Economic Assessment of Catfish Farming in Nigeria

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Thesis for the degree of PhD
in Environment and Natural Resources

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Hagfræðilegt mat á eldi á grana í Nígeríu

Olanrewaju Femi Olagunju

Ritgerð til doktorsgráðu í Umhverfis- og auðlindafræði

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Desember 2024

Félagsvísindasvið

HAGFRÆÐIDEILD

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Reykjavik, Iceland 2024

Ágrip

Þessi ritgerð inniheldur greiningu á arðsemi eldis á grana í Nígeríu, ástæður samdráttar í framleiðslu og mögulegum leiðum til þess að auka arðsemi og styðja vöxt þess í framtíðinni. Gagnasöfnun fór fram í tveimur áföngum: Forrannsókn meðal 30 framleiðenda fór fram frá júlí til ágúst 2019 og í janúar 2020. Henni var svo fylgt eftir með rannsókn á landsvísu frá maí 2021 til febrúar 2022, sem náði til 609 framleiðenda. Gögnum var safnað um aðfanganotkun, framleiðslukostnað, framleitt magn, tekjur, eldisaðferðir, uppruna og gerð fóðurs, markaði fyrir afurðir og félagshagfræðilegar upplýsingar. Gagnasöfnunin fór fram með fjölþrepa úrtöku og rafrænum spurningalistum. Rannsóknin náði yfir tíu svæði í Nígeríu sem voru valin vegna umfangs eldis, meðan framleiðendur innan hvers svæðis voru valdir af handahófi. Gögnin voru sannreynd og hreinsuð jafnóðum og þeim var safnað til að tryggja áreiðanleika. Rannsóknin er að mestu megindleg, en eigindlegum upplýsingum var einnig safnað um mat framleiðenda á áskorunum í rekstri og reynslu af aðstoð. Helstu greiningaraðferðir voru meðal annars arðsemismat, mat á framleiðni, mat á skilvirkni og greining á orsakaþáttum mismunandi árangurs í rekstri, m.a. áhrif reynslu, umfangs rekstrar og COVID-19 heimsfaraldursins á arðsemi og skilvirkni.

Niðurstöðurnar sýna að eldi á grana í Nígeríu er í heild ábatasamt en arðsemin er mjög mismunandi eftir umfangi framleiðslu og þekkingu og reynslu stjórnenda. Margir framleiðendur standa þannig frammi fyrir verulegum áskorunum, s.s. lélegri nýtingu aðfanga, háum rekstrarkostnaði og lítilli getu til að takast á við efnahagsleg áföll. Niðurstöður rannsóknarinnar gefa vísbendingar um þörf fyrir markvissa stefnumótun sem aukið gæti sjálfbærni og arðsemi eldis á grana í Nígeríu. Helstu tillögur eru meðal annars að styrkja þekkingu smærri og óreyndari framleiðenda á eldi og rekstri fyrirtækja, bæta aðgengi að hágæða aðföngum og fjárfesta í alhliða þjálfun til að byggja upp þekkingu og seiglu bænda. Rannsóknin undirstrikar mikilvægi þess að þróa viðbragðsáætlanir og stuðningskerfi til takast á við áföll, svo sem COVID-19 heimsfaraldurinn. Niðurstaða ritgerðarinnar er að stefnumótandi inngrip, bætt þjálfun, betri aðfangastjórnun og bættur skilningur smærri bænda á markaðssetningu séu nauðsynleg til að takast á við þessar áskoranir. Slíkar aðgerðir myndu hjálpa frameiðendum á grana að sigrast á núverandi áskorunum, leiða til aukinnar framleiðslu og arðsemi, bættrar sjálfbærni og bæta afkomu framleiðenda.

Lykilorð: Fiskeldi, eldi á grana, arðsemi, skilvirkni, stefnumótun

Abstract

This dissertation provides an economic assessment of catfish farming in Nigeria and offers actionable recommendations for revitalization. Data collection was conducted in two phases: a preliminary study involving 30 farms took place from July to August 2019 and in January 2020, followed by a national survey from May 2021 to February 2022, which included 609 farms. The dataset consists of variables such as production costs, quantities, socioeconomic information, farm types, pond types, feed types and market types. The data collection was carried out using a multi-stage sampling technique and electronic questionnaires. The research covered ten purposively selected states, with farmers randomly chosen within each state. The collected data was validated and cleaned to ensure accuracy. The study integrated both quantitative and qualitative approaches, employing profitability analyses, technical efficiency assessments, and policy evaluations. Key analytical techniques included budgetary analysis, stochastic frontier production functions, and regression models. The research also explored the impact of scale, experience, and the COVID-19 pandemic on profitability and efficiency.

