EVALUATION OF THE GROWTH AND ECONOMIC PERFORMANCE OF *CLARIAS GARIEPINUS* AND *ABELMOSCHUS ESCULENTUS* IN AN OUTDOOR NFT AQUAPONIC SYSTEM

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DEDICATION

This thesis is dedicated to the Almighty God, whose grace, wisdom, and strength have guided me throughout this academic journey.

I also specifically dedicate this work to my lovely soulmate, Fatu Kallon, and my daughter, Eliana Grace Kadiatu Jalloh, for the immense joy, love, and emotional support they have given toward my overall well-being.

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CERTIFICATION

I hereby certify that this work was carried out by **Gibrilla Samuel Jalloh (ID Number: 54935)** of the School of Natural Resources Management, Njala University under my supervision and that this presentation is the true reflection of results obtained by him.

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DEFINITION OF KEY WORDS

Hydroponic: Refers to a method of growing plants without soil, using nutrient-rich water solutions to supply essential minerals directly to plant roots.

Aquaponics: A sustainable agricultural system that combines aquaculture (fish farming) with hydroponics (soil-less plant cultivation) to optimize resource use and production efficiency.

Nutrient Film Technique (NFT): A hydroponic method where a thin layer of nutrient-rich water flows continuously over the roots of plants, providing nutrients while allowing aeration.

Evaluation: In this study, evaluation refers to the systematic process of assessing and analyzing the biological and economic performance of both fish (*Clarias gariepinus*) and crop (*Abelmoschus esculentus*) within the NFT aquaponic system.

Growth: Denotes the increase in length, weight, and overall condition factor of *Clarias gariepinus*, as well as the development and yield performance of *Abelmoschus esculentus*.

Economic Performance: Refers to the financial feasibility of the NFT aquaponic system, including input costs, revenue from fish and okra production, profitability, and cost–benefit analysis compared with conventional farming methods.

Clarias gariepinus: Commonly known as African catfish, *Clarias gariepinus* is a widely farmed freshwater species valued for its rapid growth, hardiness, and economic importance in aquaculture across Africa.

Abelmoschus esculentus: Also known as okra, *Abelmoschus esculentus* is a nutrient-rich vegetable crop valued for its edible pods and its role in food security and income generation.

Outdoor System: refers to the cultivation setup exposed to natural climatic conditions such as sunlight, rainfall, and temperature fluctuations, unlike controlled indoor environments.

Length-Weight Relationship (LWR): A mathematical model, expressed as $W = aL^b$ used to describe how the weight of a fish changes relative to its length and to assess growth patterns.

Condition Factor (K): A numerical index that indicates the health, robustness, or "well-being" of fish, calculated from the length and weight of the fish.

ACRONYMS AND ABBREVIATIONS

NFT	Nutrient Film Technique
DO	Dissolved Oxygen
TDS	Total Dissolved Solids
pH	Potential of Hydrogen
C. gariepinus	*Clarias gariepinus* (African catfish)
A. esculentus	*Abelmoschus esculentus* (Okra)
W	Weight (g)
L	Length (cm)
R^2	Coefficient of Determination

ABSTRACT

Innovative food production systems are essential for addressing food insecurity, resource scarcity, and environmental challenges. Among these, aquaponics particularly the Nutrient Film Technique (NFT) offers a sustainable solution by integrating aquaculture with hydroponics to enhance productivity while reducing ecological impacts. This study investigated the performance of an outdoor NFT aquaponic system combining *Clarias gariepinus* (African catfish) and *Abelmoschus esculentus* (okra), focusing on biological efficiency and economic feasibility. The research objectives included assessing fish growth, evaluating okra yield and nutrient uptake, analyzing water quality and fish condition factor, and comparing aquaponics with conventional farming methods. Data were collected biweekly, with fish growth tracked using length-weight analysis, while okra growth and nutrient absorption were evaluated through biomass measurements and nutrient analysis. Water quality was consistently monitored to ensure system stability and sustainability. Results revealed favorable fish growth, stable condition factors, high okra yield, and efficient nutrient utilization. Water quality parameters remained within acceptable ranges for both fish and plants. Economic analysis showed aquaponics to be competitive with traditional farming. The findings demonstrate that NFT aquaponics is a viable, sustainable production method. It is recommended that farmers adopt this system to boost productivity, while policymakers should support adoption through training, investment, and infrastructure development.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Aquaponic system is a sustainable way to produce food from both aquaculture and plants (agriculture). The worldwide task of guaranteeing food safety for a fast-increasing population has brought increase consideration to sustainable agricultural technology that augment resource use while minimizing environmental degradation. Aquaponics is a hybrid food production system that combines aquaculture and hydroponics, proposes a promising solution to food system challenges by producing a symbiotic environment where fish and plants coexist (Goddek et al., 2019). The fish are fed and excrete waste, which is broken down by beneficial microorganisms living inside the system into nutrients. In this closed-loop system, nutrient-rich effluents from fish tanks are circulated through NFT pipes, DWC, and plant grow beds, where crops utilize the nutrients for growth, effectively filtering the water for reuse in the aquaculture component (Rakocy et al., 2011). This dual system significantly reduces water use, enhances nutrient recycling, and eliminates the need for synthetic fertilizers, making it particularly attractive for application in regions facing water scarcity, high input costs, and environmental stress (Yep & Zheng, 2019).

Three prevalent hydroponic designs utilized in aquaponic systems include the media bed, sometimes referred to as the ebb-and-flow bed; deep water culture (DWC), commonly known as raft beds, and the nutrient film technique (NFT) (Delaide et al., 2017; Oladimeji et al., 2020). which is our main area of consideration for this study. Also, Aquaponics uses a variety of substrates as growing media, including volcanic rocks, gravel, sand, perlite, hydroton, and cocopeat (Fox et al., 2010; Putri & Rahardja, 2021). Numerous fish species, particularly freshwater ones like tilapia (*Oreochromis niloticus*), trout (*Oncorhynchus mykiss*), and African catfish (*Clarias gariepinus*), are frequently raised aquaponically. In Sub-Saharan Africa, catfish are a popular food fish species because of its strong market demand, illness resilience, and great tolerance to fluctuations and bad water quality. Catfish are a great choice for aquaculture because of their quick development (rapid growth) at high stocking densities, capacity for air breathing, high food conversion, high-quality meat, resistance to low water quality, and delicious flesh (Palm, Bissa, & Knaus, 2014). The selection of fish species is just as important as that of plants and is influenced by a number of variables. The way catfish interact with the selected media substrate has a direct impact on water quality, nutrient cycling, and ultimately the aquaponic system's overall effectiveness. An aquaponic system's performance depends on a number of variables, but choosing the right plant and fish species is essential to get the best possible growth and yield (Endut et al., 2010). In aquaponics, selecting plant and fish species is a complex process that calls for thorough evaluation of environmental factors, nutrient needs, and biological compatibility.

Plant appropriateness in aquaponics typically depends on the designs of aquaponic systems that work better for particular types of plants. A well-liked warm-season vegetable, okra is renowned for its quick growth and climatic tolerance. Okra (*Abelmoscus esculentus*) is one of the leafy, herbaceous, and fruity plants that have been grown in aquaponic systems (Azad, Salam, & Hossain, 2018; Rakocy et al., 2004; Salam, Asadujjaman, & Rahman, 2013). Okra pod is one of the most reasonably priced sources of vitamins, minerals, and antioxidants needed for optimal health (Schreinemachers, Simmons, & Wopereis, 2018). It has significant promise in aquaponic systems. Okra, regarded as one of the nutrient-dense vegetable commodities, offers vital nutrients the body requires in the form of soluble fiber (peptin and mucus), which helps lower cholesterol and lower the risk of heart disease (Harsani, Qur'ania, & Hermawan, 2019). Okra is grown all throughout the world in warm temperate and tropical climates, for its fibrous, nutrient-dense fruit pods (Anwar, Qadir, & Ahmad, 2020).

Despite the potential benefits of combining fish and vegetable production in aquaponic systems, few studies have empirically evaluated the growth and economic performance of *C. gariepinus* and *A. esculentus* within a single integrated unit. Most research tends to focus either on the aquaculture component or the hydroponic aspect independently, which fails to capture the holistic performance and viability of the system (Love et al., 2015). In light of these gaps, this study aims to evaluate both the biological and economic dimensions of aquaponics by examining the growth performance of *C. gariepinus* and *A. esculentus*, alongside water quality dynamics and financial returns.

1.2 Problem Statement

Unfortunately, traditional agriculture systems often require large area of land and water resources that are becoming progressively scarce, especially in urban and peri-urban areas (UN, 2014). The concept of aquaponics has shown substantial promise globally, its practical adoption in many developing countries, including Sierra Leone and other parts of sub-Saharan Africa, remains limited. However, in Sierra Leone, the practice is still at a very early stage, with little to no locally available data to guide farmers, investors, and policymakers. The world's population is growing rapidly, and according to the United Nations "World Urbanization Prospects The 2014 Revision" report, 6.5 billion of the total population will be living in cities by 2050. That's nearly double of what the population is today. The growing population is going to demand more resources in the form of infrastructure and food. Both entail land and cannot be effectively met through any of the traditional agricultural means. This problem is further multiplied owing to the imminent threat of an acute shortage of space to grow food and the resources required to grow it, in traditional ways.

Many urban and peri-urban areas including cities and towns will be facing depletion of arable land at a quicker rate which means we will be left with land to live but without food.

The performance of these two species when grown together in an aquaponic system has not been sufficiently studied particularly in NFT aquaponics system, despite the fact that *Abelmoschus esculentus* (okra) is a widely grown vegetable with nourishing and profitable worth and *Clarias gariepinus* (African catfish) is well-established in African aquaculture for its adaptableness and financial value (Kumar et al., 2023). The majority of existing research seeks to assess the performance of plants or fish distinctly, overlooking the cooperative (synergistic) relations (interactions) that take place in a combined system. Also, the economic viability of growing these species in aquaponic settings, taking into account labor, market pricing, yields, input costs, and biological performance, has not been fully measured or compared with traditional systems (Goddek et al., 2015). This knowledge gap is specially worrying in areas where aquaponics may be a resource-efficient, climate-smart substitute for conventional farming. To make wise investment choices, small-scale farmers and agribusiness owners need information on aquaponics' growth dynamics, nutrient cycling, system management, and profitability. Aquaponics' potential to support food security, poverty alleviation, and sustainable expansion is limited in the absence of this proof, which also limits its application in these conditions (Ibrahim. 2023).

1.3 Justification of the Study

NFT aquaponics offers faster production cycles and income generation while requiring less land area and water, which further drops expenses. Aquaponics has been recognized worldwide as a promising alternative to traditional farming because it uses significantly less water, needs less land, and offers an integrated approach to producing both fish and vegetables (Somerville et al., 2014; Goddek et al., 2019). With rapid urbanization and population growth predicted to place huge pressure on food production systems, there is a need to explore farming methods that are space-efficient, climate-smart, and sustainable (FAO, 2017). Aquaponics offers a potential solution to land and water challenges faced by conventional farming systems (Goddek et al., 2019).

This study is therefore important because it seeks to evaluate not only the growth performance of *Clarias gariepinus* (African catfish) and *Abelmoschus esculentus* (okra) in NFT aquaponic setup, but also the financial viability of the system. Both species are widely used in African diets and markets, making them fit for assessing both biological compatibility and market value (Schippers, 2000; Ayinla, 2007). By focusing on a practical, species-specific aquaponic model, this research has provided much-needed local evidence that can help farmers make informed decisions. It has also help filled the gap in scientific literature and support the progress of aquaponics as a viable, sustainable farming system in Sierra Leone. The outcome of this study provides significant information for training programs, influence agricultural policies, and contribute to improved food security and livelihoods in the region.

1.4 Aim of the Study

The aim of this study is to evaluate the growth and economic performance of *Clarias gariepinus* (African catfish) and *Abelmoschus esculentus* (okra) in an aquaponic system, with the goal of recommending the most suitable adoption strategies for potential users.

1.5 Objectives of The Study

1. To evaluate the growth performance of *Clarias gariepinus* in an outdoor NFT aquaponic system.
2. To assess the yield and nutrient uptake efficiency of *Abelmoschus esculentus* in an NFT aquaponic system.
3. To evaluate the water quality parameters of the system, and the condition factor of the experimental fish.
4. To compare the economic feasibility of aquaponic farming with conventional crop production methods.

1.6 Scope of the Study

This study evaluates the growth and economic performance of *Clarias gariepinus* (catfish) and *Abelmoschus esculentus* (okra) in an NFT aquaponic system over one production cycle. It focuses on measuring biological growth parameters, water quality, and system efficiency, along with an economic analysis including cost-benefit and return on investment.

1.7 Significance of the Study

This study highlights the potential of aquaponics as a sustainable solution for food production in resource-limited settings. By evaluating the growth and profitability of *Clarias gariepinus* and *Abelmoschus esculentus* in an integrated system, it provides valuable insights into efficient resource use, food security, and income generation.

1.8 Research Questions

1. What is the growth rate and nutrient utilization of *Clarias gariepinus* in an NFT aquaponic system to that of conventional system of farming?
2. What is the yield performance of *Abelmoschus esculentus* in the system commensurate with traditional agriculture?
3. What are the water quality parameters of the aquaponic system, and how do they influence the condition factor of *Clarias gariepinus*?
4. How does the economic feasibility of aquaponic farming compare with conventional crop production methods?

1.9 Limitations

This study had several limitations that should be acknowledged. Resource constraints, system design factors, and climatic influences affected the generalizability of the findings. The semi-controlled, small-scale experimental system did not fully represent the complexities of large-scale aquaponic operations, where costs of labor, infrastructure, and inputs differ significantly. The experiment was limited to twelve weeks, restricting observations of long-term or seasonal performance. Water quality was monitored biweekly, which may have missed short-term fluctuations in parameters such as ammonia and dissolved oxygen. Nutrient cycling analysis was limited due to the absence of detailed nutrient flow and microbiological monitoring. Finally, the economic assessment excluded potential risks such as market price fluctuations and scalability challenges.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter explores existing literature research relating to the growth and economic performance of *Clarias gariepinus* (African catfish) and *Abelmoschus esculentus* (okra) within NFT systems. The review focusses on the interactions between these two elements in an aquaponic system, specifically under the Nutrient Film Technique, which is renowned for making effective use of water and space. Understanding the underlying biological, technical, and economic components of this integrated system is crucial as interest in alternative agricultural methods that can function in constrained or marginal locations develops. This chapter draws attention to important findings from previous studies, shedding light on the practical conditions that influence fish growth, plant yield, and overall system productivity. It also provides a foundation for comparing economic outputs, identifying challenges faced by practitioners, and revealing areas where further research is needed

2.2 Concept of Aquaponics Systems

Aquaponics is a new, green agricultural method that combines aquaculture, which raises fish, with hydroponics, which grows plants without soil. Using this technique, fish excrement provides the plants with natural nutrients, while plants aid in cleaning and filtering the water before it is put back into the fish tanks. This closed-loop cycle maximizes resource efficiency while minimizing the environmental effect associated with conventional farming (Rakocy et al., 2006). The success of aquaponics depends on maintaining a balanced relationship between fish and plants. Fish waste is converted by beneficial bacteria into nutrients like nitrates and nitrites, which are essential for plant growth. The plants purify the water that is returned to the fish by absorbing these nutrients (Love et al., 2015).

