with the best value (0.76) were obtained from treatment I. Nevertheless, analysis of variance indicated that statistically there is no longer significance difference between all treatment of experimental group at ($p<0.05$). The current study's findings were in line with those of Gizaw (2017), who reported that the condition factor obtained during the study ranged between 0.504-0.54, with treatment I and III recording the best values, at 0.54 and 0.522, respectively. However, there were some numerical difference between the current study and previous study of Gizaw (2017). This numerical disparity's because of certain management systems and environmental variations. Creating a stress-free environment is important for the welfare of fingerlings. This includes providing adequate space, proper pond conditions, and minimizing disturbances. Stress can weaken the immune system of the fingerlings, making them more susceptible to diseases and health issues (Gabriel, 2016).

**Fig.** Barbell erosion; **Fig. b** Pus forming on their fin and body; **Fig. c** Skin lesion on some part of the body. This  all are characterized by high stocking densities.

**Figure 6.** External skin lesions and fin and barbell erosions due to aggressive behaviour related to high fish stocking density

### 4.3. Water Quality Parameters

Table 4 shows the result of the water quality parameter of African catfish stocked at different densities in concrete ponds.

**Table 4.** Water quality parameters of African catfish (Mean±SE)

| | **Stocking density** | | |
|---|---|---|---|
| **Parameter** | **$T_I$** | **$T_{II}$** | **$T_{III}$** |
| Temperature ($^0$C) | 21.66±0.15 | 21.83±0.15 | 21.94±0.15 |
| PH | $8.95 \pm 0.007^a$ | $8.91 \pm 0.007^b$ | $8.84 \pm 0.007^c$ |
| Turbidity (NTU) | $5.11 \pm 0.34^b$ | $6.21 \pm 0.41^b$ | $8.19 \pm 0.55^a$ |

Means with the same superscript within the same raw are not statistically different (*p<0.05*); *PH*: hydrogen ion concentration, *T*: treatment and *SE*: standard error.

The water temperature of all treatments ranged from 19.8 - 23$^o$C. The mean water temperature for treatments I, II, and III, was 21.65, 21.82, and 21.9 respectively (Table 4). ANOVA analysis indicates that the mean temperature of all treatments was not significantly different at ($p<0.05$). The recorded water temperature in the current study were almost below the tolerable temperature range recommended for African catfish production which ranged between 26 °C and 32 °C were satisfactory for the growth of African catfish fingerlings (Kasihmuddin *et al*., 2021). However, the result was agreed with the finding of Duncan (2002) who reported that a temperature range of 20$^o$C-33$^o$C was favourable for the culture of catfishes. The fish may decrease feeding as a result of this temperature reduction. Particularly, in the morning, when the temperature is lower the feed supplied to the fish left and floated over pond water. However, in the afternoon when the temperature rises they fed right away.

According to Kasihmuddin *et al*. (2021) Variation in rearing temperature did influence both the FCR and FCE of the fish due to inappropriate feeding. Therefore, African catfish require specific temperature ranges for optimal growth and health (Ogunji, and Awoke, 2017). The results of the present study were lower than the findings of Gizaw (2017) who reports that the temperature range recorded during the course of the present study ranged between 22.63-22.95$^0$C. This variation in water temperature might be due to weather condition or seasons variation.

The water pH (hydrogen ion concentration) of all treatments ranged from 8.6-9. These show that the concentration of pH in all the three treatments were alkaline and were within the optimal recommended range of pH (6.0 9.0) for fresh water culture of catfish (Momoh, and Solomon, 2017). The mean pH recorded for the treatments I, II, and III, was 8.95, 8.91, and 8.84 respectively. Treatment I had the heights pH value of (8.95) while the lowest pH value (8.84) was recorded for treatment III with a high stocking density of 47fish/m$^2$. Based on ANOVA analysis the pH measurement was statistically different among all treatments at ($p<0.05$).

Turbidity is a measure of the ability of the water to transmit light. Turbidity caused by suspended solids in the water restricts light penetration, limits photosynthesis, and inhibits algal growth and therefore oxygen production (Echiegu *et al*., 2018). Water turbidity, or clarity, can affect the feeding behaviour and stress levels of African catfish. Monitoring and maintaining appropriate turbidity levels is important for their overall well-being. Turbidity levels as low as 5 NTU can begin to stress fish within a few hours (Echiegu *et al*., 2018). Turbidity level recorded for the treatments I, II, and III, were 5.11 NTU, 6.21 NTU, and 8.19 NTU respectively. The lowest value (5.11 NTU) was recorded for treatment I while the highest value (8.19) was recorded for treatment III with a high stocking density of 47 fish. The means turbidity level was significantly different among the lowest and highest stocking densities treatments at ($p<0.05$) based on ANOVA analysis.