While catfish farming in Nigeria is on the whole profitable, the profitability differs across scales with farms producing less than 5 tons per year being mostly unprofitable. The sector also faces significant challenges, including poor management practices, high operational costs, and the adverse effects of economic crises. The implications of this study are multifaceted, highlighting the need for targeted policy interventions to enhance the sustainability and profitability of catfish farming in Nigeria. Key recommendations include strengthening technical and financial support for small-scale farmers, improving access to high-quality inputs, and investing in comprehensive training programs to build farmer capacity and resilience. The research underscores the importance of developing contingency plans and support systems to navigate economic crises, such as the COVID-19 pandemic. Strategic policy interventions, improved training, better input management, and enhanced market strategies are essential for addressing these challenges. By implementing these recommendations, the catfish farming sector can overcome major current challenges, leading to increased production and profitability, enhanced sustainability, and improved livelihoods for farmers.

Keywords: Aquaculture Management, Catfish Farming, Profitability, Technical Efficiency, Policy Intervention

Acknowledgements

*"But there is **a spirit in man**: and the **breath of the Almighty** gives him understanding."*
(Job 32:8)

I wish to thank God Almighty, the giver of inspiration and grace, for His guidance and sustenance, and for granting me life and health throughout the program. May His name be praised.

To my doctoral committee, I extend my deepest gratitude for your unwavering support and guidance, which have made this journey a reality. I am especially thankful to my immediate supervisor, Daði Már Kristófersson, for your patience and dedication in equipping me with a wide range of analytical skills, and to Tumi Tómasson, whose sharp reviews consistently elevated my work. Theódór Kristjánsson, your dedication to uncovering new perspectives often led to better results even if it meant returning to the drawing board. I am deeply grateful to you all for your continuous encouragement and belief in me, even when my confidence wavered. I appreciate God for such an exceptional team—I couldn't have asked for a better one. I also wish to thank all the reviewers of the publications produced during this PhD program for their insightful comments and guidance. Your support has not only helped me complete this PhD but has also contributed to my personal and professional growth, making me a better version of myself.

My sincere thanks go to the entire GRO-FTP team for the sponsorship and continued support I received, starting from the 6-month training through the entire PhD program. This journey began with you. Your efforts are significantly contributing to capacity building in many countries, and I implore you to keep this door of opportunity open. By doing so, as the title of our last paper suggests, you are truly "Teaching a man to fish." I also acknowledge the University of Iceland research fund for the PhD grant that significantly supported my studies, as well as the ERASMUS fund for the PhD course I attended in Denmark. These resources were vital in propelling my progress.

I extend my gratitude to the past and current Directors of the Federal Department of Fisheries and Aquaculture, Nigeria, and all my colleagues at the Department, for your continued support and willingness to assist whenever needed.

Finally, my deepest gratitude goes to my family and friends who stood by me through both the smooth and challenging moments of my PhD journey. To my wife, Temitope Olagunju, your continual prayers and encouragement have been my anchor. To my two children, your much-needed 'distractions' provided the emotional and psychological balance I needed throughout the program. Thank you for your endless understanding and support.

Contents

List of Abbreviations

List and explain all abbreviations used in the thesis.

ANCOVA: Analysis of Covariance

A statistical method that adjusts for covariates to compare group means more accurately.

COVID: Coronavirus Disease

A viral infectious disease caused by the SARS-CoV-2 virus, leading to a global pandemic declared in 2020.

FAO: Food and Agriculture Organization

A specialized agency of the United Nations that leads international efforts to defeat hunger and improve nutrition and food security.

FCR: Feed Conversion Ratio

A measure of an animal's efficiency in converting feed mass into increased body mass. It is calculated as the mass of the feed divided by the body mass gained.