This natural interaction reduces the need for chemical fertilizers and makes food production more environmentally friendly. Species such as African catfish (*Clarias gariepinus* Burchell 1822) and okra (*Abelmoschus esculentus*) exhibit the flexibility of aquaponic systems. The catfish is popular in aquaculture because it grows swiftly and adapts well to various settings. Okra is nutrient-dense, thrives in aquaponic systems, and offers both economic and nutritional benefits (Timmons & Ebeling, 2013).

2.3 Historical Development

The development of aquaponics over time demonstrates a growing interest in sustainable, resource-efficient food production methods. Although the concept of combining the growing of plants and fish stretches back to ancient civilizations, modern aquaponics only began to take shape in the late 20th century. The oldest references to aquaponic-like systems date back to ancient China and the Aztec culture, when fish were cultivated in pools alongside crops. These early actions demonstrated an understanding of the benefits of nutrient cycling, despite the fact that they lacked the present scientific foundation (Pahlow et al., 2013). However, it wasn't until the 1970s that aquaponics began to gain recognition as a distinct field. By combining aquaculture and hydroponics, researchers such as Dr. Leonard F. D. "Duke" Aquaponics laid the foundation for upcoming advancements.

The 1990s were a significant turning point. As concerns over resource depletion, environmental sustainability, and food security grew, aquaponics gained popularity as a potential solution. During this period, aquaponic systems began to be extensively studied and promoted by universities and research facilities. According to early research, aquaponics is a suitable alternative to traditional agricultural methods since it effectively manages water and nutrients (Rakocy et al., 2006). As technology advanced, so did the design and implementation of aquaponic systems. The introduction of the nutrient film technique (NFT) and other hydroponic methods improved plant growth efficiency while maintaining fish health. Aquaponics is now widely acknowledged as a practical and ecological farming method.

2.4 Overview of Clarias gariepinus

2.4.1 Biological Characteristics

Native to parts of Africa and the Middle East, the African catfish, or *Clarias gariepinus*, is a common freshwater species. Because of its big barbels, broad head, and long body, which serve as sense organs, this fish can navigate through murky waters. The species can grow up to 1.5 meters in length and 60 kilograms in weight, while farmed individuals are often smaller. One of *C. gariepinus* remarkable traits is its resistance to low oxygen levels, which enables it to thrive in a range of aquatic environments, such as rivers and stagnant ponds. In aquaculture environments, this flexibility is a huge benefit, particularly in systems where water quality may fluctuate. *C. gariepinus* exhibits a robust immune system, which helps it withstand diseases common in aquaculture practices (Balarin & Haller, 1982).

2.4.2 Growth Performance of *Clarias gariepinus* in Aquaponic Systems

The African catfish, *Clarias gariepinus*, has exceptional growth performance in aquaponic systems when compared to other fish species. Research indicates that given optimal raising conditions, including controlled water quality, temperature, and feeding regimens, *C. gariepinus* may gain a significant amount of weight. In roughly six months, it usually reaches market scale (Babatunde, Olufayo, & Adebisi, 2015; Masser & Rakocy, 1997). When fish and plant cultivation are combined in aquaponics, fish waste serves as a natural fertilizer that encourages plant growth, and plants filter and maintain the water quality for the fish, creating a synergistic nutrient cycling environment (Goddek, Joyce, Kotzen, & Burnell, 2015; Delaide et al., 2016).

To improve development rates and general fish health, studies have shown how crucial it is to maintain ideal pH levels (6.8-7.5) and dissolved oxygen concentrations over 5 mg/L (Masser & Rakocy, 1997; Simon, Svanberg, & Toth, 2020). In addition to increasing fish development, this nutrient-efficient approach also increases system sustainability and production (Palm, Winker, & Knaus, 2018).

2.5 Economic Importance of *Clarias gariepinus*

In regions with limited access to animal protein, *Clarias gariepinus* is particularly significant commercially. As a robust, fast-growing, and nutrient-rich species, it provides a substantial amount of high-quality protein that is rich in essential amino acids and omega-3 fatty acids (FAO, 2019; Eyo, 2001). Because of its adaptability in a range of culinary uses, it is highly popular in local markets (Olapade & Aluko, 2020). Additionally, both smallholder farmers and commercial producers find growing *C. gariepinus* in aquaponic systems to be cost-effective because it enables the simultaneous production of fish and vegetables, generating two revenue streams (Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014; Rakocy, Masser, & Losordo, 2006). *C. gariepinus* raised in aquaponic systems is essential for improving food security and livelihoods, particularly in developing nations, given the growing demand for sustainable and effective protein sources worldwide (FAO, 2019; Yahaya, Haruna, & Abubakar, 2021).

2.6 Overview of Abelmoschus esculentus

Commonly referred to as lady's finger or okra, *Abelmoschus esculentus* is a flowering plant in the Malvaceae family that is widely grown for its tasty green seed pods. Okra originated in Africa, but because of its nutritional value and adaptability, it is currently produced in tropical, subtropical, and warm temperate climates worldwide (Alegbejo, 2012). The plant is prized for its quick growth, large yield, and ability to withstand severe weather, which makes it perfect for aquaponics and other sustainable farming methods. With a relatively quick development cycle of 50-60 days from seed to harvest, it usually reaches a height of 1-2 meters, depending on the variety and environmental factors (Gemede et al., 2015). In an aquaponic systems, okra grows best at warm temperatures (25-35°C) and well-drained soils with a pH of 6.0-6.8, which is neutral to slightly acidic. Harvesting the pods when they are young and delicate encourages more flowering and pod development. Okra is a viable option for water-efficient farming techniques like nutrient film technique (NFT) aquaponics because of its deep root structure and resistance to water stress (Kumar et al., 2020). Okra has significant nutritional and therapeutic benefits. The pods include mucilage, a soluble fiber that aids in blood sugar and cholesterol regulation, and are high in fiber, vitamin C, folate, and antioxidants (Adetuyi & Ibrahim, 2014). *A. esculentus* is increasingly being researched as a viable crop for sustainable production systems due to its importance in both food and health sectors.

2.6.1 Biological Characteristics of *Abelmoschus esculentus*

Tropical and subtropical conditions are ideal for the robust morphology of the annual herbaceous plant *Abelmoschus esculentus*. According to biology, it is a fast-growing dicotyledon with a fibrous stem that can reach a height of two meters, lobed palmate leaves, and a taproot system (Alegbejo, 2012). Its enormous, dark-centered, yellow flowers self-pollinate, while insects frequently cross-pollinate them as well. After pollination, the edible portion, a capsule-like pod, develops into a fruit in roughly five to seven days. Because of its indeterminate growth, okra can continue to produce fresh fruits and blossoms for a long time, especially in ideal circumstances. Okra thrives in temperatures between 25 and 35°C and needs 10 to 12 hours of sunlight per day. The plant is perfect for controlled settings like aquaponic greenhouses because of its resistance to drought, insect resistance (particularly against common aquaponic pests like aphids and whiteflies), and quick vegetative development (Kumar et al., 2020).

Okra roots are well adapted to shallow channels, such as those present in NFT systems, since they effectively absorb nutrients through a dense network of lateral roots. Because it is physiologically a strong feeder of potassium and nitrogen, okra can be grown in nutrient-rich aquaponic water that is high in nitrates (Sace & Fitzsimmons, 2013). Its mucilage, which is made of polysaccharides, protects the plant from water stress and helps to maintain osmotic equilibrium. This mucilage also contributes to the plant's medicinal qualities. Multiple harvests per year are made possible by the plant's short growing cycle, which in NFT systems can be as short as 60 days. This supports continuous production models (Gemede et al., 2015). These biological characteristics demonstrate that *A. esculentus* is a resilient vegetable crop that thrives in aquaponic settings, particularly in systems that use the nutrient film approach, which maximizes root oxygenation and nutrient availability.

2.6.2 Growth Performance of *Abelmoschus esculentus* in Aquaponics

Numerous field and laboratory studies have shown that *Abelmoschus esculentus* grows well in aquaponic systems, particularly when utilizing the nutrient film method (NFT). Okra grows quickly and healthily thanks to the NFT system's constant nutrient delivery, oxygen-rich water, and effective root exposure. Because of its great capacity to absorb nitrogen, okra thrives in aquaponic settings and complements the nitrate-rich wastewaters produced by fish culture (Sace & Fitzsimmons, 2013; Delaide et al., 2016). According to studies, okra cultivated in aquaponic systems can produce yields that are on par with or better than those produced in soil, frequently yielding 20-30% more under ideal circumstances (Palm et al., 2018). Depending on the cultivar and system design, okra in regulated aquaponic settings reaches harvest maturity 45-60 days after transplantation. It is especially appropriate for vertical NFT setups or staggered growing beds due to its vertical growth habit and small spatial footprint (Kumar et al., 2020). Nematode infestation and soil-borne illnesses are two issues that aquaponic systems help to alleviate when growing okra in soil. Because of the steady pH of the water, less competition for nutrients, and lack of soil pollutants, aquaponic okra plants typically have healthier root systems and higher-quality pods (Gemede et al., 2015). By using up to 90% less water than typical farming, aquaponic systems' recirculating nature encourages sustainability (Goddek et al., 2015). However, challenges such as clogging of NFT channels by roots, accumulation of solid waste, and occasional nutrient imbalances can affect okra growth if not properly managed.

2.7 Nutrient Cycling in Aquaponic Systems

The foundation of any aquaponic system is nutrient cycling, which makes it possible to convert fish waste into useful nutrients for plants. The symbiotic interaction between fish, microorganisms, and plants is essential to the effective operation of this cycle (Goddek et al., 2015). They observed that ammonia, a waste product excreted by fish, is transformed into nitrate, a type of nitrogen that plants may use, by the bacteria Nitrosomonas and Nitrobacter. Delaide et al. (2017) also noted that the increased surface area for bacterial colonization and constant water flow that supplies nutrients straight to plant roots speed up this process in Nutrient Film Technique (NFT) aquaponics.

According to Somerville et al. (2014), phosphorus, potassium, and other micronutrients that are vital for plant health are released when heterotrophic bacteria break down solid waste as part of nutrient cycling. They underlined that preventing the harmful buildup of ammonia or nitrite requires a stable microbial community. This opinion was reinforced by Palm et al. (2018), who emphasized the need for a careful balance between nutrient intake and production. According to Yahaya et al. (2021), NFT systems with short nutrient retention times place a premium on nutrient cycling efficiency. Therefore, it is essential to continuously monitor factors like pH, ammonia, and electrical conductivity (EC) in order to prevent toxic accumulation or nutrient deficits.

2.7.1 Role of Fish in Nutrient Supply

In aquaponic systems, fish are the main source of nutrients for plants in addition to being a source of protein. The basis of the nutrient supply chain in these systems is fish feed, which excretes between 60 and 70 percent of its nitrogen as ammonia, according to Rakocy et al. (2006). They underlined that maintaining nutrient output, particularly in NFT systems where nutrient flow is continuous and roots are in close contact with the circulating solution, depends heavily on appropriate feeding procedures and fish health. According to Babatunde et al. (2015), *Clarias gariepinus* is particularly well-suited for aquaponics due to its high feed conversion efficiency and versatility. They observed that sustained plant development is supported by the consistent nutritional waste produced by this species. Simon et al. (2020) echoed this observation, warning that improper fish stocking can lead to imbalances either nutrient overload or deficiency thereby affecting both fish welfare and plant performance. Additionally, Goddek et al. (2015) noted that trace minerals and phosphorus can be recovered through mineralization or filtering from fish waste and uneaten feed. According to their findings, these wastes improve the system's nutrient variety when properly handled. According to Somerville et al. (2014), the structure of the microbial community is indirectly shaped by fish waste, which affects nutrient bioavailability and nitrification efficiency. The significance of fish in preserving the system's equilibrium is further supported by this biological connection.

2.7.2 Plant Nutrient Requirements

NFT aquaponic plants rely solely on dissolved nutrients from fish and microbiological activities. According to Delaide et al. (2016), micronutrients like iron and magnesium, as well as macronutrients like potassium, phosphorus, and nitrogen, are essential for the proper growth of plants. They pointed out that the byproduct of nitrification, nitrate, is particularly crucial for the growth of leaves. According to Palm et al. (2018), a plant's growth stage affects the nutrients it needs; fruiting crops like okra (*Abelmoschus esculentus*) require greater levels of potassium and phosphorus, while young seedlings require more nitrogen. According to their research, physiological problems like chlorosis and stunted growth are caused by nutrient imbalances like an excess of nitrogen or an iron shortage. Because micronutrients like iron tend to precipitate out at high pH values, Rakocy et al. (2006) highlighted the need of pH regulation. To avoid nutritional lockout, they suggested adding chelated iron to the system as a supplement. This was corroborated by Somerville et al. (2014), who showed that extra micronutrient inputs are occasionally required for optimal plant performance, even in systems that are operating well. Goddek et al. (2015) talked about how root oxygenation and water flow affect nutrient uptake. They pointed out that NFT systems cover roots with a thin, oxygen-rich layer of water, improving nutrient absorption while necessitating exact control over EC and flow rates. According to Yahaya et al. (2021), efficiency is increased when plant species are matched to the aquaponic system's nutrient profile. Crops with high nutrient demands may require either increased feed inputs or supplemental nutrient dosing.

2.8 Outdoor vs. Indoor Aquaponic Systems

The decision between indoor and outdoor aquaponics systems has a big impact on environmental control, sustainability, and productivity. Both environments have special benefits and limitations, especially in systems that use the Nutrient Film Technique (NFT). In order to save energy, outdoor systems usually make use of ambient temperatures and natural sunlight. They are, nevertheless, subject to environmental stressors like pests, rain, and temperature changes. On the other hand, because indoor systems depend on artificial lighting and climate control equipment, they have greater operating costs even if they provide year-round output with perfect temperature, humidity, and lighting control.

While outdoor systems can flourish in areas with steady tropical temperatures, Rakocy et al. (2006) noted that environmental unpredictability frequently calls for protective structures or seasonal changes. Similarly, Goddek et al. (2015) said that indoor aquaponics is becoming more popular in urban farming because of its capacity to reduce the dangers associated with external climate conditions and its flexibility to vertical systems. According to Delaide et al. (2016), high-value crops and species like *Clarias gariepinus*, which need regulated temperatures for optimum growth, benefit greatly from indoor NFT systems. Researchers such as Somerville et al. (2014) noted that the necessity for interior installations is frequently driven by space constraints in metropolitan centers, especially in high-density locations. However, they also cautioned that without proper light spectrum and intensity, plant growth could be suboptimal. In contrast, Palm et al. (2018) argued that with adequate shading and water quality management, outdoor aquaponics can perform remarkably well in low-income settings where electricity is a constraint.

2.8.1 Advantages and Disadvantages of Aquaponic Systems

Although aquaponics, particularly the NFT variety, has several advantages over traditional aquaculture and agriculture, there are drawbacks as well that should be taken into account. Its resource efficiency is one of its main benefits. Compared to conventional soil farming, aquaponics can use up to 90% less water (Somerville et al., 2014). This is due to the water's constant recirculation, which uses fish excrement as nutrients to support plant development. According to Palm et al. (2018), if properly managed, this method produces zero discharge and drastically lowers the demand for synthetic fertilizers. Aquaponics makes it possible to economically produce both vegetables and fish, which can give farmers a steady source of revenue.