## 4.4. Blood Serum Biochemical

In the present study, blood serum samples of African catfish were measured for indications of biomarkers, particularly on three parameters: total protein (TP), total glucose (GLU), and total cholesterol (CHOLE). Monitoring these biomarkers in the blood serum biochemistry of African catfish can provide important information about their overall health, nutritional status, and metabolic function (Saha *et al*., 2022).

**Table 5.** Blood serum biochemistry test results (Mean ± SE)

| | **Stocking densities** | | | **Normal range** |
|---|---|---|---|---|
| **Parameters** | **$T_I$** | **$T_{II}$** | **$T_{III}$** | **Bonny fish** |
| TP(mg/dl) | 4.62±0.25 | 4.52±0.22 | 4.5±0.22 | 4-7 mg/dl |
| GLU(mg/dl) | 62.56±7.06 | 69.67±7.16 | 45.28±7.00 | 40-100 mg/dl |
| CHOLE(mg/dl) | 42.66±3.12 | 49.22±3.12 | 38.86±3.12 | 0-150 mg/dl |

Means with the same superscript within the same raw are not statistically different at $(p<0.05)$; *TP*: total protein, *GLU*: glucose, *CHOLE*: cholesterol

Total protein is reflects the overall nutritional status and liver function of the fish. The average total protein results recorded for treatment I, II, and III, was 4.62, 4.52, and 4.5 respectively. These values suggest that the total protein levels are consistent and within a narrow range. However, the effect did not show any appreciable reduction with increasing in stocking densities and was not significantly different among all treatment within different stocking densities at ($p<0.05$) based on ANOVA analysis. The same results are reported by Ajani *et al.* (2015) High stocking densities gave no significant variation in plasma protein level.

The level of glucose in the blood serum can indicate the fish's metabolic status and ability to regulate blood sugar levels (Agina *et al*., 2020). The Mean glucose level for treatments I, II, and III, was 62.56, 69.67, and 45.28 respectively (Table 5). However, ANOVA analysis indicates that the mean glucose level of all treatments was not significantly different at ($p<0.05$). The results suggest that the stocking density of African catfish may not have a significant impact on their glucose levels within the ranges tested (27, 37, and 47 fish/$m^2$). The results of current study were contrary to the idea of Ajani *et al.* (2015) who report that the plasma glucose of the fish increases with increase in stocking density and lowest value recorded at lowest stocking density.

Total cholesterol levels can be an indicator of the overall health and well-being of the fish. Abnormal cholesterol levels can be associated with various health issues, including cardiovascular problems and fatty liver disease. The Mean cholesterol level for treatments I, II, and III, was 42.66, 49.22, and 38.86 respectively (Table 5). However, ANOVA analysis indicates that the mean cholesterol level had no significant difference among all treatments at ($p<0.05$).

### 4.5. Proximate Composition of African Catfish Fillet

The biochemical composition results of African Catfish fillets collected from the ponds was carried out to find how different stocking densities affected the fillet's proximate composition (Table 6).

**Table 6.** Proximate composition of fish fillets

| Parameter | $T_I$ | $T_{II}$ | $T_{III}$ | Overall mean |
|---|---|---|---|---|
| MC | 76.03±0.51 | 74.48±0.50 | 74.70±0.50 | 75.07 |
| DM | 23.96±0.48 | 25.51±0.51 | 25.30±0.50 | 24.92 |
| CP | 20.47±0.79 | 21.26±0.82 | 21.82±0.84 | 21.18 |
| EE | $8.36±1.24^b$ | $7.35±1.09^b$ | $12.03±1.78^a$ | 9.25 |
| Ash | $5.33±0.10^a$ | $4.26±0.08^c$ | $4.82±0.09^b$ | 4.80 |

Means with the same superscript within the same raw are not statistically different ($p<0.05$); *EE*: ether extract

According to the results revealed above the moisture contents of the fillets among the three treatments were observed to be 76 in treatment one, 74.5 in treatment two, and 74.7 in treatment three (Table 6). The overall mean value of moisture content in the current study was 75.07% which is a suitable level of moisture and falls within the acceptable level of a standard range of moisture content of (60 - 84%) reported by Clucas and Ward (1996). It is a precursor of the relative content of protein, lipid and energy (Msuku and Kapute, 2018).