FMARD: Federal Ministry of Agriculture and Rural Development

The Nigerian government ministry responsible for formulating and implementing agriculture and rural development policies. The Federal Department of Fisheries and Aquaculture was previously under the Federal Ministry of Agriculture and Rural Development (FMARD) but is now part of the Federal Ministry of Marine and Blue Economy, which was created in August 2023. The department officially transitioned to the new ministry in December 2023.

GRP: Glass Reinforced Plastics also known as fibre glass tanks

Storage tanks commonly used in various industries for storing water and other liquids, made from a composite material consisting of glass fibres embedded in a polymer matrix (usually a polyester resin). They are produced in government boatyards in Nigeria and are specifically promoted for use in homestead/backyard fish farming.

HLPE: High Level Panel of Experts

An advisory body established as part of the Committee on World Food Security to provide scientific and knowledge-based analysis and advice on food security and nutrition.

IBC: Intermediate Bulk Container

Also known as a pallet tank, it is a reusable industrial container to transport and store bulk liquid and granulate substances, which some fish farmers have adapted for fish production in aquaculture.

LHR: Labour to Harvest Ratio

A measure used to evaluate the amount of labour required per unit of harvested product in catfish farming.

LRtest: Likelihood Ratio Test

A statistical test used to compare the goodness of fit of two models, one of which is nested within the other. This was used in deciding best model for the Technical Efficiency analysis.

NFI: Net Farm Income

The total revenue from farm production minus the total costs associated with the production.

ODK: Open Data Kit

An open-source suite of tools that helps organizations collect, manage, and use data in resource-constrained environments.

OPM: Operating Profit Margin

A financial metric used to assess a company's profitability by calculating the percentage of profit a company makes from its operations before deducting interest and taxes.

ROI: Return on Investment

A performance measure is used to evaluate an investment's efficiency or profitability, calculated as the ratio of net profit to investment cost.

SFA: Stochastic Frontier Analysis

A method of economic modelling that estimates the level of efficiency and productivity in production, separating random errors from inefficiencies.

SR: Seed to Harvest Ratio

Also known as the fingerlings to harvest ratio, this measure evaluates the number of fingerlings (young fish) required to produce a unit of harvested catfish.

UNDP: United Nations Development Programme

A United Nations organization aimed at helping countries achieve sustainable development by advocating for change and connecting countries to knowledge, experience, and resources.

List of Figures

List a short title of all figures in the thesis.

List of Tables

List a short title of all tables in the thesis.

List of Original Papers

This thesis is based on the following original publications, which are referred to in the text by their Roman numerals (I, II, III, ... [as needed]):

I. Olagunju, O. F., Kristofersson, D., Tomasson, T., & Kristjánsson, T. (2022). Profitability assessment of catfish farming in the Federal Capital Territory of Nigeria. Aquaculture, 555, 738192. https://doi.org/10.1016/J.aquaculture.2022. 738192

II. Olagunju, O. F., Kristofersson, D., Kristjánsson, T., & Tomasson, T. (2023). Technical efficiency of African catfish production in Nigeria: An analysis involving input quality and COVID-19 effects. Aquaculture Economics & Management, 1–27,1–27. https://doi.org/10.1080/13657305.2023.2222687

III. Olagunju, O. F., Kristofersson, D., Tómasson, T., & Kristjánsson, T. (2024). Farm strategies and characteristics influencing profitability in Nigerian catfish aquaculture: Lessons on resilience during economic crisis and COVID-type shock. Journal of the World Aquaculture Society, e13058. https://doi.org/10.1111/jwas.13058

IV. Olagunju, O. F., Kristofersson, D., Kristjánsson, T., & Tomasson, T. (2024). Teach me to fish: policy options for profitable and sustainable aquaculture. "Submitted to Aquaculture Journal for publication"

V. Olagunju, O. F., Kristofersson, D., Tomasson, T., & Kristjánsson, T. (2024). A national survey data for the technical and economic assessment of African catfish production in Nigeria before and during the COVID-19 period. Data in Brief, 52, 109917. https://doi.org/10.1016/j.dib.2023.109917

All papers are reprinted by kind permission of the publishers.

Declaration of Contribution

I contributed to the planning of the research, manual work, writing of the papers, and drawing conclusions for both the complete work and the listed papers in the following ways:

1. Planning and Research Design:
    a. Conceptualized the research objectives and developed the overall research design.
    b. Conducted an extensive literature review to identify gaps in current knowledge and to inform the research questions.
    c. Designed the methodological framework, incorporating both quantitative and qualitative approaches to comprehensively address the research objectives.