Smallholder farmers in Nigeria that used aquaponics systems reported a 30% increase in household income in just one production cycle (Yahaya et al., 2021). Furthermore, *Clarias gariepinus* has demonstrated exceptional aquaponic adaptation, especially when combined with okra or green vegetables (Olapade & Aluko, 2020). But there are some problems with the system. The high initial investment cost, which includes grow beds, pumps, tanks, and, in the case of indoor systems, heating and lighting equipment, is one of the main obstacles (Goddek et al., 2015). Maintaining a balance between hydroponics and aquaculture calls for ongoing observation. In order to prevent stress on the fish or plants, Rakocy et al. (2006) stressed the importance of closely monitoring nutritional levels, pH, temperature, and oxygen. Another issue is technical knowledge. As Masser and Rakocy (1997) pointed out, aquaponics systems require interdisciplinary expertise in water chemistry, fish biology, and plant nutrition, which may be lacking in rural communities.

2.8.2 Environmental Factors Affecting Growth in Aquaponics

The effectiveness of aquaponic systems is largely dependent on environmental elements like humidity, light, temperature, and water quality. These factors can have a major impact on fish metabolism and plant nutrient uptake in NFT systems, where water flows in a thin layer over plant roots. The ideal water temperature for *Clarias gariepinus* is between 26 to 30°C; above this, stress and slower growth are noted (Simon et al., 2020). Another important factor is the amount of dissolved oxygen. Fish need DO levels over 5 mg/L to survive, and anything below that jeopardizes their health and feeding effectiveness (Masser and Rakocy, 1997). Similarly, in order to avoid nutrient lockout and root rot, plants cultivated in NFT channels require sufficient oxygenation. Goddek et al. (2015) reported that systems with poor aeration suffered reduced vegetable yields and higher fish mortality. Light is crucial for plant photosynthesis. While outdoor systems benefit from natural sunlight, indoor systems depend on artificial lighting, which must mimic the light spectrum needed for plant growth. According to Delaide et al. (2016), full spectrum LEDs are perfect, although they can raise energy expenses. Furthermore, Palm et al. (2018) noted that excessive heat or light, particularly in tropical areas, can cause algae bloom or plant wilting.

System production is also influenced by the pH of the water and the content of nutrients. According to Rakocy et al. (2006), a pH range of 6.8 to 7.2 is optimal for ensuring food availability to plants and minimizing ammonia toxicity to fish. The microbial activity that propels the nitrogen cycle can be disrupted by any variation. Environmental instability, such as abrupt rains or heat waves, can upset this delicate balance, particularly in outdoor systems, according to Somerville et al. (2014). As Yahaya et al. (2021) noted, even small deviations can cascade into major system failures if not addressed promptly.

2.9 NFT in Aquaponics: System Design and Functionality

Because of its straightforward design and effective use of resources, the Nutrient Film Technique (NFT), a hydroponic growing technology, has been included into aquaponic systems more and more. In NFT-based aquaponics, plant roots are suspended in a thin layer of nutrient-rich water generated from fish waste that is constantly pumped along shallow channels, usually composed of PVC or food-grade plastic (Somerville et al., 2014). According to Goddek et al. (2015), the basic concept is to keep the water flow shallow so that the roots may still absorb vital nutrients from the film and get enough oxygen from the atmosphere. One of the main benefits of NFT systems, according to researchers like Delaide et al. (2016), is their low water and nutrient retention, which makes them perfect for green vegetables with quick development cycles. NFT systems also lessen the chance of microbial accumulation and root rot because the roots are not submerged. They did note, nevertheless, that preserving a steady water flow and preventing clogs are essential for system stability. According to Palm et al. (2018), in order to guarantee appropriate water flow, NFT channels should be slightly sloped (1-3%).

By promoting gravity-assisted drainage, the slope lowers the likelihood of water stagnation. NFT systems are commended for their low substrate requirements and space efficiency, but they are also susceptible to temperature changes and power interruptions. As Rakocy et al. (2006) noted, any interruption in water flow can rapidly stress plants due to the thin water film's low buffering capacity. Thus, backup systems and real-time monitoring tools are often recommended for effective NFT operations.

2.9.1 Impact of NFT on Plant and Fish Growth

The Nutrient Film Technique (NFT) in aquaponics has a complicated and promising effect on fish and plant growth. For tiny, quick-growing crops like lettuce and herbs, NFT offers a regulated environment on the plant side that promotes effective nutrient uptake and quick root oxygenation. The thin layer of nutrient-rich water promotes the best possible nutrient exchange at the root zone, which speeds up the accumulation of plant biomass (Delaide et al., 2016). Vegetables grown in NFT aquaponic systems generally have higher chlorophyll content and better leaf development than their conventional soil-grown counterparts, according to research by Yep and Zheng (2019). They maintained that NFT channels' constant aeration and nutrient availability are the main causes of this. However, they also noted that such systems require precise balancing of nutrient concentrations, particularly nitrogen and potassium, to avoid deficiencies or toxicities. On the aquaculture side, the plant filtering process in NFT systems indirectly benefits fish such as *Clarias gariepinus*. The general quality of the water increases when the plants take up nitrate, ammonia, and other metabolites from fish excrement. According to Simon et al. (2020), fish raised in properly maintained NFT aquaponics outperformed fish raised in traditional recirculating aquaculture systems without plant integration in terms of growth and survival rates. They proposed that the plants' ability to stabilize pH, lower ammonia, and raise dissolved oxygen levels is the cause. However, the delicate balance of the system can provide difficulties. For example, Babatunde et al. (2015) pointed out that temperature, light intensity, and plant maturity can all alter how well plants absorb nutrients, which could lead to nutritional imbalances that could harm fish health.

2.9.2 Types of Aquaponic Systems: Focus on NFT (Nutrient Film Technique)

The three main categories of aquaponic systems are nutrient film technology (NFT), deep water culture (DWC), and media bed systems. Although each has a unique design, advantages, and disadvantages, NFT has drawn a lot of interest because of its effectiveness and simplicity. A thin layer of water enriched with nutrients from fish excrement continuously flows over the roots of plants growing in long, narrow channels in an NFT configuration. According to Rakocy et al. (2006), this continuous flow gives plants a consistent supply of oxygen, nutrients, and water, promoting rapid and healthy growth. NFT systems work especially well with crops that have little roots, like okra, spinach, and lettuce. According to studies, NFT systems are ideal for regulated environments and urban settings, and they can optimize water consumption efficiency (Pantanella et al., 2012). Plant stress or loss may result from the roots rapidly drying up due to any disturbance in flow or pump failure (Junge et al., 2017). Despite this, NFT's flexibility, ease of cleaning, and possibility for vertical farming continue to make it a popular option for many small-scale and research aquaponic systems.

2.10 Economic Performance of Aquaponic Systems

Because of their potential to increase the efficiency of food production, aquaponic systems especially those that employ the Nutrient Film Technique (NFT) have gained more and more attention. In terms of economics, the system allows for two revenue streams by combining the production of fish and plants. When aquaponic systems are optimized, they can provide competitive yields with comparatively reduced input costs over time when compared to traditional agriculture, according to researchers like Palm et al. (2018). Goddek et al. (2015) state that following system setup, operational costs stabilize despite the significant initial capital investment, particularly for equipment like grow beds, pumps, and tanks.

According to Delaide et al. (2016), aquaponics' closed-loop nutrient cycling greatly minimizes the demand for chemical fertilizers, which lowers input costs and boosts profit margins. In South Africa, farmers using NFT aquaponics had higher returns per square meter than those using soil-based vegetable growing, according to Mchunu et al. (2017). They pointed out that *Clarias gariepinus* increases income when combined with high-yielding crops like okra or lettuce. Furthermore, aquaponics' year-round productivity is a significant benefit in areas with seasonal constraints. Profitability depends on proper system management and local market conditions, Somerville et al. (2014) pointed out. Experts also contend that diversifying aquaponic production can increase long-term profitability. Rakocy et al. (2006) noted that high-value leafy greens and herbs often command premium prices in urban markets, thereby supporting financial sustainability. However, they also acknowledged that technical knowledge and market access are crucial to success.

2.10.1 Cost-Benefit Analysis

An essential method for assessing the financial viability of NFT aquaponic systems is cost-benefit analysis, or CBA. Construction supplies, plumbing, air pumps, water circulation systems, and fish and seedling feeding are frequently included in the initial expenses. A CBA on catfish and okra NFT aquaponics in Nigeria was carried out by Yahaya et al. (2021), who found that the system was highly viable economically with a positive benefit-cost ratio of 1.62. They stressed that the money made from the sale of both fish and vegetables exceeded variable costs including feed, energy, and labor. In a similar vein, Endut et al. (2011) discovered that properly scaled systems resulted in a large reduction in operating expenses.

According to their Malaysian study, fish survival rates rose, feed conversion ratios improved, and water usage dropped as soon as a stable biological balance was reached all of which supported economic sustainability. Goddek and Körner (2019) highlighted the significance of lifecycle costing, which takes operational effectiveness and long-term durability into account, particularly in NFT systems where nutrient distribution and water flow are constant. Aquaponic systems combined with solar energy can save electricity costs by more than 40%, increasing profitability in isolated or off-grid locations, according to Dalsgaard et al. (2013). But they also emphasized how important it is for farmers to be financially literate in order to properly track expenses and assess return on investment. Somerville et al. (2014) argued that while break-even points vary depending on system size and market access, most small-scale systems can recoup investment within 18 to 24 months if managed well. They noted that externalities such as training costs and access to extension services must also be considered.

2.10.2 Market Demand for Fish and Vegetables

One important factor influencing the sustainability of NFT aquaponic systems is market demand. Olapade and Aluko (2020) claim that because of its flavor, low cost, and high protein content, African catfish (*Clarias gariepinus*) are becoming more and more popular in urban marketplaces. Aquaponics operators are able to satisfy a variety of customer demands by producing both vegetables and fish. According to Palm et al. (2018), the lack of artificial fertilizers and pesticides makes vegetables grown in aquaponic systems appear healthier, which makes them more appealing to consumers who are health-conscious. According to Bamgbose et al. (2020), green vegetables grown in aquaponic systems using NFT techniques, like lettuce and amaranth, sold for more money in urban areas than those grown on conventional farms.

They found that consumers were prepared to pay up to 15% extra for produce cultivated aquaponically in their trial conducted in Lagos. In a similar vein, the FAO (2019) observed an increasing tendency in supermarkets and lodging establishments that prioritize ethically produced fish and organic vegetables, both of which aquaponics easily provides. Goddek et al. (2015) made the case that growing urbanization and growing consciousness of food safety will probably raise demand for aquaponics goods from a scaling standpoint. They pointed out that aquaponic systems close to cities can benefit from cheaper transportation and quicker market delivery. Furthermore, Yahaya et al. (2021) highlighted that farm-to-table models and community-supported agriculture (CSA) programs offer fresh chances for direct sales, increasing profitability. However, researchers like Dalsgaard et al. (2013) caution that fluctuating market prices and competition from industrial agriculture can challenge aquaponics' commercial scalability. Thus, they recommend integrating market research and consumer education into aquaponic business models to strengthen demand and ensure long-term sustainability.

2.11 Challenges and Solutions in Aquaponics

Although aquaponics, and the Nutrient Film Technique (NFT) system in particular, is praised for its sustainability and resource efficiency, it has unique operating issues that need to be resolved to guarantee long-term viability. System imbalances, especially between fish nutrient output and plant nutrient demands, are a widespread problem, according to researchers like Goddek et al. (2015). For example, whereas fish waste offers phosphate and nitrogen, it frequently contains insufficient amounts of iron or potassium, requiring extra supplementation. Technical intricacy is another obstacle. According to Somerville et al. (2014), interdisciplinary expertise in hydroponics, microbiology, and aquaculture is necessary for successful operation. This complexity can be overwhelming for small-scale farmers, especially in regions with limited access to training and technical support. They emphasized that training programs and locally adapted technology are key solutions.

Despite being commended for its sustainability and resource efficiency, aquaponics and the Nutrient Film Technique (NFT) system in particular has special operational problems that must be fixed to ensure long-term viability. System imbalances are a common issue, particularly between the nutrient demands of plants and the nutritional production of fish (Goddek et al., 2015). For instance, fish waste often contains inadequate levels of iron or potassium, necessitating further supplementation, even if it provides phosphate and nitrogen. A further barrier is technical complexity. Somerville et al. (2014) state that successful operation requires interdisciplinary competence in aquaculture, microbiology, and hydroponics.

2.11.1 Disease Management

If not adequately controlled, disease outbreaks in aquaponic systems, especially those containing *Clarias gariepinus*, can result in large output losses. Because of these systems, fish and plants coexist in a special ecosystem where biosecurity is essential. Delaide et al. (2016) claim that because of the constant water cycling in closed-loop systems, germs can multiply quickly. In warm, nutrient-rich environments, fish diseases are commonly recorded, particularly fungal infestations and bacterial infections like Aeromonas hydrophila. Disease outbreaks are frequently caused by imbalanced nutrition and inadequate stocking density management (Masser and Rakocy, 1997). They recommended following stringent biosecurity procedures and conducting regular health monitoring.

It's interesting that some researchers are looking into natural ways to reduce disease risks. Babatunde et al. (2015) noted that the inclusion of medicinal plants such as Azadirachta indica (neem) in feed or water has shown promise in boosting immunity in *Clarias gariepinus*. Although these techniques cannot take the place of traditional treatment, they can lessen the need for antibiotics and support the sustainability of the system. Regular tank sanitation and quarantine procedures for new fish stocks are strongly recommended. According to Simon et al. (2020), cleaning tanks in between production cycles considerably lowers the microbial burden and the risk of disease transmission. Additionally, they emphasized how probiotics help to improve disease resistance and preserve gut health. Somerville et al. (2014) emphasized that early detection and isolation of affected fish can prevent the spread of pathogens without necessitating chemical treatments that might harm plants.

2.11.2 Water Quality and Recirculation

Water quality is the backbone of a successful NFT aquaponic system. Because the same water is used to support both fish and plants, even minor imbalances can compromise the entire system. As reported by Goddek et al. (2015), maintaining stable parameters such as pH, dissolved oxygen, ammonia, and nitrates is crucial. They explained that fluctuations not only reduce plant nutrient uptake but can also stress or kill fish. Fish like *Clarias gariepinus* thrive in well-oxygenated water with a pH between 6.8 and 7.5. Simon et al. (2020) emphasized the importance of dissolved oxygen levels above 5 mg/L for optimal fish respiration and plant nutrient absorption. Inadequate aeration in the NFT channels can lead to root rot and fish stress, making continuous water movement and aeration essential.

Ammonia accumulation is another serious concern. If not efficiently converted by nitrifying bacteria into nitrites and then nitrates, it becomes toxic to fish. Rakocy et al. (2006) highlighted that efficient biofiltration is essential in closed-loop systems to maintain nitrogen balance. Regular water testing is therefore critical. Delaide et al. (2016) reported that UV sterilization and mechanical filtration help remove suspended solids and pathogens, thereby improving water clarity and reducing disease risk. They also suggested that using a settling tank before biofilters can enhance the removal of uneaten feed and faecal matter. Palm et al. (2018) pointed out that recirculating systems offer the advantage of water conservation, especially in regions facing water scarcity. However, they cautioned that over time, salts and other dissolved solids may accumulate, necessitating partial water replacement.