The current results agreed with the idea of Silva *et al*. (2015) who reported that moisture and ash contents decreased linearly with the increase in body weight (stocking densities).

The moisture content of catfish in the current study was lower than that reported by Adeyemi and Akande (2011) who stated that the moisture content in catfish fillet was (77.2%). However the result was higher than the finding of Zhu *et al*. (2015) who reported that catfish fillets had a moisture content of 68.77%. This variation might be due to different level of stocking density, feeding, stress and water quality which affects the fish fillets water holding capacity.

The fat content of the fish fillet was (8.36%) in treatment of LD, (7.35%) in treatment of MD, and (12%) in treatment of HD fish (Table 6). This result indicates that there were probably increased trends of fat content of fish fillet with increasing stocking densities. The highest value of fat content (12%) was found in higher stocking densities however, the lowest value of fat content (7.35%) was found in medium stocking densities. The overall mean value of fat content in the current study was (9.25%).

According to the ANOVA table, there was a significant difference between higher and lower stocking densities. The current results was in consistence with the idea of Silva *et al*. (2015) who revealed that the body fat content increased linearly as a function of increase body weight (stocking densities). The overall mean results of present study was higher than the results showed by Abdel-Mobdy *et al*. (2021) who mentioned that the fat contents of catfish fillets were 8.10±0.09. However it is lower than the finding of Zhu *et al*. (2015) who revealed that fat content of untreated raw catfish fillets was 13.47±0.81%.

The ash content is the inorganic remaining which is obtained when all the organic matter is burned off. It is always found in small quantity. It was detected that the percentage of ash was (5.33%) in treatment of LD, (4.26%) in treatment of MD, and (4.82%) in treatment of HD fish. The overall mean of ash (4.80%) was observed in the sampled fish fillet. Based on ANOVA table there is a significant different among all treatment of experimental group at ($p<0.05$). The results was lined with the previous findings of Edea *et al*. (2018) who reported that in both Nile tilapia and African catfish there is a decrease of the ash content with the increase of body weight. The results of current study was higher than the results of Abdel-

Mobdy *et al*. (2021) and Deng, (2018) who reports that The ash content of catfish meat was 1.05±0.14 and 1.7±0.06% respectively.

Regarding protein content the mean CP (20.47) was found in the treatment I, the mean CP (21.26) was found in the treatment of medium stocking densities, and the mean CP (21.82) was found in higher stocking densities fish (Table 6). Accordingly, the results show that there is no significant difference amongst the mean value of all treatments. This result was agreed with the present results of current study on blood serum biochemistry analysis which is no difference on serum total protein of the fish. Silva *et al*. (2015) was reported that increased crude protein contents of fish fillet with increased bodyweight. The results of current study were higher than the results reported by Abdel-Mobdy *et al*. (2021) who show that the crude proteins of catfish fillets were 19.03±0.46. This difference may be due to management systems and feed quality used for the experiment.

# 5. CONCLUSION AND RECOMMENDATIONS

## 5.1. Conclusion

The findings of the present study revealed that stocking densities influenced the mean weight gain, specific growth rate, feed efficiency, feed conversion ratio, survival rate, and welfare of the fingerlings. Particularly the weight gain of the fish was affected by stocking densities. The results indicate that lower stocking densities are more favourable for higher weight gain in the fish when fed the same feed in concrete ponds. This could be attributed to reduced competition for food and space, which allows the fish to feed more efficiently and to grow better. The best FCR was obtained from lower stocking densities.

Moreover, the results showed an increasing trend of feed conversion ratio with increasing stocking. This increment may be due to competition on feed and space as a result of increasing fish stocking densities. The mean Feed conversion ratio and feed efficiency of the fingerlings were significantly different among all treatments. The survival rate and welfare of the fish are also affected by stocking densities. The blood glucose level and total cholesterol had no linear relationship with stocking densities. The best values of both glucose and cholesterol levels were recorded in treatment with medium stocking densities.

However, water temperature, turbidity, and feed conversion ratio were increased with increasing stocking densities. The moisture content and crude protein contents of fish fillets had no significant difference among all treatments. The moisture contents of the fillets were falls within the acceptable level of a standard range of moisture content of (60 - 84%). The moisture content of catfish is important and needs consideration in preserving the fish fillet. The fat and ash contents of the fish fillet had significant differences among all treatments.