2. Data Collection and Manual Work:
    a. Played a central role in designing the data collection strategy, including the development of questionnaires and selection of sampling techniques.
    b. Actively involved in a significant portion of the fieldwork, including data collection from the selected farms.
    c. Managed and coordinated a team of field assistants during the data collection phase, ensuring accuracy and consistency in data gathering.
    d. Oversaw the data cleaning and validation process, ensuring the dataset was robust and reliable for analysis.

3. Data Analysis and Interpretation:
    a. Led the statistical analysis of the collected data, applying techniques such as stochastic frontier production functions, budgetary analysis, and regression models.
    b. Interpreted the results in the context of the broader literature and theoretical frameworks, identifying key patterns and insights relevant to the Nigerian catfish farming industry.

4. Writing of Papers:
    a. Drafted all sections of the research papers, from introduction to discussion and conclusion.

b. Integrated feedback from supervisors and peer reviewers to refine the manuscripts, ensuring clarity, coherence, and academic rigor.

c. Took the lead in structuring the arguments and ensuring that each paper aligned with the overarching goals of the dissertation.

5. Drawing Conclusions and Recommendations:

   a. Synthesized findings from all papers to draw overarching conclusions about the state of catfish farming in Nigeria.

   b. Developed actionable recommendations based on the research findings, targeting policy interventions, and practical strategies to enhance the sustainability and profitability of the industry.

   c. Contributed to the formulation of future research directions, highlighting areas that require further investigation to support the long-term growth of the aquaculture sector.

Through these contributions, I have played a pivotal role in the research, analysis, and dissemination of findings related to the economic assessment of catfish farming in Nigeria. The project conceptualisation was done in consultation with my supervisor. My collaborative work with my supervisor has also been instrumental in refining the research methodology and drawing robust conclusions that inform policy for the sector's growth and sustainability.

1 Introduction

Aquaculture plays a pivotal role in global nutrition and food security, offering a sustainable solution to meet the increasing demand for fish and seafood (FAO, 2024b). In Nigeria, aquaculture is integral to the country's economy and food system, with catfish farming emerging as a dominant sector due to the species' adaptability to local environmental conditions and its high nutritional value (Ogunji & Wuertz, 2023). However, there has been a decline in production in recent years. This dissertation aims to conduct an economic assessment of catfish farming in Nigeria, identifying the factors affecting the industry and proposing actionable recommendations to revitalize it, thereby enhancing its sustainability and contributions to the nation's economy and food security.

To provide a comprehensive understanding of aquaculture's role and its specific context within Nigeria, this introductory chapter is organized as follows: section 1.1 explores "Aquaculture's Contribution to Food and Nutrition Security," highlighting the industry's importance in enhancing food availability and improving nutritional outcomes. Section 1.2 provides a brief history of the sector and is subdivided into three parts: the types of species commonly farmed and why catfish is predominant, the methods and practices employed, and how accessibility of major inputs have favoured the growth of the sector in Nigeria. Section 1.3 presents the research gap identified based on a review of the literature. Section 1.4 contextualises why the impact of the COVID-19 pandemic is included in the study. Section 1.5, "The Contribution of this Research," outlines the specific objectives and significance of the study with a focus on understanding the current status and operational challenges of Nigerian catfish farmers; exploring strategies to enhance resilience and profitability; and providing insights and recommendations for policy development. Lastly, section 1.6 presents the structure of the dissertation.

1.1 Aquaculture's Contribution to Food and Nutrition Security

Fish is an essential component of global nutrition and food security, contributing significantly to the dietary needs of millions of people globally (FAO, 2024b; HLPE, 2014). Its rich nutrient profile, including high-quality protein, essential fatty acids, vitamins, and minerals, makes it a crucial food source for maintaining health and preventing malnutrition. The protein found in fish is complete, meaning it contains all the essential amino acids the human body requires. This makes it a crucial dietary component, especially in regions where other animal protein sources are scarce or expensive (FAO, 2024b).