2.12 Case Studies and Previous Research

Numerous case studies have highlighted the efficacy of aquaponics, particularly the Nutrient Film Technique (NFT), in boosting sustainable food production. Researchers such as Goddek et al. (2015) emphasized the modularity and scalability of NFT systems, especially in urban and resource-limited settings. In a field trial conducted by Delaide et al. (2017), NFT systems were used to grow lettuce in combination with tilapia. The researchers noted that the consistent flow of nutrient-rich water enhanced the physiological response of plants, contributing to faster growth cycles and improved nutrient uptake. In West Africa, Yahaya et al. (2021) documented the performance of *Clarias gariepinus* in an integrated aquaponic setup in Nigeria. They observed that the catfish reached market size within 5 to 6 months, while vegetables such as amaranth and okra showed above-average biomass yields. These results support Rakocy et al.'s (2006) earlier findings that aquaponics can serve as a dual production system that maximizes water and nutrient use efficiency.

Palm et al. (2018) also noted in their multi-county study that aquaponic case studies across Africa and Latin America revealed high adaptability of local crops and fish species to controlled NFT systems. They concluded that knowledge sharing, especially among small-scale producers, remains critical to success. Meanwhile, researchers like Somerville et al. (2014) emphasized that context-specific adaptations such as selecting heat-tolerant plants or species tolerant to fluctuating water quality are vital for operational success. These case studies offer a strong empirical foundation for aquaponics research. They collectively indicate that while the NFT system requires technical knowledge and regular monitoring, its productivity benefits and environmental efficiency make it a viable model for sustainable agriculture. Moreover, they reinforce the idea that well-documented field experiences are essential in guiding practical adoption and policy formulation.

2.13 Water Quality Parameters and Nutrient Cycling

Water quality is central to the success of any aquaponic system, as it affects the health of both fish and plants. Key parameters such as temperature, pH, dissolved oxygen (DO), ammonia, nitrites, and nitrates must be carefully monitored and maintained within optimal ranges to sustain the biological balance (Endut et al., 2010). The interaction between fish metabolism, microbial activity, and plant nutrient uptake creates a complex but manageable nutrient cycling process, where waste is transformed into usable forms for plants. Ammonia produced by fish is initially toxic, but nitrifying bacteria *Nitrosomonas* and *Nitrobacter* convert it first to nitrites and then to nitrates, which plants can absorb efficiently (Tyson et al., 2008). This biological filtration is vital, as excess ammonia or nitrites can lead to fish mortality. According to Goddek et al. (2015), maintaining a pH between 6.8 and 7.2 is ideal, as it supports nitrification and enhances nutrient availability for plants. Research by Lennard and Leonard (2006) indicated that consistent DO levels above 5 mg/L are necessary to support both fish respiration and microbial oxidation. Likewise, Endut et al. (2011) demonstrated that nitrate levels between 40-80 mg/L promote optimal plant growth without compromising fish health.

2.14 Sustainability and Resource Efficiency in Aquaponics

Aquaponics is widely recognized as a sustainable food production system because it efficiently integrates aquaculture and hydroponics to minimize resource use and environmental impact. One of the key sustainability advantages is water conservation; aquaponics systems use up to 90% less water than traditional soil farming due to water recirculation and reduced evaporation (Goddek et al., 2015). This efficiency makes aquaponics particularly suitable for water-scarce regions and urban agriculture. Resource efficiency also extends to nutrient cycling. Aquaponics reduces the need for chemical fertilizers by recycling fish waste as a natural nutrient source, thus lowering environmental pollution risks commonly associated with conventional agriculture (Tyson et al., 2011). Furthermore, aquaponics promotes biodiversity by combining fish and plants in a symbiotic relationship, mimicking natural ecosystems and reducing monoculture vulnerabilities (Goddek & Keesman, 2018). Several studies emphasize the reduced carbon footprint of aquaponics when compared with conventional food production, especially when powered by renewable energy sources (Palm et al., 2018). The closed-loop nature also limits nutrient leaching into waterways, addressing major concerns in traditional farming and aquaculture practices. However, sustainability is influenced by system design, species selection, and local conditions. As noted by Lennard and Leonard (2006), optimizing these factors improves resource use efficiency and reduces waste.

2.15 The Role of Organic-Based Resources

Organic-based resources play a vital role in enhancing the sustainability and productivity of aquaponic systems. These resources, such as organic fish feed, biofilters, and organic amendments, contribute to nutrient cycling and support the growth of beneficial microbial communities critical for system health (Goddek et al., 2016). The use of organic fish feed, which often includes locally available ingredients like agricultural by-products, can reduce reliance on commercial feeds, lower costs, and improve the sustainability of aquaponic operations (Zhou et al., 2017). For example, Okemwa et al. (2021) demonstrated that incorporating organic feed formulations adapted to local availability improved growth rates of *Clarias gariepinus* while maintaining water quality in West African aquaponic systems. Biofilters composed of organic substrates help convert toxic ammonia excreted by fish into nitrates usable by plants, a process fundamental to aquaponics (Rakocy et al., 2006). Organic-based substrates such as coconut coir and rice husks have been effectively used as biofilter media, enhancing microbial colonization and nutrient retention (Goddek & Keesman, 2018). Moreover, integrating organic amendments into the system, such as compost teas or microbial inoculants, can improve plant health and resistance to diseases without relying on synthetic chemicals (Tyson et al., 2011). This approach aligns with the principles of organic farming and supports environmentally friendly aquaponic practices.

2.16 Technical Challenges and Considerations in Aquaponics Systems

Aquaponic systems, while innovative, face various technical challenges that can affect system stability, productivity, and scalability. One major concern is maintaining optimal water quality parameters, such as pH, temperature, dissolved oxygen, and nutrient concentrations, which are critical for the health of both fish and plants (Rakocy et al., 2006). Small fluctuations can lead to stress or mortality in fish and reduced nutrient uptake by plants, demanding continuous monitoring and control. Another technical consideration is the design and choice of the aquaponic subsystem. The Nutrient Film Technique (NFT), media beds, and deep-water culture each have unique operational requirements and efficiencies (Lennard & Leonard, 2006). For example, NFT systems require precise water flow management to avoid root desiccation, while media beds can accumulate solids, potentially clog the system if not properly maintain. Biofilter management is also crucial; these biological filters convert harmful ammonia from fish waste into nitrates usable by plants but can be sensitive to changes in system conditions and require careful balancing of microbial communities (Goddek et al., 2016). Energy demands present another challenge. Pumps, aerators, and lighting systems consume electricity, often increasing operational costs and carbon footprints if renewable energy sources are not utilized (Palm et al., 2018). The system scalability is constrained by the complexity of balancing fish and plant needs simultaneously, which can become increasingly difficult at larger commercial scales (Love et al., 2015).

2.17 Comparative Studies of Fish and Plant Growth

Comparative studies in aquaponic systems have provided valuable insights into optimizing both fish and plant growth, particularly under NFT configurations. For instance, Endut et al. (2010) compared the performance of several leafy vegetables grown in aquaponic versus hydroponic systems. They reported that while hydroponics showed slightly faster early growth, aquaponics produced vegetables with superior nutritional content and resilience to disease, suggesting that aquaponics fosters healthier plant systems due to the presence of natural microbial communities. In terms of fish, researchers like Babatunde et al. (2015) observed that *Clarias gariepinus* demonstrated remarkable adaptability and fast growth in aquaponic environments compared to traditional earthen pond systems. According to their report, fish reared in the integrated system achieved better feed conversion ratios and uniform size distribution. They attributed this to the improved water quality and stable thermal conditions maintained through continuous nutrient cycling.

Delaide et al. (2016) performed a comparative growth analysis of basil grown in recirculating aquaponic systems with different fish species, including tilapia and African catfish. Their findings showed that basil growth was significantly higher in systems coupled with *C. gariepinus*, likely due to the species' nitrogen-rich waste profile. Similarly, Nelson and Pade (2008) emphasized that plant growth rates can differ markedly depending on fish type, density, and feeding frequency. Simon et al. (2020) highlighted the relationship between dissolved oxygen levels and the concurrent health of fish and plants. They concluded that maintaining optimal DO levels above 5 mg/L not only improved fish growth but also prevented root rot and nutrient deficiency in plants. These studies underline the interdependency of fish and plant health in NFT systems and emphasize the need for balanced system design.

2.18 Economic Assessments of Aquaponic Systems

Economic assessments are vital for determining the scalability and long-term viability of aquaponic systems, especially in resource-constrained regions. According to Rakocy et al. (2006), the dual-income potential of aquaponics through fish and plant sales significantly enhances profitability compared to standalone aquaculture or hydroponic setups. They demonstrated that even small systems, if efficiently managed, can achieve a return on investment within two years. Yahaya et al. (2021) carried out an economic analysis of aquaponics in northern Nigeria and concluded that the system was cost-effective for smallholder farmers. Their study revealed that the combined yield of fish and vegetables provided a stable cash flow, which was less vulnerable to seasonal price fluctuations. They also noted reduced dependency on external fertilizers and water, lowering operational costs.

Meanwhile, Palm et al. (2018) discussed how local economic conditions and market demand strongly influence the feasibility of aquaponic ventures. Their multi-country study showed that while capital investment remains a barrier, operational costs can be minimized through resource reuse, such as solar energy integration and biofiltration. This sentiment is echoed by Somerville et al. (2014), who argued that initial investment in aquaponics is often justified by long-term environmental and economic returns, particularly where land and water are scarce. Olapade and Aluko (2020) reported that consumer preferences in West African markets favored African catfish and locally grown vegetables, making NFT aquaponic systems commercially viable. They pointed out that demand for clean, chemical-free produce is rising, and aquaponic outputs align well with this trend.

2.19 Areas for Future Research

Given the identified gaps and summarized insights, future research should prioritize region-specific studies focusing on NFT aquaponics in tropical climates. For instance, it remains unclear how seasonal variations in ambient temperature and humidity affect plant transpiration and fish oxygen requirements in NFT setups. Studies by Yahaya et al. (2021) and Simon et al. (2020) advocate for localized research that tailors water quality and nutrient management practices to local climatic and socioeconomic conditions. Moreover, integrating renewable energy sources into NFT aquaponic systems remains underexplored. Goddek et al. (2015) suggested the need for evaluating the use of solar-powered pumps and temperature regulators to improve sustainability. There is also a call for interdisciplinary studies that combine aquaculture science, plant physiology, engineering, and economics to build a more holistic understanding of system viability.

Another key area involves nutrient supplementation strategies. As Delaide et al. (2016) mentioned, certain nutrients such as potassium, iron, and calcium are often deficient in aquaponic systems and may require supplementation. Future experiments could investigate organic and locally sourced supplements to reduce dependency on industrial inputs. Additionally, research should explore the socio-economic impact of NFT aquaponics in rural and peri-urban communities. Understanding how farmers adopt, adapt, and benefit from such systems will help shape policy and extension strategies. As Somerville et al. (2014) noted, while technical knowledge is growing, uptake remains low due to a lack of outreach and training. Future studies should thus integrate socio-economic assessments alongside biological performance metrics.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The study employed an experimental research design to evaluate the growth and economic performance of *Clarias gariepinus* and *Abelmoschus esculentus* in an aquaponic system. This approach was suitable for assessing the interactions between fish and plant species within a controlled environment, allowing for the quantification of key performance indicators such as growth rate, nutrient utilization, and financial viability.

3.2 Description of the Study Area

This study was conducted at the INCiTiS Living Lab Njala University Njala Campus. Njala University, located in the Moyamba district of the southern province in Sierra Leone, is the top university in the country. it is a public, rural, research university in Sierra Leone with its main campus in Njala, Moyamba District, situated on a generally flat landscape on the banks of the River Taia. It also has a significant campus in Bo, the second largest city in Sierra Leone, and a smaller campus in Bonthe. The main Njala campus is located in the Kori Chiefdom, about 125 miles east of Freetown and 36 miles southeast of Bo. The university host the School of Natural Resources Management (SNRM), and in the SNRM, is the Department of Aquaculture and Fisheries Management houses the Living Lab. Apart from constructing a secure lab for the INCiTiS project, the department possesses advanced facilities such as a modern RAS (Recirculating Aquaculture System), a fish feed mill, and sets of concrete tanks for fish breeding and production. With the support of the Multi Donor Trust Fund (MDTF), the department has established an integrated fish farm village that encompasses fish, vegetable, poultry, piggery, and insect production, serving both training and commercial purposes. The Njala University Living

Lab, well-built and enclosed, has received backing from the university administration and is recognized as a center of excellence for aquaponics and hydroponics training in Sierra Leone.

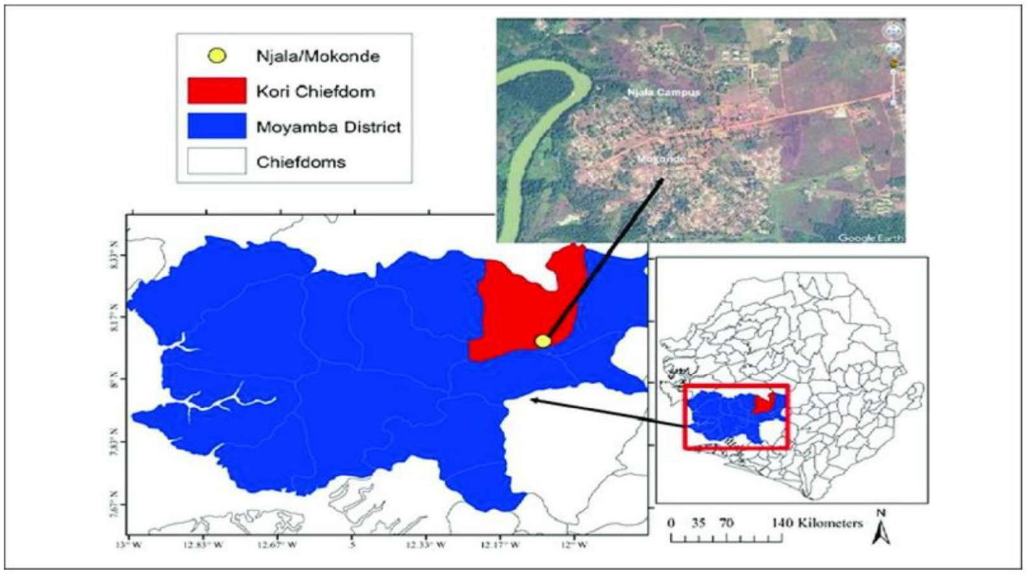

Fig. 1: Map of Sierra Leone Showing the Study area

Fig. 2: INCiTiS Laboratory Department of Aquaculture and Fisheries Management

3.3 Experimental Design

Each NFT pipe had 18 planting spaces, and five (5) NFT pipes of 5.63 meters (18.7 feet) were used to set up the system. However, only 15 planting spaces per pipe were utilized for the experiment, resulting in 25 planting spaces per treatment, corresponding to five replicates per treatment. In total, 75 planting spaces were used for the entire research. The spacing between individual plants was maintained at 30 cm. Thus, a Completely Randomized Design (CRD) was employed to minimize bias and enhance the reliability of statistical comparisons.