Generally, higher stocking densities were found to affect various aspects of the cultured fish in concrete ponds under current management systems. Because of that, it is important to manipulate stocking densities, to determine the optimum number of fish that can be raised in a given pond size to achieve the highest growth rates, standard water quality, and optimal feed efficiency ratios.

## 5.2. Recommendations

The following recommendations are made based on the findings of the present study:

- Further research efforts are necessary to evaluate the growth performance, feed utilization, and survival rate of African catfish under different stocking densities for different production systems because optimum stocking densities are the basis for aquaculture growth and development.
- According to the current finding, lower stocking densities, with 27 fish per meter square, were recommended for optimal results in terms of weight gain, specific growth rate, and feed efficiency ratio, with the exception of some parameters.

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# APPENDICES

## Appendix 1: Appendix Tables

**Appendix Table I.** Components of the feeds used for current study

| SI. No. | Parameters | Starter feed | Grower feed | Finisher Feed | Brooder Feed |
|---|---|---|---|---|---|
| i) | Fish weight (g) | < 50 | 50-200 | ≥ 200 | ≥ 50 females)<br>≥ 80 (males) |
| ii) | Feeding rate% body weight | 6 – 8 | 3 | 2 – 4 | 4 – 6 |
| iii) | Crude protein % (min). | 35 | 30 | 30 | 32 |
| iv) | Energy (DE) Kcal/Kg (min). | 2500 | 2750 | 2900 | 2800 |
| v) | Amino acid levels | | | | |
| | a) Lysine g/kg (min). | 2.1 | 1.7 | 1.7 | 1.7 |
| | b) Methionine g/kg (min | 0.9 | 0.8 | 0.8 | 0.8 |
| | c) Methionine +cysteine | 1.4 | 1.1 | 1.1 | 1.1 |
| | d) Threonine | 1.3 | 1.0 | 1.0 | 1.0 |
| | e) Tryptophan | 0.5 | 0.4 | 0.4 | 0.4 |
| vi) | Crude fiber % (max). | 4 | 10 | 10 | 10 |
| vii) | Crude fat % . | 5-12 | 5-15 | 5-15 | 5-15 |
| Viii) | Fatty Acids | | | | |
| | a) Linoleic acid | 0.5 - 1.0 | 0.5 - 1.0 | 0.5 - 1.0 | 0.5 - 1.0 |
| viii) | Pellet size(mm) | 2 (max) | 2-5 | 4-6 | 2-5 |
| ix) | Pellets should float on water for (minutes-minimum) | 2 | 2 | 2 | 2 |
| x) | Moisture content of pellets (% Max). | 10 | 10 | 10 | 10 |
| xi) | Calcium % | 0.4 - 0.7 | 0.4 - 0.7 | 0.4 - 0.7 | 0.4 - 0.65 |
| xii) | Phosphorus % | 0.8 – 1.5 | 0.8 – 1.5 | 0.8 – 1.5 | 0.8 – 1.5 |

***Source*:** Standard, F.D.K., 2010

**Appendix Table II**. Level of minerals and vitamins in the experimental feeds

| **SI. No.** | **Minerals and Vitamins on dry matter basis per kg of feed (min)** | **Starter Feed** | **Grower feed** | **Finisher feed** | **Brooder feed** |
|---|---|---|---|---|---|
| 1 | Copper mg/Kg | 6 | 3 | 6 | 6 |
| 2 | Zinc mg/Kg | 100 | 50 | 100 | 100 |
| 3 | Manganese mg/Kg | 50 | 25 | 50 | 50 |
| 4 | Iodine mg/Kg | 6 | 3 | 6 | 6 |
| 5 | Iron mg/Kg | 60 | 30 | 60 | 60 |
| 6 | Vitamin A IU/Kg | 3000 | 1500 | 3000 | 3000 |
| 7 | Vitamin D IU/Kg | 1500 | 750 | 1500 | 1500 |
| 8 | Choline mg/Kg | 1000 | 600 | 1000 | 1000 |
| 9 | Vitamin E mg/Kg | 120 | 60 | 120 | 120 |
| 10 | Riboflavin mg/Kg B2 | 24 | 12 | 24 | 24 |
| 11 | Pyridoxine mg/Kg B6 | 15 | 13 | 13 | 15 |
| 12 | Pantothenic mg/Kg | 48 | 24 | 48 | 48 |
| 13 | Biotin mg/Kg | 0.2 | 0.1 | 0.2 | 0.2 |
| 14 | Ascorbic acid mg/Kg | 300 | 150 | 300 | 300 |
| 15 | Inositol mg/Kg | 150 | 75 | 150 | 150 |
| 16 | Thiamine mg/Kg B1 | 18 | 9 | 18 | 18 |