Global fish supply comes from two main sources: capture fisheries and aquaculture. Capture fisheries have historically been the primary source of fish for human consumption. However, the growth of capture fisheries has stagnated due to several factors, including overfishing, habitat degradation, and the effects of climate change. Aquaculture, or fish farming, has grown rapidly over the past few decades and now accounts for more than half of global fish production (FAO, 2024b). The rapid growth of aquaculture has been driven by technological advancements, increased demand for fish, and the recognition of its potential to supplement declining capture fisheries (Garlock et al., 2022).

Developing countries have dominated aquaculture production, particularly those with large populations and significant natural resources (Garlock et al., 2020). These countries have recognized the potential of aquaculture to contribute to food security, employment, and economic development. In many cases, aquaculture production is primarily geared towards local consumption, playing a crucial role in meeting the dietary needs of the population. By improving the availability and affordability of fish, aquaculture helps to enhance diet quality and reduce the risk of malnutrition.

Aquaculture, particularly catfish farming, plays a significant role in contributing to food security in Nigeria. It provides a reliable and affordable source of animal protein, helping to meet the population's dietary needs. The consumption of fish, including catfish, is therefore an important part of the Nigerian diet and contributes to improved nutrition and health outcomes while enhancing food security.

1.2 Aquaculture in Nigeria: A Historical Perspective

1.2.1 Cultured Species

The history of aquaculture in Nigeria like that of other sub-Saharan African countries is relatively recent as compared to Asian countries. The industry began during colonial times in the 1950s with the introduction of catfish, carp, and tilapia, all freshwater species across various regions (Anetekhai, 2013). Initially, the production of low-input tilapia was dominant, but over time, the African catfish, *Clarias gariepinus* (Figure 1), has emerged as the most sought-after species (Miller & Atanda, 2011). This is due to its remarkable adaptability to adverse environmental conditions, including varying salinity levels, low dissolved oxygen, and low pH. Rapid growth rate, enabling two production cycles per year, resistance to diseases and efficient food conversion ratios (FCR) coupled with high preference among consumers have contributed to its dominance (Adewumi, 2015; Iwalewa et al., 2017).

Today, Nigeria stands as the largest producer of African catfish globally, followed by the Netherlands, Brazil, Hungary, Kenya, the Syrian Arab Republic, South Africa, Cameroon, and Mali (FAO, 2024a). Significant production also occurs in Asian countries like China, Indonesia, Thailand, and Malaysia, although FAO statistics on the species for these regions are not available (FAO, 2024a). In addition to *Clarias gariepinus*, Nigeria cultures other catfish species such as *Heterobranchus longifilis*, which, despite its slower initial growth, can reach a larger size. Hybrids of these species, known as Heteroclarias spp., are also farmed to combine their advantageous traits, although they are non-fertile and thus grown only to table size (Anetekhai, 2013). Consumer preferences in Nigeria tend to focus on the size of the fish rather than the specific species (Manyise et al., 2024), with catfish commonly referred to by various local names: eja abori/eja aro (Yoruba), arira (Igbo), tarwada (Hausa), and kemudu (Kanuri). Aquaculture in Nigeria has evolved significantly over the past seven decades.

Figure 1. The African Catfish[1] (*Clarias gariepinus*)

1.2.2 Production Systems and Practices

In the early stage of aquaculture development in Nigeria, catfish production was mostly subsistence with many farms practising extensive to semi-intensive culture (Gabriel et al., 2007). Polyculture of catfish with other species was also a common practice and many government agencies (Federal and State) championed aquaculture development. Through the help of development agencies, especially UNDP and FAO, the government spread the know-how of aquaculture, particularly catfish farming as many aquaculture training centres were built across different regions of the country (Anetekhai, 2013). However, with increased demand and market for the species, intensification of the culture ensued, and more private individuals engaged in catfish farming as an alternative economic activity (Miller & Atanda, 2011).

The production systems have also improved over the years. The dominant use of earthen ponds later paved the way for more use of concrete ponds which requires less space and allowed fish to be raised near to home (Ekine et al., 2019; Miller & Atanda,

[1] "Photo courtesy: Right - Oluwadamilola Adebayo, Oyo State; Left - Joseph Anteyi, Benue State".