3.3.1 Aquaponics design set up.

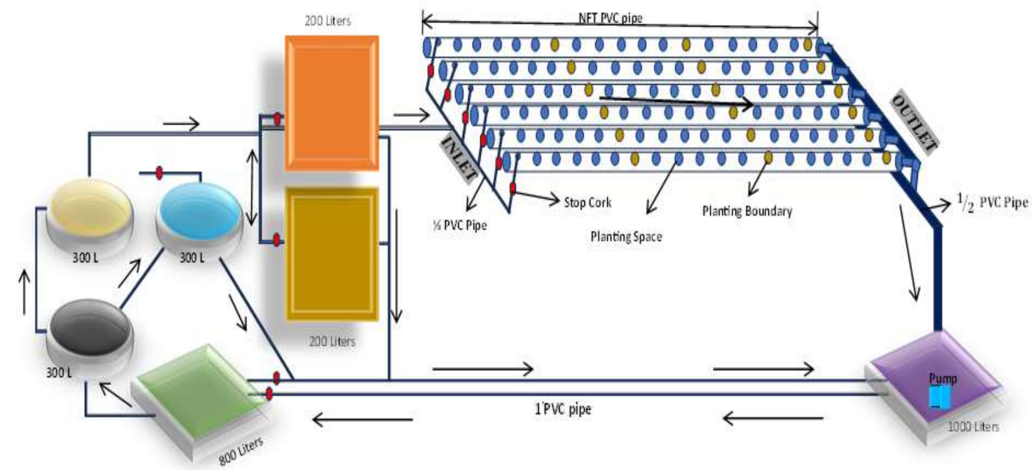

Fig. 3. The experimental setup (Aquaponics System)

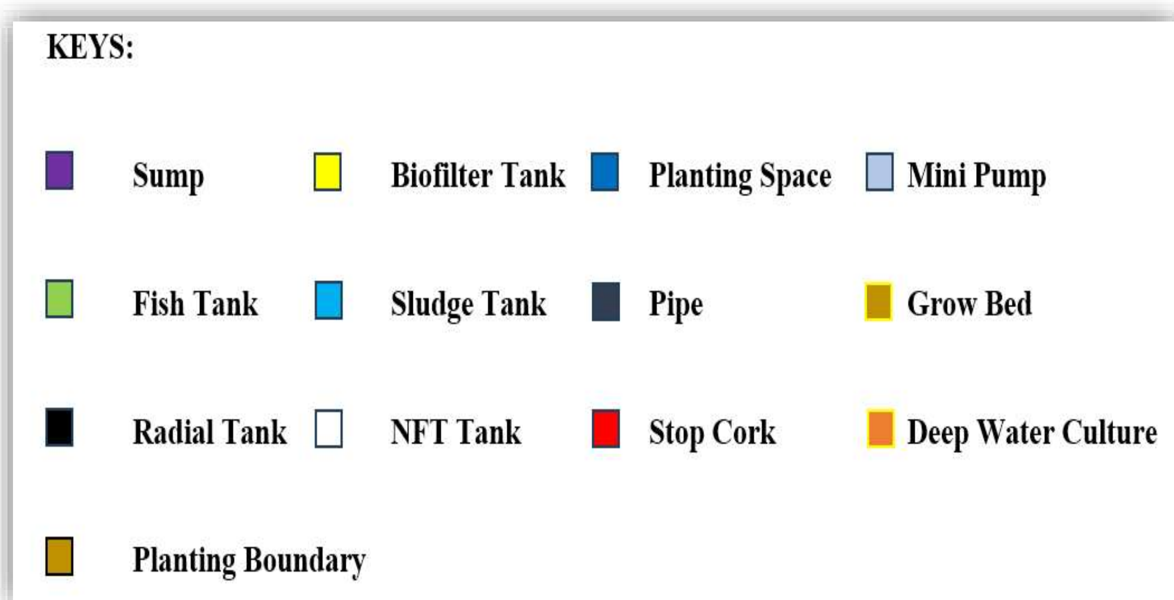

Fig. 4. The keys describing the experimental design

3.4 Sampling Tools

Water quality parameters such as dissolved oxygen (DO), pH, ammonia, nitrate, nitrite, total dissolved solids (TDS), and temperature were monitored using a Multiparameter, portable water testing meter kit (Model: AZ86031-K) equipped with probe tubes, pH Meter (Model: pH-009(III)), together with Umlecoa Aquarium Test Strips (Model: X003EO0A37) and standard analytical reagents. Growth measurements of *Clarias gariepinus* were recorded using a Camry Digital Electronic Weighing Scale (Model: EK3250), while the length of plants (*Abelmoschus esculentus*) was measured with a calibrated 12"/30cm transparent plastic ruler. Plant leaf number and fruit counts were obtained manually, and fruit yield was weighed using the same electronic scale. Data collection was conducted at regular intervals of every two weeks (14 days) for a period of 10 weeks, ensuring consistent monitoring of both water quality and biological performance throughout the study.

Table 1: Sampling Tools Summary

Sample Tools/Instrument and their Model						
Pictures						
Name & Model	Multiparameter	pH Meter	Test Strips	Electronic Scale	Reagents	Plastic ruler
	AZ86031-K	pH-009(III)	X003EO0A37	EK3250	Standard	12"/30cm

3.5 Sampling Technique

3.5.1 Fish Fingerling Sourcing

Purposive sampling was employed to obtain *Clarias gariepinus* fingerlings from a reputable hatchery located in Mile 91. This approach was chosen to ensure uniformity in the initial size, age, and health condition of the fingerlings, thereby minimizing variability in growth performance.

3.5.2. *A. esculentus* Seeds Sourcing

For the plant component, selective sampling technique was similarly applied in selecting *Abelmoschus esculentus* (okra) seeds. The seeds were carefully self-nursed to maintain quality and ensure consistency in germination and growth characteristics. This method reduced genetic and physiological variation, ensuring that differences observed during the experiment could be attributed more to system performance rather than disparities in seed quality.

3.6 Sample Size

The study used 56 *C. gariepinus* fingerlings (Initial mean weight: 4g ± 0.5 g) and 75 surviving A. *esculentus* seedlings. The experimental setup was divided into three treatments with five replicates each, ensuring statistically valid comparisons

Fig. 5: The experimental setup divided into three treatments

3.7 Data Collection

The main categories of data collection included water quality parameters, fish growth performance indicators, and crop growth metrics. Water quality data covered temperature, pH, dissolved oxygen (DO), ammonia, nitrate, and total dissolved solids (TDS), which are essential for sustaining both *Clarias gariepinus* fingerlings and *Abelmoschus esculentus* plants. Fish growth performance was monitored through measurements of initial and final body weight, weight gain, feed conversion ratio (FCR), and survival rate etc. Similarly, plant data involved, plant height, leaf number, flowering time, and final yield per plant. In addition to biological data, records on feed quantity and operational costs were collected to support the evaluation of economic performance. The structured collection process ensured that reliable and representative information was available for subsequent statistical analysis, enabling the study to draw valid conclusions on the growth, yield, and economic viability of the NFT system.

3.7.1 Methods of Collecting Data

A combination of direct measurement, observation, and the use of standard instruments was employed to collect data throughout the experimental period. Water quality parameters were assessed bi-weekly (every 14 days) for 10 weeks using a AZ86031-K multiparameter water quality meter for temperature, dissolved oxygen, and TDS, pH-009(III) pH meter for checking pH, while ammonia and nitrate concentrations were analysed with standard reagents and water testing strips. Fish growth was monitored by randomly weighing them with a CAMRY digital scale (Model EK3250), and measuring their length with a graduated measuring board and clear plastic ruler. Mortality was recorded, and feed input was documented to calculate feed conversion ratios. For the hydroponic component, plant height and leaf number were measured with a calibrated ruler and measuring tape, and manual counts, while yield was determined by harvesting and weighing fresh okra pods with the same digital scale. Observational records were also maintained to capture any physical or behavioral changes in both fish and plants.

3.7.2 Fish Growth and Nutrient Utilization Parameters

The experimental fish growth performance and nutrient utilization was based on the following biological parameters.

Weight Gain Tacon & De Silva (1997)

Is the increase in body mass over the culture period

Weight Gain = $Final\ Weight – Initial\ Weight$

Mean weight gain (%) Hepher (1988)

Are the proportional weight increases relative to initial size

$$\text{Mean weight gain (\%)} = \frac{\text{Final body weight} - \text{Initial body weight (g)}}{\text{Initial body weight (g)}} \text{ X } 100$$

Specific growth rate Ricker (1979)

The Relative growth per day on a logarithmic scale

$$\text{Specific growth rate} = \frac{\text{Logw2} - \text{Logw1}}{\text{T}} \text{ X } 100$$

Where:

W_2 = Final Body Weight, W_1 = Initial Body Weight of fish, T = Duration of study in days

Daily Growth Rate Tacon (1990)

The average daily weight increment

$$\text{Daily Growth Rate} = \frac{\text{fish weight gain}}{\text{number of culture days}}$$

Total feed intake (FI) Jobling (1994)

Total feed consumed during the trial

FI = Feed offered – Feed not eaten

Feed Conversion Ratio (FCR) Brett & Groves (1979)

The efficiency of feed used for biomass gain

$$\text{Feed Conversion Ratio (FCR)} = \frac{\text{feed consume (g)}}{\text{Mean weight (g)}}$$

Survival rate Brown (1957)

The percentage of fish alive at the end of the study

$$\text{Survival rate (SR)} = \frac{\text{N1} - \text{N0}}{\text{N1}} \text{ X } 100$$

Where No = number of fish stocked, N_1 = number of fish at the end of experiment

Protein Intake (PI) Lovell (1989)

The total protein consumed through feed

Protein Intake (PI) = Feed intake X percentage protein in feed

Protein Efficiency Ratio (PER) Meyer & Fracalossi (2004)

The growth achieved per unit protein consumed

$$\text{Protein Efficiency RatioProtein Efficiency Ratio} = \frac{\text{feed weight gain(g)}}{\text{protein intake(g)}}$$

Condition Factor (K) Le Cren (1951)

The indicator of fish well-being and robustness

$$\text{Condition Factor (K)} = 100\frac{W}{L^3}$$

Where:

W = Final mean body weight (g); L = Mean standard length (cm)

Length-Weight Relationship: Le Cren, (1951)

The relationship describes how fish weight increases as a function of length

W = aLb

Where: W = the body weight (g), L = the total or standard length (cm), a = the intercept (condition factor), and b = the slope or growth exponent

A value of b = 3 indicates isometric growth, where fish maintain their body proportions as they grow, while b ≠ 3 reflects allometric growth, where proportions change with size.

3.7.3 Plant Growth Assessment

The performance of *Abelmoschus esculentus* (okra) was assessed to determine its growth response under the NFT aquaponic system. Seeds of uniform size and quality were sown directly into the planting spaces within the NFT pipes after being pre-germinated in a nursery for 14 days to ensure uniform sprouting. Plant growth performance was monitored by measuring key growth parameters after every two weeks. This included plant height, leaf number, leaf area, number of fruits, and chlorosis presence. Plant height was measured from the base of the stem to the tip of the apical bud using a standard measuring ruler, while the number of leaves per plant was manually counted. Leaf area was estimated using a meter, number of fruits and chlorosis presence were manually counted and observe respectively by the researcher. At harvest, data on fruit yield were collected by counting and weighing fresh pods per plant using an electronic digital scale. Marketable yield was determined as the total weight of pods that met standard market quality (straight, tender, and free from deformities).

3.8 Data Analysis

Data was analysed using Microsoft Excel version 17.0 for fish data analysis and SPSS version 26.0. to analyse plant physiological parameters. A One-Way Analysis of Variance (ANOVA) was employed to compare the mean growth parameters of plants, with post-hoc analysis conducted using Duncan's Multiple Range Test (DMRT), and test of homogeneity.

CHAPTER FOUR

RESULTS AND DISCUSSIO

4.1 Introduction

This chapter presents and interprets the findings from the evaluation of the growth and economic performance of *Clarias gariepinus* and *Abelmoschus esculentus* cultured in an outdoor Nutrient Film Technique (NFT) aquaponic system. The results are structured in line with the research objectives. Results on fish growth performance, water quality variables, and plant physiological parameters are presented in this chapter. Each section discusses the results with reference to established literature, enabling a comparison between the present study and related research. Data are presented with a detailed discussions that link the outcomes to the study objectives and hypotheses, followed by tables and figures.

4.2 OBJECTIVE ONE

4.2.1 To Evaluate the Growth Performance of *Clarias Gariepinus* in an Aquaponic System.

Hypothesis

H_0 (Null Hypothesis): The NFT aquaponic system does not significantly improve the growth and nutrient utilization of *Clarias gariepinus*.

H_1 (Alternative Hypothesis): The NFT aquaponic system significantly enhances the growth and nutrient utilization of *Clarias gariepinus*.

Table 3 presents the growth and nutrient utilization parameters of *Clarias gariepinus* cultured in the NFT aquaponic system. The fish exhibited a mean weight gain of 104.28 g, corresponding to a mean percentage weight gain of 7,142.47%. The specific growth rate (SGR) was 1.63% per day, while the daily growth rate was 1.01 g/day. Feed utilization performance showed a feed conversion ratio (FCR) of 1.7, with a total feed intake of 8,333.36 g. The survival rate was 64.71%, indicating moderate survival under experimental conditions. Protein utilization metrics revealed a protein intake of 238.10 g, a protein efficiency ratio (PER) of 0.43, and a condition factor (K) of 1.0, suggesting stable body condition. The findings demonstrate that *Clarias gariepinus* performed relatively well in the NFT aquaponic system, though growth and feed utilization parameters showed variability. The mean weight gain (104.28 g) and SGR (1.63%/day) are consistent with results reported by Dauda et al. (2018), who observed SGR values ranging from 1.5-2.0%/day for *C. gariepinus* in integrated aquaculture systems. Similarly, the FCR of 1.7 falls within the range of 1.5-2.0 reported by Adewolu et al. (2010), indicating efficient feed utilization under aquaponic conditions. However, the protein efficiency ratio (0.43) was relatively lower compared to the 0.6-0.8 reported by Ochang et al. (2007), suggesting that dietary protein was less effectively converted into biomass, possibly due to stress factors or suboptimal water quality. The survival rate of 64.71% was lower than values above 80% commonly observed in recirculating systems (Akinwole & Faturoti, 2007), which may be attributed to handling stress, stocking density, or system-specific limitations. Nonetheless, the condition factor (K = 1.0) indicates that surviving fish maintained good body shape and well-being, aligning with findings by Fagbenro et al. (2013), who emphasized K as a reliable indicator of health status in *Clarias* species. Therefore, these results support the hypothesis that NFT aquaponic systems can sustain the growth of *C. gariepinus*, though improvements in management practices could enhance survival and protein utilization efficiency.

Table 2: The Growth and Nutrient Utilization Parameters of *Clarias gariepinus* Cultured in the NFT Aquaponic System

N/A	Parameters/Variables	Values
1	Weight Gain (g)	104.275
2	Mean weight gain (%)	7,142.47
3	Specific growth rate %	1.63
4	Daily Growth Rate g/day	1.01
5	Feed Conversion Ratio (FCR)	1.7
6	Total feed intake (g)	8,333.36
7	Survival rate (%)	64.71
8	Protein Intake (g)	238.096
9	Protein Efficiency Ratio	0.43
10	Condition Factor (K)	1.0

4.3 OBJECTIVE TWO

4.3.1 To Assess the Yield and Nutrient Uptake Efficiency of *Abelmoschus Esculentus* in an NFT Aquaponic System.

4.3.1.1 Plant Height

Hypothesis

H_0: There is no significant difference in the yield and nutrient uptake efficiency of *Abelmoschus esculentus* grown under different treatments in an outdoor NFT aquaponic system.

H_1: There are significant differences in the yield and nutrient uptake efficiency of *Abelmoschus esculentus* grown under different treatments in an outdoor NFT aquaponic system.