***Source*:** Standard, F.D.K., 2010

**Appendix Table III.** Total length and weight of African catfish (Mean±SE)

| | **Stocking density** | | | | | |
|---|---|---|---|---|---|---|
| **Period** | **$T_I$** | | **$T_{II}$** | | **$T_{III}$** | |
| | TL(cm) | TW(g) | TL(cm) | TW(g) | TL(cm) | TW(g) |
| $M_1$ | $18.10 \pm 0.43^a$ | $65.07 \pm 1.13^a$ | $18.04 \pm 0.43^a$ | $65.30 \pm 1.14^a$ | $17.72 \pm 0.42^a$ | $61.96 \pm 1.08^a$ |
| $M_2$ | $23.42 \pm 0.13^a$ | $87.58 \pm 1.60^a$ | $23.10 \pm 0.12^a$ | $86.84 \pm 1.59^a$ | $22.91 \pm 0.12^a$ | $85.94 \pm 1.57^a$ |
| $M_3$ | $25.69 \pm 0.26^a$ | $112.77 \pm 1.30^a$ | $25.05 \pm 0.25^{ab}$ | $110.44 \pm 1.28^a$ | $24.10 \pm 0.24^b$ | $100.25 \pm 1.25^b$ |
| $M_4$ | $27.16 \pm 0.32^a$ | $151.81 \pm 1.93^a$ | $26.63 \pm 0.32^{ab}$ | $140.00 \pm 1.78^b$ | $25.63 \pm 0.30^b$ | $128.43 \pm 1.63^c$ |

Means with the same superscript within the same raw are not statistically different ($p<0.05$); *TL*= Total length, *TW*= Total weight, *T*= treatment, *M*= month, *SE*= Standard error

**Appendix Table IV.** Analysis of variance for final weight of African catfish

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 4 | 993.373333 | 248.343333 | 26.01 | 0.0040 |
| Error | 4 | 38.191667 | 9.547917 | | |
| Corrected Total | 8 | 1031.565000 | | | |
| Overall mean | | 140.0833 | | | |
| CV | | 2.205809 | | | |
| SE | | 1.783995 | | | |

**Appendix Table V.** Analysis of variance for weight gain of African catfish

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 4 | 718.8591111 | 179.7147778 | 9.48 | 0.0256 |
| Error | 4 | 75.8145778 | 18.9536444 | | |
| Corrected Total | 8 | 794.6736889 | | | |
| Overall mean | | 75.96889 | | | |
| CV | | 5.730738 | | | |
| SE | | 2.5135396 | | | |

**Appendix Table VI.** Analysis of variance for FCR of African catfish

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 4 | 0.85224444 | 0.21306111 | 30.25 | 0.0030 |
| Error | 4 | 0.02817778 | 0.00704444 | | |
| Corrected Total | 8 | 0.88042222 | | | |
| Overall mean | | 2.485556 | | | |
| CV | | 3.376758 | | | |
| SE | | 0.04845769 | | | |

**Appendix Table VII.** Analysis of variance for FE of African catfish

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 4 | 0.02477778 | 0.00619444 | 15.07 | 0.0111 |
| Error | 4 | 0.00164444 | 0.00041111 | | |
| Corrected Total | 8 | 0.02642222 | | | |
| Overall mean | | 0.405556 | | | |
| CV | | 4.999531 | | | |
| SE | | 0.01170628 | | | |

**Appendix Table VIII.** Analysis of variance for specific growth rate (SGR)

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 4 | 0.01638978 | 0.00409744 | 3.06 | 0.1523 |
| Error | 4 | 0.00536044 | 0.00134011 | | |
| Corrected Total | 8 | 0.02175022 | | | |
| Overall mean | | 0.650444 | | | |
| CV | | 5.628079 | | | |
| SE | | 0.021 | | | |