2011). However, these production systems limited the culture to only those who had access to and ownership of lands. However, the barrier of land tenure and ownership is increasingly being overcome through technology innovations and leasehold practices. There has been an increase in the use of mobile, transferable, make-shift ponds that don't require land ownership, big space or a lot of construction work. Fibre glass tanks are produced in government boatyards in Nigeria and are specifically promoted for use in homestead/backyard fish farming (FDF, 2007). Aside from the fibre glass tanks, many other containers are now being used, including other types of glass-reinforced plastic tanks, tarpaulins framed with iron or wood and any large plastic container (Figure 2). The use of small moveable tanks for backyard/in-house fish farming in Nigeria has become quite common as many households can now easily raise fish without the limitation of space or land ownership.

Participation in cluster farming has been another way of circumventing the need for land ownership. Communities and individuals that own large expanses of land suitable for catfish farming now rent them out for fish farming sometimes on a production cycle or an annual basis. Cluster farming is common in communities with lands that are not well-suited for housing development, such as waterlogged areas (also known as fadama). These areas have good access to water, making them ideal for fish farming (Achoja & Enwa, 2019; Enwa et al., 2024). However, other models of cluster farming do not depend on low plains, but the objective remains to circumvent the need for land ownership (Adewumi & Olaleye, 2011). The use of mobile ponds and cluster farming have created more channels of entrance into the industry and have contributed to the growth of aquaculture in Nigeria.

a. Earthen pond

b. Concrete pond

c. Fibre glass tank used in the backyard

d. IBC or pallet tank used in the backyard

e. Tarpaulin pond on a wooden frame

f. Tarpaulin ponds on a metal frame

Figure 2. Different types of production systems used for catfish farming.
Pictures c, d, e and f represent some types of mobile ponds.

1.2.3 Major Production Inputs – Feeds and Fingerlings

Availability and access to fingerlings and feeds have improved over the years. Feed development has transitioned from relying on single ingredients, un-pelleted meal to increased use of pelleted feeds (Adewumi & Olaleye, 2011). With more knowledge of fish nutritional requirements of fish and feed composition, compounded feeds were produced which were more varied and richer than single-ingredient feed (Miller & Atanda, 2011). However, as aquaculture practices intensified and the demand for higher-quality feed increased, farmers increasingly relied on imported feeds to meet these needs (Miller & Atanda, 2011). The expansion of African catfish farming in Nigeria was said to have been boosted by, among other factors, the availability of high-quality feed (Ogunji & Wuertz, 2023).

The increased demand for high-quality commercial feed led to international feed companies establishing production facilities within the country (Miller & Atanda, 2011). This development spurred the emergence of numerous indigenous companies, which joined the market to meet the growing needs of the aquaculture industry (Table 1). Among the global conglomerates producing fish feed in Nigeria is Nutreco which produces feed of various sizes under the product Skretting. The company also produces starter feeds with the product Gemma Wean which many hatcheries rely on as a substitute for live feeds for the early growth stage of the fish. OLAM also produces different feed brands which are mostly used for the grow-out stage. Nevertheless, local feeds are still in use, often partially and mostly because of their cheaper price, but there are issues of inconsistencies in the quality, and knowing the right source for the quality ones makes some farmers avoid them completely.

Table 1. Some of the major commercial feeds used by fish farmers across the country.

S/N	FEED	PRODUCER/OWNER	FACTORY ADDRESS
	IN-COUNTRY COMMERCIAL FEEDS		
1.	Skretting Fish Feed	Nutreco	Ibadan, Oyo State, Nigeria
2.	Vital Feed	Grand Cereal Ltd.	Plateau State, Nigeria
3.	Blue Crown	OLAM-Crown Flour Mills	Ilorin, Kwara State, Nigeria
4.	Ecofloat	OLAM-Crown Flour Mills	Ilorin, Kwara State, Nigeria
5.	Aqualis	OLAM-Crown Flour Mills	Ilorin, Kwara State, Nigeria
6.	Top Fish Feed	Premier feed mills	Ibadan, Oyo State, Nigeria
7.	Ace Catfish Feed	Ace Farms and Feed Mill	Ibadan, Oyo State,

S/N	FEED	PRODUCER/OWNER	FACTORY ADDRESS
			Nigeria
8.	Hygold Fish Feed	Hybrid Feeds, Ibadan	Ibadan, Oyo State, Nigeria
9.	Aqua Plus Fish Feed	Hybrid Feeds, Kaduna	Kaduna State, Nigeria
10.	Aqua Manna Fish Feed	Hybrid Feeds, Kaduna	Kaduna State, Nigeria
	IMPORTED COMMERCIAL FEED		
11.	Coppens	Alltech Coppens	Germany
12.	Aller Aqua	Aller Aqua Group, Denmark	Denmark
13.	Prime feeds	Zemach Feed Mill, Israel	Israel