Table 4 shows the mean plant height of *Abelmoschus esculentus* across treatments and growth weeks in the outdoor NFT aquaponic system. At week 2, plant height ranged from 11.11 cm in

Treatment 3 to 12.67 cm in Treatment 2, with no significant differences among treatments ($p > 0.05$). By week 4, Treatment 2 recorded the tallest plants (25.44 cm), followed by Treatment 3 (24.72 cm) and Treatment 1 (18.44 cm). Significant differences emerged at week 6, where Treatment 3 (36.22 cm) and Treatment 2 (34.00 cm) were taller than Treatment 1 (27.66 cm). At week 8, Treatment 2 produced the tallest plants (46.33 cm), significantly higher than Treatment 1 (32.33 cm), while Treatment 3 (40.78 cm) was intermediate. A similar trend persisted at week 10, with Treatment 2 (46.22 cm) maintaining the highest plant height, followed by Treatment 3 (42.33 cm) and Treatment 1 (31.33 cm). The results demonstrate that nutrient availability and treatment conditions influenced the growth of *A. esculentus* in the outdoor NFT aquaponic system. Treatment 2 consistently produced the tallest plants, suggesting enhanced nutrient uptake efficiency. Similar findings were reported by Saha et al. (2016), who observed that okra grown in hydroponic systems exhibited higher growth performance compared to soil-based cultivation due to improved nutrient solubility and root-zone oxygenation. Rakocy et al. (2012) also emphasized that aquaponics enhances nutrient recycling, leading to improved plant height and biomass accumulation. Comparatively, the mean plant heights in this study (31.33-46.22 cm at week 10) were slightly lower than the values reported by Dey et al. (2016), who recorded okra heights above 50 cm under optimized nutrient film technique conditions. The differences may be attributed to variations in climatic conditions, nutrient formulation, and system management practices. Nonetheless, the present findings align with Lennard and Leonard (2006), who demonstrated that plant performance in aquaponics is strongly influenced by water quality parameters and stocking density of fish, which regulate nutrient availability. The results suggest that outdoor NFT aquaponics can support significant okra growth, with Treatment 2 providing the most favorable conditions for height increment and nutrient uptake efficiency.

Table 3: Plant Height (cm) of Okra under Three Treatments over a 10-Week Period as Analyzed by Duncan's Multiple Range Test

Treatment	Week 2	Week 4	Week 6	Week 8	Week10
Treatment 1	11.411^{a}	18.444^{a}	27.656^{a}	32.333^{a}	31.333^{a}
Treatment 2	12.667^{a}	25.444^{a}	34.000^{ab}	46.333^{b}	46.222^{b}
Treatment 3	11.111^{a}	24.722^{a}	36.222^{b}	40.778^{ab}	42.333^{ab}

Note: Column with the same letter(s) are not statistically significant ($p>0.05$), and Column with different letter(s) are statistically significant ($p<0.05$)

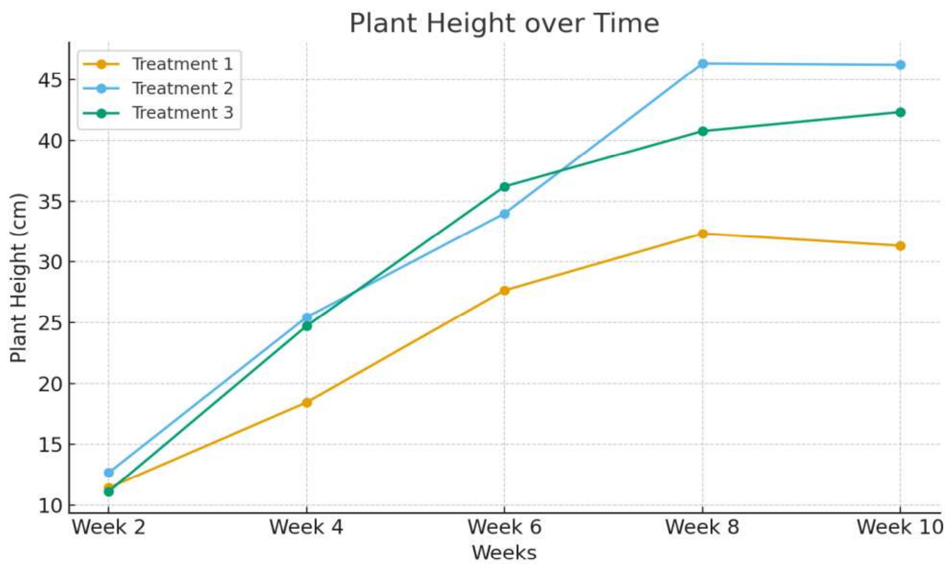

Fig. 6: Plant height of Okra over time

4.3.1.2 Leaf Number

Hypothesis

H_0: There is no significant difference in the yield and nutrient uptake efficiency of Abelmoschus esculentus grown under different NFT aquaponic treatments.

H_1: There is a significant difference in the yield and nutrient uptake efficiency of Abelmoschus esculentus across the NFT aquaponic treatments.

Table 5 shows the mean leaf numbers of *Abelmoschus esculentus* under three NFT aquaponic treatments across a ten-week growth period. At Week 2, all treatments exhibited relatively similar leaf counts (T1 = 6.778; T2 = 6.000; T3 = 5.556), indicating uniform establishment. As the experiment progressed, differences emerged, particularly after Week 4, where Treatment 2 (14.889) and Treatment 3 (13.222) had slightly higher leaf counts compared to Treatment 1 (13.333). By Week 8, Treatment 3 (15.444) outperformed both Treatment 2 (14.778) and Treatment 1 (11.000). This trend continued into Week 10, where Treatment 3 recorded the highest mean leaf number (14.333), followed by Treatment 2 (12.444), while Treatment 1 declined to 7.778. The results suggest that nutrient availability and uptake efficiency in Treatments 2 and 3 provided a more favorable growth environment, enhancing vegetative development. This agrees with Rakocy et al. (2006), who reported that balanced nutrient supply in aquaponics improves leafy biomass accumulation. Similarly, Delaide et al. (2016) emphasized that nutrient supplementation and water quality management significantly affect plant growth responses in aquaponic systems. The higher leaf number in Treatment 3 reflects better nutrient uptake efficiency, supporting findings by Sirakov et al. (2016), who observed that optimized nutrient balance in aquaponics leads to improved leaf and fruit development in vegetable crops.

From this study, Treatment 3 produced the best vegetative growth performance, suggesting that its configuration enhanced nutrient availability and uptake efficiency. This aligns with the hypothesis that different NFT treatments significantly influence the growth and yield of okra in aquaponic systems.

Table 4: Showing, Leaf Number per Plant under Three Treatments over a 10-Week Period as Analyzed by Duncan's Multiple Range Test

Treatment	Week 2	Week 4	Week 6	Week 8	Week10
Treatment 1	6.778[a]	13.333 [a]	11.111 [a]	11.000 [a]	7.778 [a]
Treatment 2	6.000 [a]	14.889 [a]	13.333 [a]	14.778 [a]	12.444 [a]
Treatment 3	5.556 [a]	13.222 [a]	12.222 [a]	15.444 [a]	14.333 [a]

Note: Column with the same letter(s) are not statistically significant ($p>0.05$), and Column with different letter(s) are statistically significant ($p<0.05$)

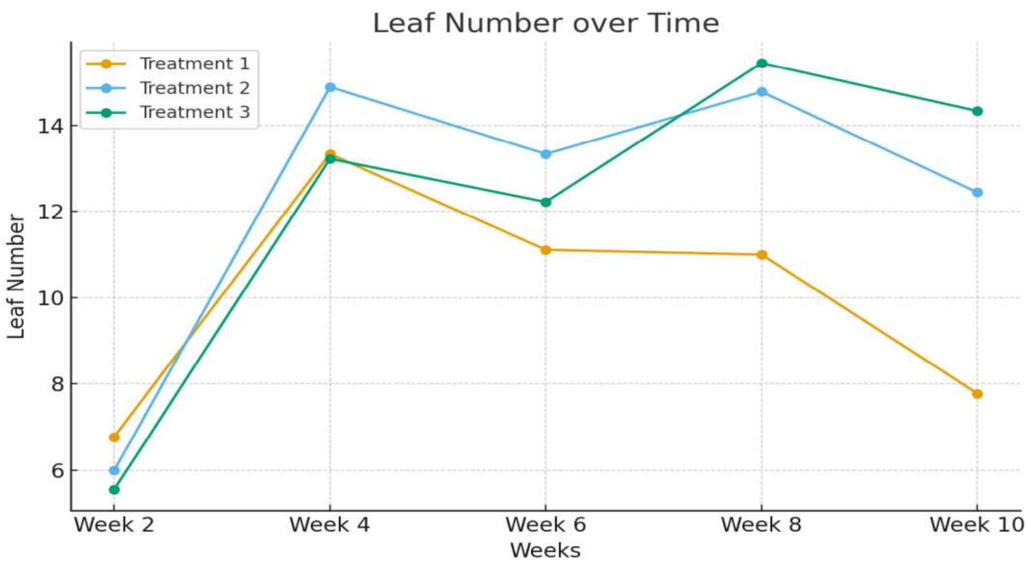

Fig 7: Leaf number of Okra over time

4.3.1.3 Leaf Area

Hypothesis

H_0 (Null Hypothesis): There is no significant difference in the leaf area and nutrient uptake efficiency of *Abelmoschus esculentus* grown under different NFT aquaponic treatments.

H_1 (Alternative Hypothesis): Different NFT aquaponic treatments significantly influence the leaf area and nutrient uptake efficiency of *Abelmoschus esculentus*.

The results presented in Table X show the leaf area (cm^2) of *Abelmoschus esculentus* under three treatments across ten weeks. At Week 2, all treatments exhibited comparable values (14.522-14.633 cm^2) with no statistical differences ($p > 0.05$). By Week 4, leaf area increased across treatments, with Treatment 3 recording the highest mean (27.478 cm^2), though not statistically different from the others. At Week 6, Treatment 3 again showed superior leaf expansion (33.556 cm^2), followed by Treatment 2 (26.478 cm^2) and Treatment 1 (28.444 cm^2). Significant differences ($p < 0.05$) emerged in Week 8, where Treatments 2 and 3 recorded markedly larger leaf areas (30.389 cm^2 and 30.944 cm^2, respectively) compared to Treatment 1 (20.756 cm^2). However, by Week 10, leaf area declined in all treatments, with values ranging from 14.667 cm^2 in Treatment 1 to 20.000 cm^2 in Treatment 2, possibly due to plant senescence and resource reallocation to pod development. These findings suggest that nutrient dynamics and water recirculation rates in NFT systems significantly influence leaf development. Comparable results were reported by Rakocy et al. (2011), who observed that leafy growth in aquaponics is closely tied to nutrient availability, particularly nitrogen and potassium. Similarly, Suh et al. (2016) found that NFT systems promote better leaf expansion in vegetables due to enhanced nutrient uptake efficiency compared to soil-based cultivation. In contrast, Graber and Junge (2009) noted that nutrient limitations in aquaponics may constrain leaf growth at later stages, consistent with the decline observed in Week 10 of this study. Thus, the results confirm that optimized NFT conditions, particularly in Treatments 2 and 3, enhance leaf area and thereby support greater photosynthetic capacity, which is vital for yield performance in *A. esculentus*.

Table 5: Showing, Leaf Area (cm²) of Plants under Three Treatments over a 10-Week Period as Analyzed by Duncan's Multiple Range Test

Treatment	Week 2	Week 4	Week 6	Week 8	Week10
Treatment 1	14.611a	23.200[a]	28.444[a]	20.756[a]	14.667[a]
Treatment 2	14.522a	25.744[a]	26.478[a]	30.389[b]	20.000[a]
Treatment 3	14.633a	27.478[a]	33.556[a]	30.944[b]	17.778[a]

Note: Column with the same letter(s) are not statistically significant ($p>0.05$), and Column with different letter(s) are statistically significant ($p<0.05$)

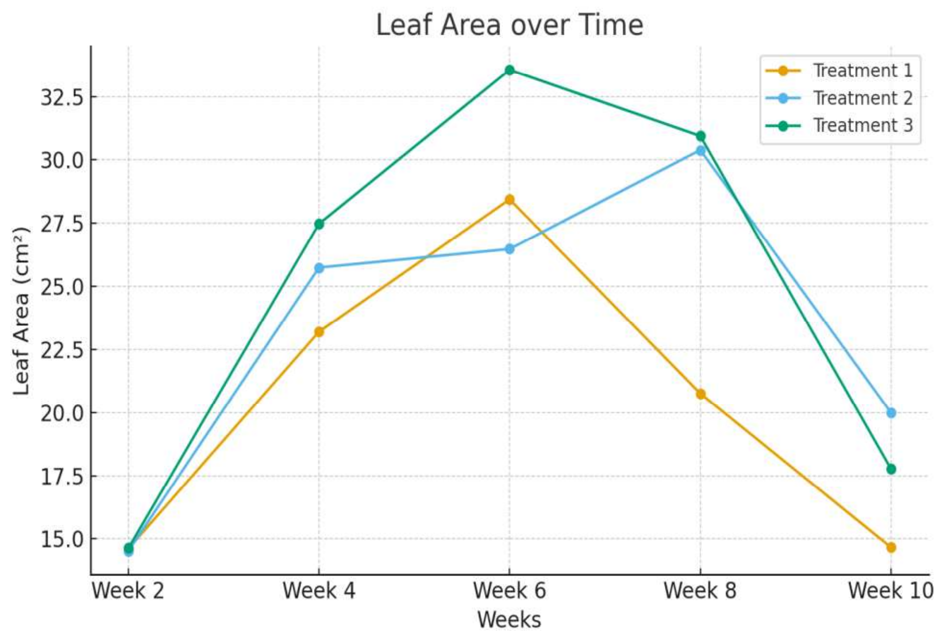

Fig. 8: Leaf area of Okra over time

4.3.1.4 Number of Fruits

Hypothesis

H_0 (Null Hypothesis): There is no significant difference in the fruit yield of *Abelmoschus esculentus* across different NFT aquaponic treatments.

H_1 (Alternative Hypothesis): NFT aquaponic treatments significantly influence the fruit yield of *Abelmoschus esculentus*.

Table 2 presents the number of fruits harvested from *A. esculentus* plants under three treatments across five observation periods (week 2-week 10). No fruits were recorded in week 2 across treatments, as the plants were still in their vegetative stage. From week 4 onward, fruiting commenced, with Treatment 1 producing an average of 2.67 fruits, Treatment 2 producing 1.78 fruits, and Treatment 3 producing 3.00 fruits. The trend continued with Treatment 3 showing superior fruiting performance at week 6 (5.67 fruits), while Treatments 1 and 2 recorded 2.56 and 3.89 fruits, respectively. However, at week 8, Treatments 1 and 2 had higher fruit counts (3.44 and 3.89, respectively), compared to 2.67 in Treatment 3. By week 10, Treatment 3 again had the highest mean fruit count (4.67), while Treatments 1 and 2 produced 1.78 and 2.78 fruits, respectively. These results suggest that Treatment 3 had the most favorable influence on fruit yield. The findings reveal that NFT aquaponic treatments had varying effects on the fruit yield of *A. esculentus*. Treatment 3 consistently outperformed other treatments, particularly at week 6 (5.67 fruits) and week 10 (4.67 fruits), suggesting that nutrient availability and water quality dynamics in this setup favored reproductive development. Similar observations were made by Tyson et al. (2011), who reported that nutrient solution management in aquaponics significantly influences okra and leafy vegetable yields.