**Appendix Table IX.** Analysis of variance for Ash contents of fish fillet

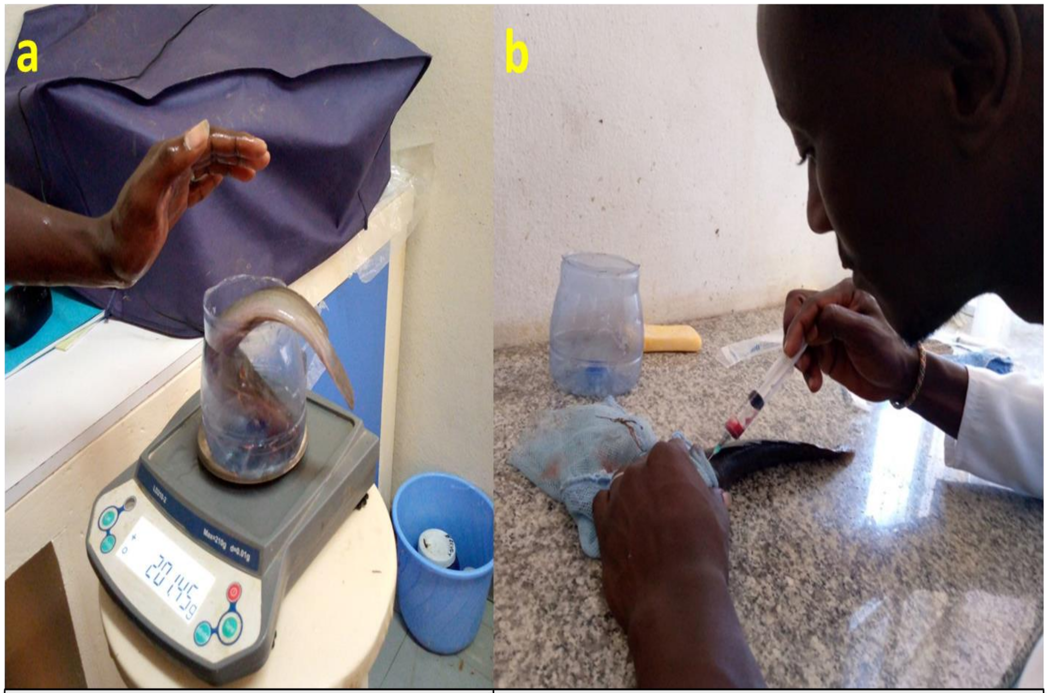
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 4 | 2.84872311 | 0.71218078 | 23.88 | 0.0047 |
| Error | 4 | 0.11931644 | 0.02982911 | | |
| Corrected Total | 8 | 2.96803956 | | | |
| Overall mean | | 4.808778 | | | |
| CV | | 3.591579 | | | |
| SE | | 0.099 | | | |

## Appendix 2: Appendix Figures

**Appendix Figure I.** Experimental fish collection from Koka Reservoir.

Appendix Figure 1. Photo taken during fingerling collection from Koka reservior

**Appendix Figure II.** Weighting and sampling of experimental fish for blood collection.



| **Fig. a** weighting of sample fish. | **Fig. b** Blood sampling from fish by using hypodermic needle. |
|---|---|