Another earlier initiative that contributed to the expansion of catfish farming was the simplicity of breeding fingerlings. Between 1975 and 1990 many fish seed multiplication projects were initiated in the country by the government (Issa et al., 2022) many of which also provided training on how to produce fingerlings (Anetekhai, 2013). The knowledge of the artificial propagation of catfish has been widely disseminated through various government programmes with technical assistance from UNDP and FAO (Anetekhai, 2013; Issa et al., 2022). Subsequently, the government intervention has been primarily to support privately-managed fingerlings production centres, as increasing number of private individuals began producing fingerlings for their own needs or as dedicated hatcheries (Miller & Atanda, 2011). From the availability of favorable species and improvements in culture systems and practices to increased access to major inputs, these factors have collectively contributed to the rapid expansion and development of the aquaculture sector of Nigeria.

1.3 Status and the Challenges Facing the Aquaculture Sector

Aquaculture in Nigeria has been said to have the potential to significantly improve food security and nutrition, create employment opportunities, and contribute to economic growth and poverty alleviation (Subasinghe et al., 2021). This potential is particularly evident in catfish farming, underscoring its economic viability through job creation and revenue generation. It is estimated that the catfish sector could create approximately 30,000 jobs and generate an annual revenue of around $160 million (Chiekezie et al., 2023). This financial impact is vital in a country where unemployment and poverty are significant challenges. Furthermore, catfish contributes significantly to the animal protein intake of Nigerians, accounting for about 40% of the animal protein consumed in the country (Olabode & Olaniyi, 2023). Despite these promising prospects, Nigeria’s aquaculture production has recently declined, dropping from 316,727 metric tons in 2015 to 296,191 metric tons in 2017, with further decreases observed in subsequent years (FAO, 2022b). Several factors, both economic and non-economic, have been cited as contributing to this downturn including the quality of inputs such as fish feeds and fingerlings which have adversely affected production efficiency and profitability (Digun-Aweto & Oladele, 2017; Edema-Sillo et al., 2017).

Numerous studies have assessed the economic performance of catfish farms across Nigeria, often highlighting their profitability. In southern Nigeria, for example, Olaoye et al. (2013) reported significant profits with a gross margin of N2,376,616.36 and approximately 70% profit, as well as favourable cost-benefit and gross revenue ratios. Similar positive profitability assessments have been reported in Southern Nigeria (Bassey et al., 2013; Busari, 2018; Tunde et al., 2015; Ume et al., 2016) and in Northern Nigeria (Issa et al., 2014; Kudi et al., 2008; Olukotun et al., 2013; Umar et al., 2017). Another way to look at the performance of fish farms is through efficiency measurements, which evaluate how closely farms approach optimal performance benchmarks. Most studies on the technical efficiency of catfish farmers, however, indicate that most farmers operate below optimal efficiency (Ibeun et al., 2018; Ikpoza et al., 2021; Inoni et al., 2017; Isiaka Baruwa & Damilola Omodara, 2019; Itam et al., 2014; Ogunmefun & Achike, 2018; Omobepade et al., 2014). However, some of the studies on technical efficiencies that assess profitability still indicate that farmers are making profit (Inoni et al., 2017; Itam et al., 2014).

While the high profitability reported in these studies should ideally drive increased production and investment, this expectation is not fully reflected in the current state of the industry. This difference could stem from the fact that studies often report average performance, which may inadvertently highlight the success of larger farms while overlooking the specific challenges faced by smaller farms. Therefore, it is important to delve deeper into the factors affecting the economic performance of farmers.

1.4 Implication of the Pandemic (COVID-19)

This project began at a critical moment in global history marked by the COVID-19 pandemic, which has caused widespread disruptions in global economies and introduced uncertainties for businesses and industries. In Nigeria, the pandemic's impact intensified towards the end of the first quarter of 2020 when the government shut down many businesses and imposed strict movement restrictions. Although these restrictions later excluded the transport of food, medical supplies, and other essential items, agricultural businesses, including aquaculture, did not operate as usual and were affected.