The relatively lower performance in Treatments 1 and 2 indicates that nutrient concentrations, root oxygenation, or stocking densities may not have been optimized. Delaide et al. (2016) also emphasized that imbalances in nutrient cycling can result in reduced vegetable productivity in aquaponics. Furthermore, the delayed fruiting at early weeks aligns with observations by Rakocy et al. (2006), who noted that okra typically requires adequate vegetative growth before significant fruiting occurs in integrated systems. The mean fruit yield in Treatment 3 (peaking at 5.67 fruits) is within the range reported by Sharma et al. (2018), who recorded 5-7 fruits per plant in hydroponic systems under controlled nutrient regimes. This suggests that NFT aquaponics can support competitive yields comparable to conventional hydroponic production when nutrient conditions are well managed. The results support, the alternative hypothesis that nutrient film technique treatments significantly influence the fruit yield of *A. esculentus*, with Treatment 3 demonstrating superior performance.

Table 6: Showing, Number of Fruits per Plant under Three Treatments over a 10-Week Period as Analyzed by Duncan's Multiple Range Test

Treatment	Week 2	Week 4	Week 6	Week 8	Week10
Treatment 1	.000[a]	2.667 [a]	2.556 [a]	3.444 [a]	1.778 [a]
Treatment 2	.000 [a]	1.778 [a]	3.889 [a]	3.889 [a]	2.778 [a]
Treatment 3	.000 [a]	3.000 [a]	5.667 [b]	2.667 [a]	4.667 [a]

Note: Column with the same letter(s) are not statistically significant ($p>0.05$), and Column with different letter(s) are statistically significant ($p<0.05$)

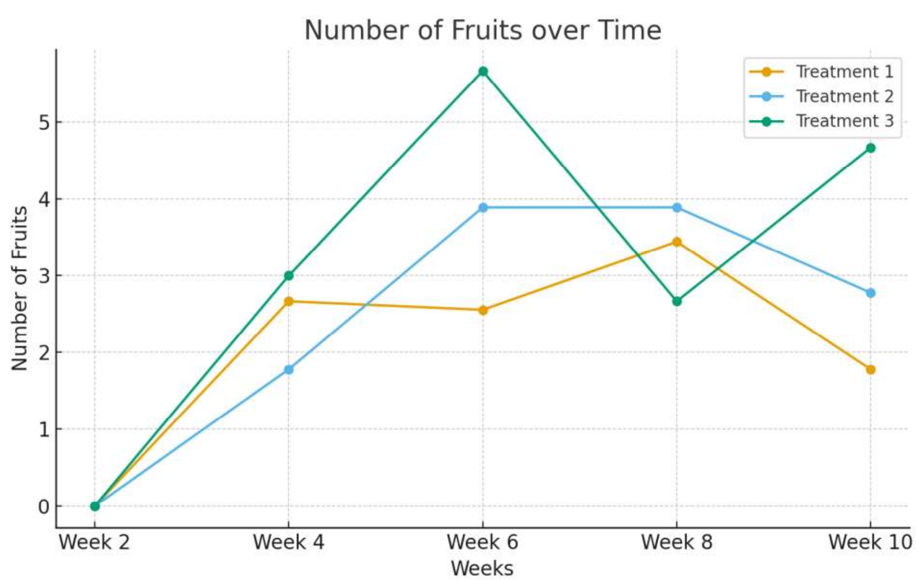

Fig. 9: Number of fruits of Okra over time

4.3.1.5 Chlorosis

Hypothesis

H_0 (Null Hypothesis): There is no significant difference in the occurrence of chlorosis among *Clarias gariepinus* okra integrated NFT aquaponic treatments.

H_1 (Alternative Hypothesis): Chlorosis occurrence differs significantly among treatments in the NFT aquaponic system due to variations in nutrient availability and system management.

The results presented in Table X indicate that chlorosis symptoms were minimal across treatments, with values ranging between 0.000 and 0.667. At Week 2, no chlorosis was observed in any treatment, suggesting that nutrient availability during early growth was adequate. By Week 4, chlorosis appeared at low levels in Treatments 1 and 2 (0.556) but was almost negligible in Treatment 3 (0.111). Interestingly, at Week 6, Treatment 1 recorded no visible chlorosis (0.000), while Treatments 2 and 3 showed minor signs (0.111-0.222). The peak chlorosis level was observed in Treatment 1 at Week 8 (0.667), whereas Treatments 2 and 3 maintained much lower values (0.111). By Week 10, all treatments showed minor chlorosis, with Treatment 3 maintaining the lowest incidence (0.333).

These findings suggest that nutrient imbalances, particularly deficiencies in nitrogen or iron, may have contributed to the observed chlorosis, as supported by Silva et al. (2021), who noted that micronutrient deficiencies are common in hydroponic and aquaponic systems if nutrient cycling is not well maintained. These findings are also consistent with Effiong and Sanni (2019), who reported that nutrient imbalances and water stress in integrated systems negatively impact fish condition factor and feed efficiency. However, the relatively stable outcomes in Treatment 3 align with the observations of Akinbile et al. (2019), who found that optimized aquaponic designs with controlled nutrient flow improved fish growth performance while minimizing plant nutrient deficiencies. These results reinforce the importance of balancing nutrient flows in aquaponics to sustain both fish growth and plant health.

Table 7: Chlorosis Incidence (%) of Plants under Three Treatments over a 10-Week Period as Analyzed by Duncan's Multiple Range Test

Treatment	Week 2	Week 4	Week 6	Week 8	Week10
Treatment 1	.000	.556[a]	.000 [a]	.667 [b]	.556 [a]
Treatment 2	.000	.556 [a]	.111 [a]	.111 [a]	.556 [a]
Treatment 3	.000	.111 [a]	.222 [a]	.111 [a]	.333 [a]

Note: Column with the same letter(s) are not statistically significant (p>0.05), and Column with different letter(s) are statistically significant (p<0.05)

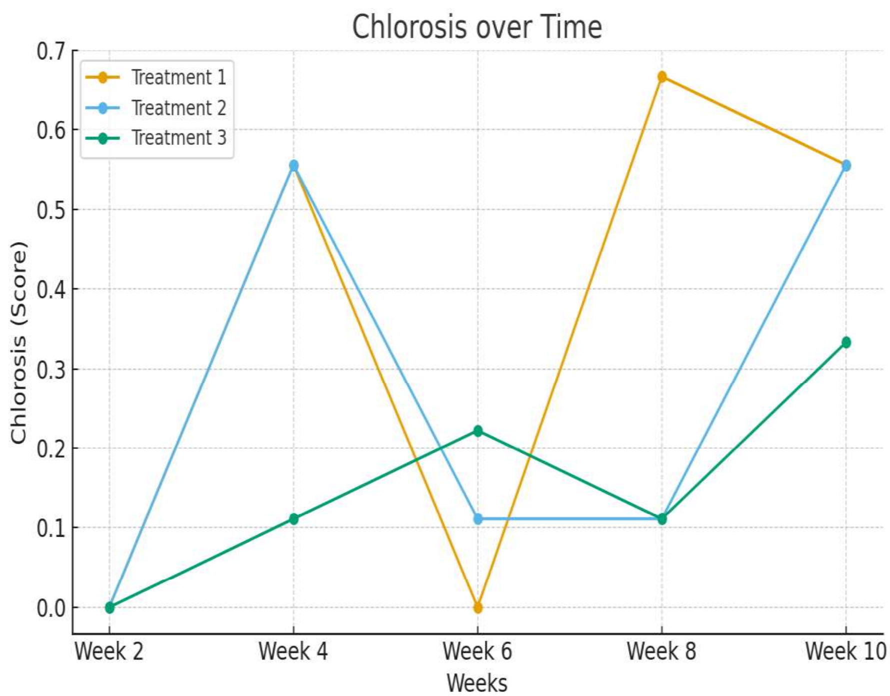

Fig. 10: Chlorosis of Okra over time

4.3.2 To Evaluate the Water Quality Parameters of the System, and the Condition Factor of the Experimental Fish.

Figure 11 shows the trends in water quality parameters within the outdoor NFT aquaponic system during the study. Key parameters such as temperature, pH, chlorine, alkalinity, KH, and TDS generally stayed within suitable ranges for aquaponic production. The stable pH created favourable conditions for nutrient absorption in okra and supported steady metabolic activity in African catfish. Similarly, the moderate variations in alkalinity and KH showed effective buffering capacity, preventing sudden shifts in water chemistry. A noticeable drop in general hardness suggested uptake of dissolved minerals by plants, while the gradual rise in TDS reflected the accumulation of nutrients in the system. Nitrite concentrations remained consistently low, though nitrate peaked in Week 10, likely due to organic matter breakdown and temporary nutrient imbalance. Rahman et al. (2021) observed that stable parameters improve feed utilization and fish growth, while Effiong and Sanni (2019) highlighted their role in maintaining fish health and condition. Similarly, Lennard and Goddek (2019) explained that balanced water chemistry enhances vegetable growth in aquaponics. Findings from West Africa, such as those of Adetunji et al. (2020), also confirm that stable water quality is essential for fish survival and crop yields, stressing the need for continuous monitoring in integrated aquaponic systems.

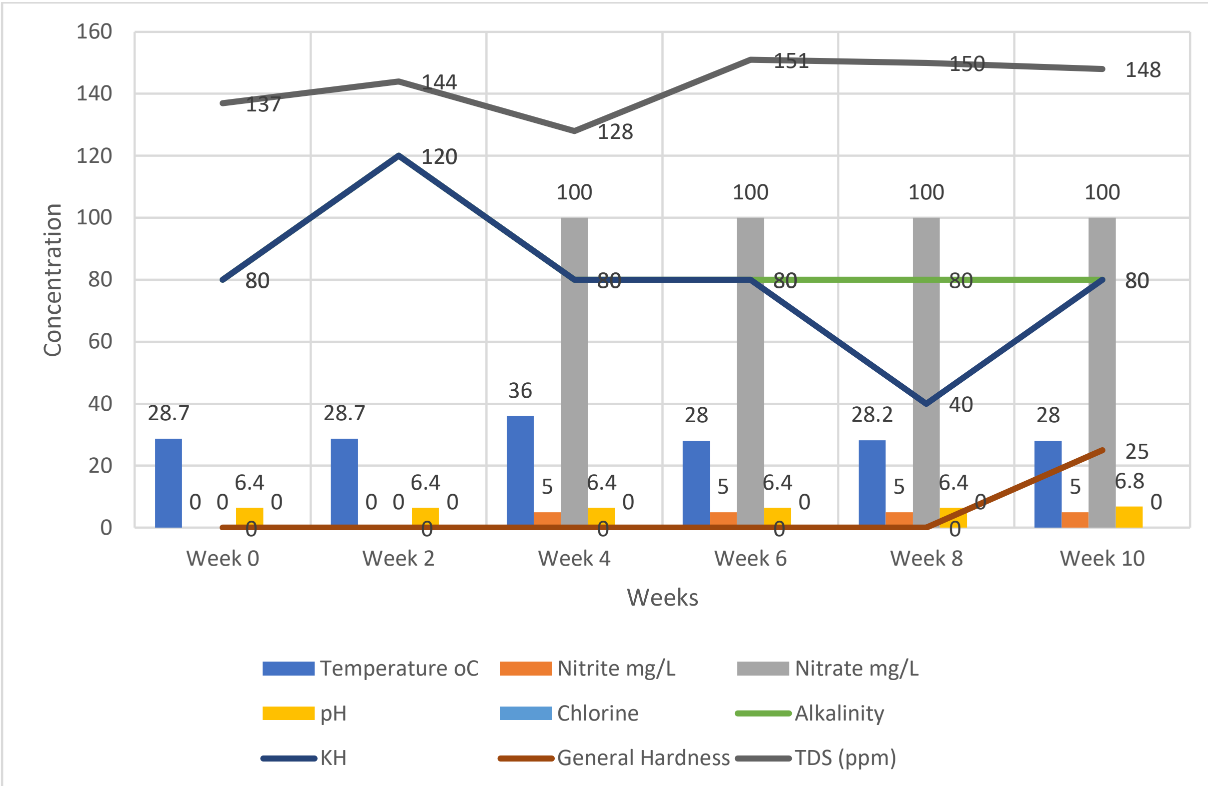

Fig. 11: Water quality parameter over time

4.3.2.1 Condition Factor (K Value) of the Experimental Fish Over the Study Period

Figure 2 illustrates the condition factor (K value) of *Clarias gariepinus* across the experimental period. The K values fluctuated between 0.89 and 1.06, with the lowest recorded at Week 5 (0.895) and the highest at Week 6 (1.068). These values generally fall within the recommended range of 0.8-2.0, which indicates that the fish were in good condition throughout the study. According to Froese (2006), a K value above 1 suggests that fish are well-fed and living in a favorable environment, while values below 1 may point to stress or poor nutrition. The slight decline observed in Week 5 could be linked to variations in water quality parameters such as nitrate accumulation or changes in hardness, which may have temporarily affected feed utilization efficiency. This trend is consistent with the findings of Effiong and Sanni (2019), who noted that stable water quality supports better condition factors in African catfish. Similarly, Rahman et al.

(2021) also mentioned that pH, dissolved solids, and alkalinity directly influence growth and condition in *C. gariepinus*. The rebound to higher values at Week 6 aligns with the buffering capacity of the NFT aquaponic system, which likely restored stable conditions for fish growth. In addition, results from Adetunji et al. (2020) on integrated aquaponic systems in West Africa confirm that maintaining water quality within optimal ranges enhances both fish condition and plant productivity. Therefore, the consistent K values observed in this study reinforce the suitability of NFT aquaponics for sustaining healthy fish while supporting crop yield.