**Appendix Figure III.** Blood sample of African catfish

**Appendix Figure IV.** Crude protein determination  of African catfish fillet

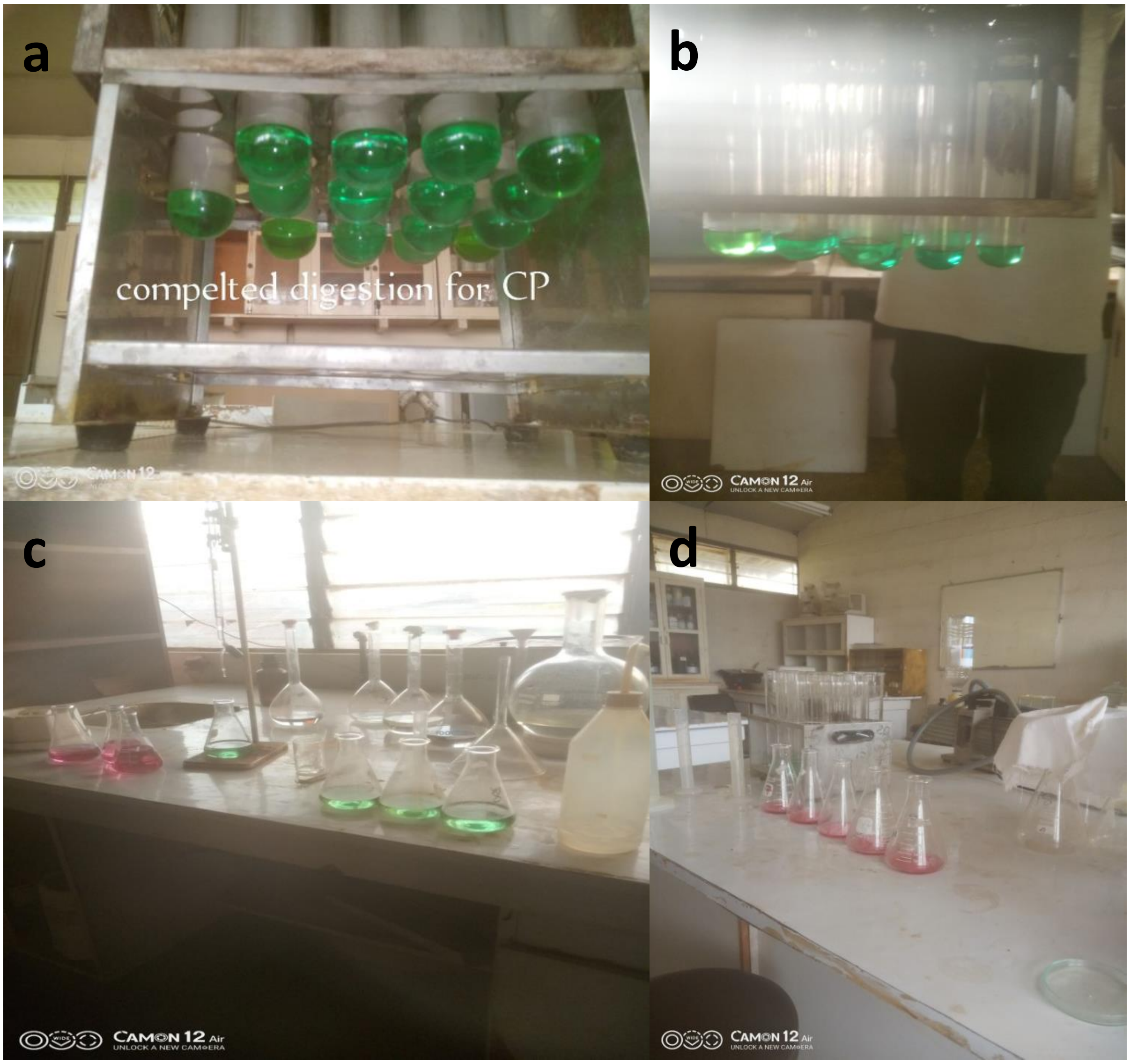


**Figure a & b.** indicates the sample after complete digestion with sulphuric acid

**Figure c.** indicates sample after distillation

**Figure d.** indicates sample after titration

**Appendix Figure V.