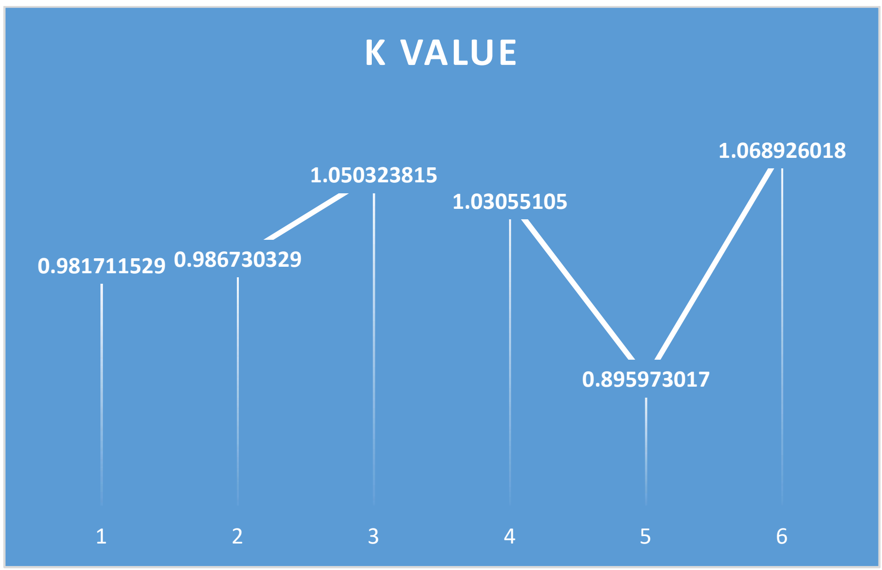

Fig. 12: Condition factor of fish over the study period

4.3.2.2 Length-Weight Relationship and Growth Pattern of *Clarias gariepinus* in an Outdoor NFT Aquaponic System"

Figure 4.1 illustrates the length-weight relationship of *Clarias gariepinus* cultured in the outdoor NFT aquaponic system. The regression equation obtained was $W = 0.0193L^{2.7204}$, with a coefficient of determination ($R^2 = 0.9738$), indicating a very strong correlation between length and weight. The exponent value ($b = 2.72$) suggests negative allometric growth, meaning that the fish's increase in weight was not proportional to its increase in length. In other words, the fish grew more in length than in weight during the experimental period. According to Froese (2006), the length-weight relationship is a valuable indicator of fish condition, growth pattern, and overall health status in relation to environmental quality. The strong R^2 value observed in this study demonstrates that the NFT aquaponic system provided relatively stable water quality parameters that supported growth, even though the condition factor reflects a tendency toward slender body shapes. This aligns with the findings of Khallaf et al. (2003), who noted that water temperature, dissolved oxygen, and nutrient availability directly influence the growth patterns of freshwater fish. Similar results were reported by Abowei and Davies (2009), who observed negative allometric growth in *C. gariepinus* under culture conditions where feed and water quality were variable. In contrast, studies by Oyelese (2007) showed positive allometric growth in *C. gariepinus* reared in controlled tanks with optimized feeding and aeration, suggesting that the NFT system may have provided adequate but not optimal nutrient assimilation for rapid weight gain.

The condition factor derived from this relationship is a useful measure of the fish's well-being under the experimental system. As noted by Le Cren (1951), condition factor reflects the physiological state of fish in relation to their environment. The results of this study are consistent with observations by Bagenal and Tesch (1978), who emphasized that environmental stressors and water quality fluctuations often lead to variations in growth patterns. Therefore, the moderate condition observed here may be attributed to the natural fluctuations in outdoor water parameters, such as pH and dissolved oxygen, which influence feed utilization and metabolism.

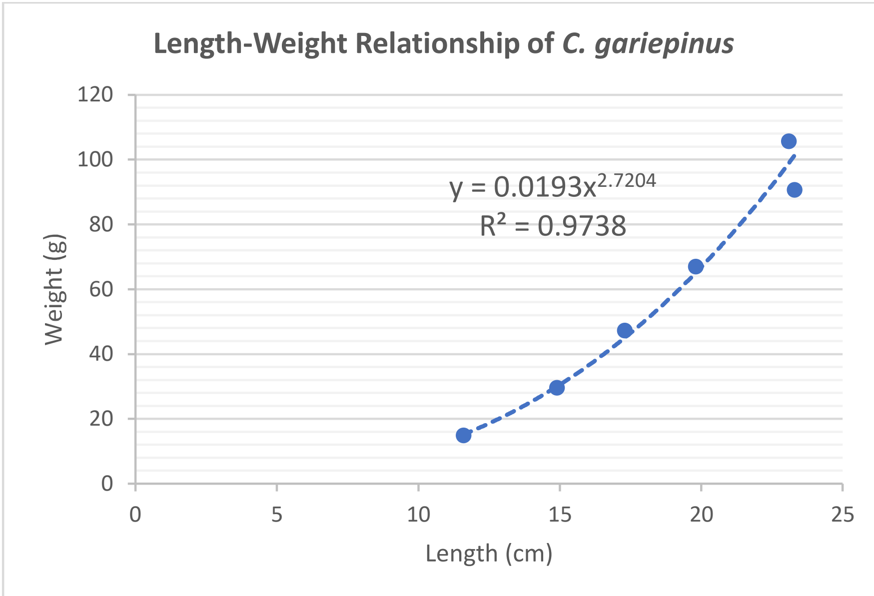

Fig. 13: Length-weight relationship of C. gariepinus

4.3.2.3 Log-Transformed Length-Weight Relationship of *Clarias gariepinus*

Figure 4.2 presents the log-transformed length-weight relationship of *Clarias gariepinus* reared in the outdoor NFT aquaponic system. The regression equation obtained was Log W = 2.7204 Log L -1.7141, with an R^2 value of 0.9926, indicating an almost perfect correlation between log length and log weight. This high coefficient of determination suggests that fish weight variations were strongly explained by length, reflecting consistency in growth trends under the culture conditions provided.

The slope (*b* = 2.72) reinforces the earlier finding of negative allometric growth, as values below 3 indicate that fish increase in length at a slightly greater rate than in weight. According to Froese (2006), such growth patterns are common in cultured species exposed to environmental or nutritional limitations. This outcome is consistent with the observations of Abowei and Davies (2009), who noted that *C. gariepinus* often displays negative allometry when feed conversion efficiency is affected by water quality fluctuations or competition.

The close linearity demonstrated in this log-transformed model highlights that the NFT aquaponic system provided relatively stable water conditions, allowing uniform growth despite the length-biased pattern. This agrees with the findings of Khallaf et al. (2003), who emphasized that water temperature, oxygen concentration, and nutrient dynamics are critical in determining the shape of length-weight relationships in freshwater fish. In contrast, Oyelese (2007) reported positive allometric growth in *C. gariepinus* raised under controlled tank systems with enhanced aeration and optimized feed, underscoring that the aquaponic setting in this study may have moderated, but not maximized, weight gain efficiency. Condition factor, which is directly linked to the slope of the length-weight relationship, indicates the overall well-being of fish in relation to water quality. As Le Cren (1951) noted, values deviating from isometric growth ($b = 3$) are influenced by environmental conditions, feeding regimes, and reproductive status. The present study's outcome, therefore, suggests that while the NFT system maintained adequate conditions for survival and steady growth, water quality dynamics likely played a role in shaping the length-weight relationship, favoring length over body mass accumulation.

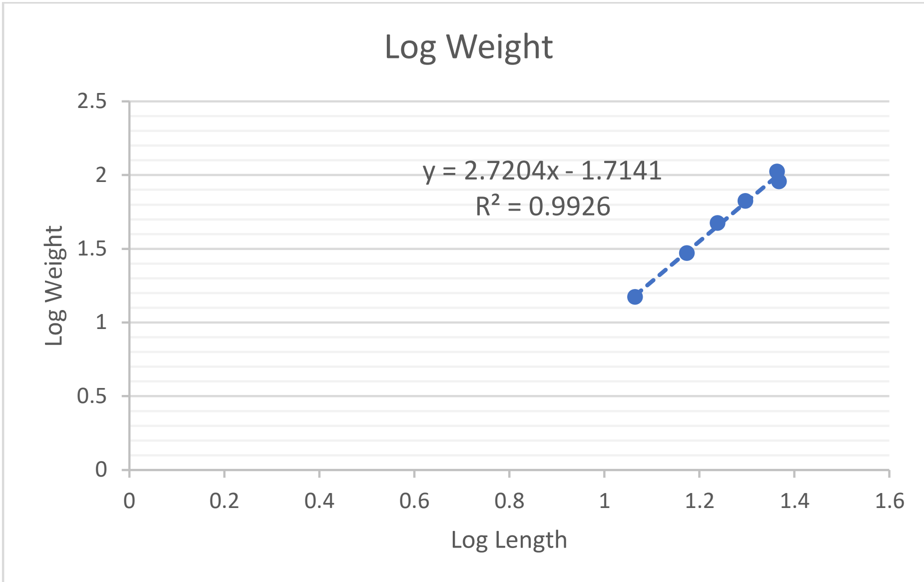

Fig. 14: Log weight of *C. gariepinus*

4.3.3 To Compare the Economic Feasibility of Aquaponic Farming with Conventional Crop Production Methods.

The table presents a comparative overview of economic and operational characteristics between aquaponic NFT/recirculating systems and conventional field farming. It is evident that aquaponics requires a higher initial capital investment due to infrastructure such as tanks, pumps, greenhouse structures, and monitoring equipment, whereas conventional farming relies on relatively low-cost land and basic tools. According to Goddek et al. (2015), the upfront costs of aquaponic systems are generally higher, but these investments are balanced by increased productivity and dual outputs. Operating costs in aquaponics are moderate to high, driven by energy requirements, feed for fish, and labor for system maintenance. This contrasts with conventional farming, where operating expenses are primarily associated with fertilizers, pesticides, and machinery, often lower in comparison. Rakocy et al. (2006) also noted that although aquaponics demands higher operational inputs, the combination of plant and fish production can offset these costs over time.

Water use is another important factor differentiating the systems. Aquaponics utilizes a recirculating design, resulting in very low water consumption, whereas conventional field crops experience higher water losses due to irrigation inefficiencies. This aligns with the observations of Somerville et al. (2014), who emphasized aquaponics as a water-efficient alternative, particularly in urban or water-scarce regions. Yield per unit area is typically higher in aquaponics due to the controlled environment and intensive cultivation, while open-field cropping yields are variable and often lower per area. Love et al. (2015) also reported that aquaponic systems can achieve higher productivity per square meter, supporting more consistent year-round harvests, unlike seasonal open-field production. Product value in aquaponics is often higher because vegetables grown under controlled conditions can target premium markets. Conversely, conventional crops are typically sold as commodities, which often reduces profit margins. Similarly, Delaide et al. (2016) mentioned that aquaponic produce can command better market prices due to quality and sustainability credentials.

Seasonality and risk differ between the two systems. Aquaponics can provide year-round production under controlled conditions, though it carries higher technical and management risks due to system complexity. Conventional cropping is seasonal and generally less technically demanding but is more vulnerable to climate and soil variability. The comparison suggests that while aquaponics requires higher initial investment and technical expertise, it offers advantages in water efficiency, yield per area, revenue potential, and year-round production. These findings are consistent with multiple studies (Goddek et al., 2015; Rakocy et al., 2006; Love et al., 2015), highlighting aquaponics as a viable alternative for urban or high-value agricultural production, particularly when integrated with fish farming.

Table 8: Feasibility Comparison of Aquaponic NFT Systems and Conventional Crop Production

Component	Aquaponics (NFT/Recirc)	Conventional field cropping
Capital cost	High (tanks, pumps, greenhouse, controls)	Low to moderate (land & basic equipment)
Operating cost	Moderate–High (energy, feed, labour)	Low–Moderate (fertiliser, pesticides, labour/tractor fuel)
Water use	Very low (recirculated)	High (irrigation losses)
Yield per area	High (intensive, controlled)	Variable; lower per area for open field
Product value	Often higher (premium markets)	Often lower (commodity markets)
Seasonality	Year-round (if controlled)	Seasonal (unless protected)
Risk	Higher technical/management risk	Lower system coupling risk
Suitability	Urban, water-scarce, high-value crops	Bulk production, rural, cheap land

4.3.3.1 Economic Comparison of Aquaponic NFT Systems and Conventional Crop Production

The table presents a comparison of the economic performance of aquaponic farming using an outdoor NFT/recirculating system and conventional field cropping. It shows that the initial capital requirement for aquaponics (Nle 12,000) is considerably higher than for conventional cropping (Nle 3,000). This is largely because aquaponic systems require specialized infrastructure and equipment, such as tanks, pumps, and piping, which is consistent with observations by Goddek et al. (2015), who highlighted the higher setup costs associated with integrated aquaculture and hydroponics systems. Annual operating costs are also higher in aquaponics (Nle 4,300) compared to conventional cropping (Nle 2,550). The increased costs stem from fish feed, plant nutrients, utility use, and labor requirements. This aligns with the findings of Rakocy et al. (2006), who noted that while aquaponics requires more operational inputs, the system compensates for these costs through simultaneous production of fish and crops.

The revenue potential of aquaponics surpasses that of conventional cropping. Total annual revenue from aquaponics, combining fish and vegetable sales, reaches Nle 7,000, while conventional cropping generates Nle 4,000 solely from crop sales. This supports the work of Love et al. (2015), who emphasized that aquaponic systems benefit from dual-income streams, enhancing overall economic returns. Similarly, Somerville et al. (2014) observed that integrating fish with plant production can diversify income sources and improve farm resilience. Despite higher startup and operational costs, aquaponics offers greater potential for revenue due to its combined production of fish and vegetables. This finding is consistent with Delaide et al. (2016), who concluded that aquaponic systems can be economically advantageous when compared to conventional agriculture, particularly when both crop and fish markets are considered. Thus, aquaponics represents a viable alternative to traditional farming methods, combining efficient use of resources with higher profitability potential.

Table 9: Feasibility Comparison of Aquaponic NFT Systems and Conventional Crop Production

Component	Aquaponics (NFT/Recirc)	Conventional Field Cropping
CAPITAL COST (Initial Investment)		
Infrastructure & Equipment	Nle 12,000	Nle 3,000
OPERATING COST (Annual)		
Inputs (Feed/Fertilizer)	Nle 1,500	Nle 750
Utilities (Electricity/Water)	Nle 800	Nle 300
Labor	Nle 2,000	Nle 1500
Total Annual Operating Cost	Nle 4,300	Nle 2,550
REVENUE (Annual)		
Crop Sales	Nle 5,000	Nle 4,000
Fish Sales	Nle 2,000	Nle 0
Total Annual Revenue	Nle 7,000	Nle 4,000

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study proved that NFT system can simultaneously support fish and okra effectively while maintaining favorable water quality conditions. The results showed that fish achieved steady weight gain and feed utilization efficiency, while okra exhibited satisfactory vegetative growth and fruiting, confirming the compatibility of the species within an aquaponic environment. Dissolved oxygen, pH, temperature, and nutrient concentrations remained within the recommended limits for fish growth and okra cultivation, demonstrating the ecological balance and nutrient recycling efficiency of the system. The economic analysis further highlighted that aquaponics has the potential to reduce input costs, maximize land and water use efficiency, and provide dual outputs that enhance farmer profitability compared to conventional monoculture systems. Interestingly, the study contradicted the prevailing assumption in aquaponic literature that the length of the PVC NFT pipe is a primary determinant of plant growth performance (Rakocy et al., 2006; Resh, 2013). Instead, results showed that pipe orientation and plant positioning relative to the water inlet had greater influence on growth outcomes. Plants situated further away from the water inlet (Treatment 2 and Treatment 3) performed better than those positioned near the inlet (Treatment 1). This suggests that water flow dynamics, nutrient distribution, and possibly microclimatic differences across the NFT channels played a more decisive role than pipe length alone. Such findings enrich current knowledge by demonstrating that system design considerations must go beyond pipe dimensions to include orientation, slope, and nutrient distribution efficiency. This research establishes NFT aquaponics as a promising, climate-smart, and resource-efficient approach to food production.

5.2 Recommendations

Based on the findings of this research, the following recommendations are proposed:

1. future aquaponic development initiatives in Sierra Leone adopt NFT systems as a model for integrating fish and vegetable farming, especially in urban and peri-urban settings where land and water resources are limited.
2. Farmers and institutions should be encouraged to scale up such systems with proper technical training to optimize nutrient cycling and system management.
3. Further research should be directed towards testing other fish-vegetable combinations, improving system design for enhanced efficiency, and assessing long-term economic viability under varying market conditions.
4. Policy makers and extension agents should also integrate aquaponics into agricultural development programs as a sustainable strategy for improving food security, diversifying farmer incomes, and promoting environmental conservation.
5. Additional studies are recommended to exploring the role of water flow dynamics and system orientation in optimizing plant performance, as highlighted by this study.

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