** Crude fat and ash content determination of African catfish fillet

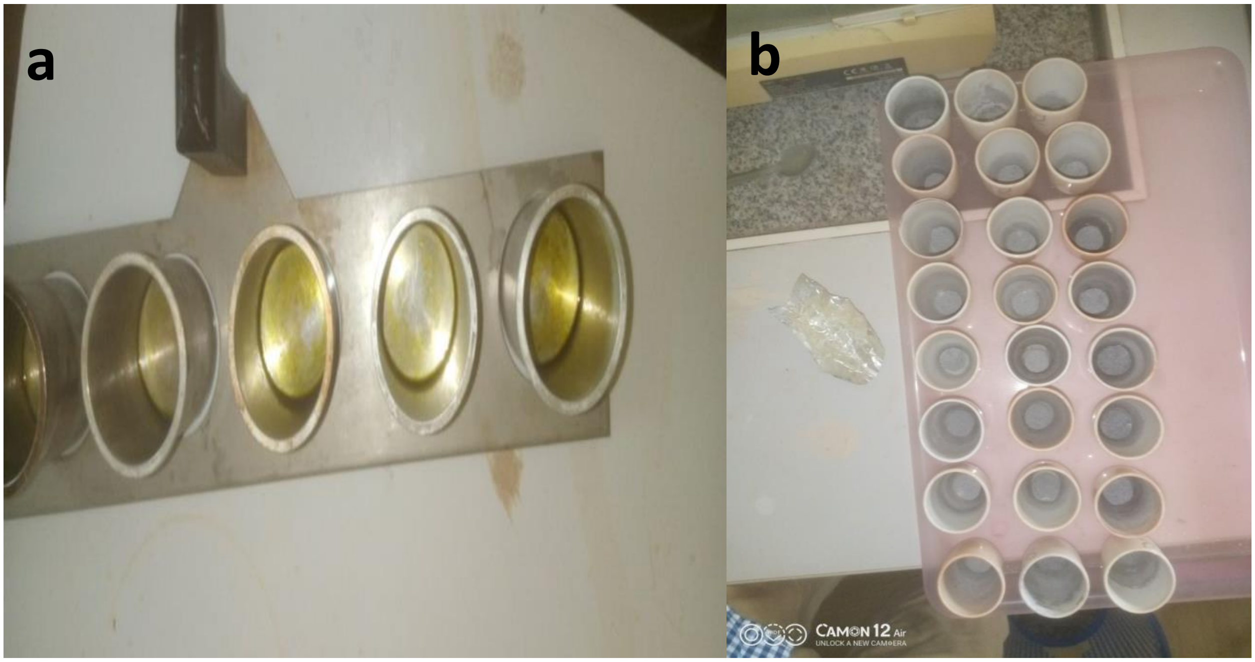
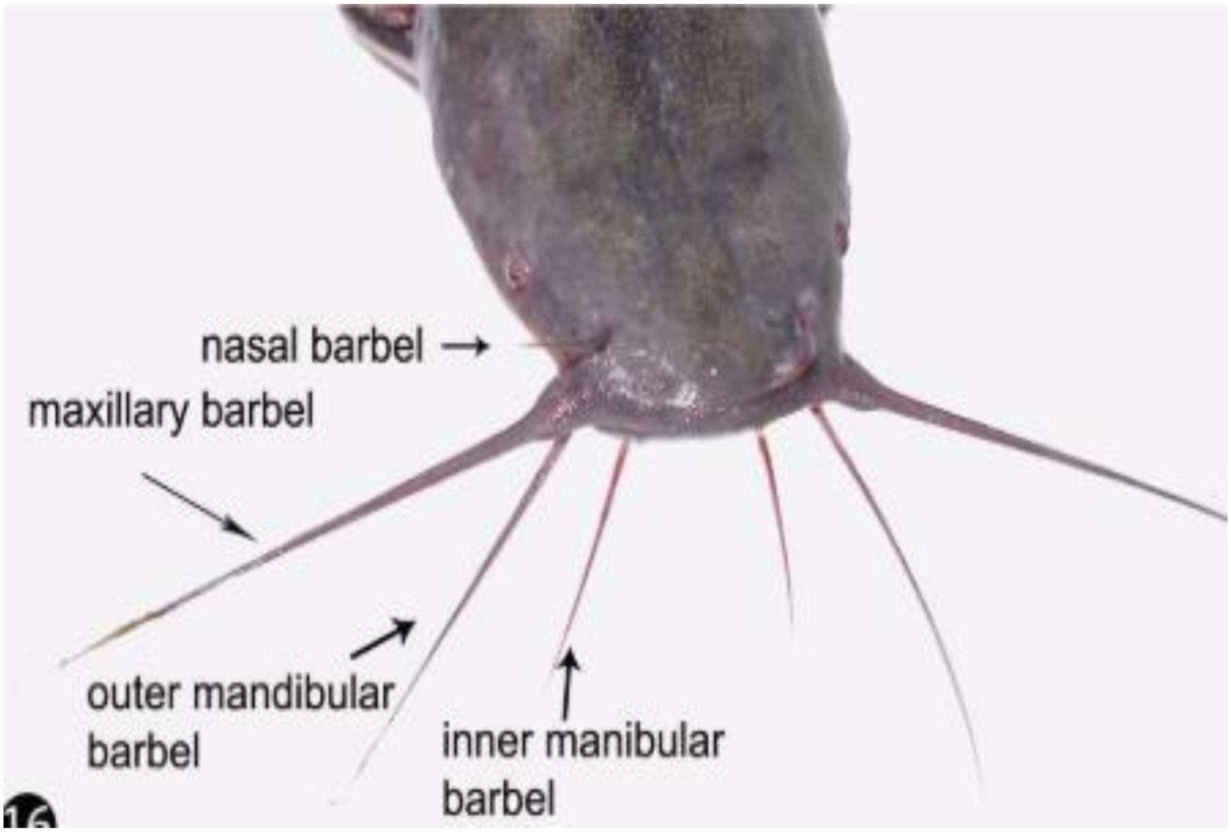


**Figure a**. fat content determination

**Figure b.** ash content determination

**Appendix Figure VI.** Head of the adult African catfish showing the types of barbell



***Source***: El-Gendy *et al.*, 2017.