The aquaculture sector in Nigeria had been experiencing a decline even before the pandemic. However, it was evident that COVID-19 would exacerbate these challenges. The full nature of the pandemic's impact on the industry and the factors contributing to its resilience during this period remains unclear. Therefore, in addition to assessing the overall economic performance of the sector, this study considered assessing the impact of the COVID-19 pandemic on catfish farming operations and evaluating the factors that may have contributed to the resilience of farmers. By doing so, the study seeks to identify strategies that could help the aquaculture sector survive future shocks similar to the pandemic.

1.5 The Contribution of this Research

1.5.1 The Case of Nigerian Aquaculture

Nigerian aquaculture, particularly catfish farming, represents a vital component of the country's agricultural sector. Out of about 3.6 million tons of fish consumed in Nigeria, only 1.4 million tons is produced locally, with the remaining deficit being supplemented by imports (Ogunji & Wuertz, 2023). This reliance on imports negatively impacts the country's foreign reserves. Capture fisheries contribute approximately 70% of Nigeria's fish production; however, catches have been declining over the years (FAO, 2022a), with indications of overfishing (Asche et al., 2021). As a result, the only viable option is to increase aquaculture production. However, recent declines in aquaculture production highlight the need for a comprehensive understanding of the sector's status and the operational challenges faced by farmers. This research seeks to fill this gap by providing detailed insights into the economic performance, production practices, and specific obstacles catfish farmers encounter. By examining factors such as production scale, input quality, technical efficiency, and market access, the study aims to offer a clear picture of the operational realities within Nigerian aquaculture. This understanding is crucial for identifying areas requiring targeted interventions to enhance the sector's productivity and sustainability.

Beyond addressing immediate production concerns, this research has the potential to influence broader economic and social outcomes. By enhancing the productivity and sustainability of catfish farming, the study can contribute to food security, rural development, and poverty alleviation in Nigeria. Improved aquaculture practices could lead to higher incomes for farmers, job creation in rural areas, and a more stable supply of affordable protein for the population. Additionally, the insights gained could serve as a model for other developing countries with similar agricultural and environmental conditions, promoting global advancement in sustainable aquaculture.

1.5.2 Resilience and Profitability Strategies

In light of the economic and environmental challenges, including the COVID-19 pandemic, that have impacted Nigerian aquaculture, it is essential to explore strategies that enhance resilience and profitability by examining how catfish farmers have managed to navigate these challenges, identifying critical factors that contributed to their success. By highlighting these resilience and profitability strategies, the study aims to provide a roadmap for farmers to improve their operations and sustainability.

The exploration of resilience and profitability strategies extends beyond individual farm success, potentially benefiting the entire aquaculture sector. By identifying and disseminating effective practices, the research can foster a more resilient industry capable of withstanding future shocks and uncertainties. This can lead to a more stable food supply chain, support national economic stability, and reduce vulnerability to global disruptions.

1.5.3 Policy Options for Aquaculture Development

In light of the above, this research also offers insights and recommendations for policy development. The study identifies critical areas where targeted policy interventions could significantly enhance the sector's sustainability and growth by thoroughly examining the operational characteristics and economic performance of catfish farming in Nigeria. Implementing these policy options can lead to more effective support for farmers, fostering a more robust and profitable aquaculture sector.

The policy recommendations derived from this research have the potential to significantly shape the future of aquaculture in Nigeria. By advocating for evidence-based policy interventions, the study can influence governmental and institutional support structures, leading to improved regulatory frameworks, better access to financing, and enhanced infrastructural development. These policy changes can create a more enabling environment for aquaculture, attracting investment and encouraging innovation. Furthermore, the insights provided could inform regional and international policy discussions, contributing to the development of global best practices in sustainable aquaculture and supporting international efforts to combat food insecurity and promote economic growth.

1.6 Dissertation Structure

This dissertation comprises four major thematically related papers that can also stand alone individually. Three of these have been published while the fourth has been submitted to an international journal for publication. The data from this study has also been uploaded to an online archive with its separate doi and the detailed methodology has subsequently been published as a separate article in a data journal. The papers on which this dissertation is based are titled as follows:

Paper I: Profitability assessment of catfish farming in the Federal Capital Territory of Nigeria.

Paper II: Technical efficiency of African catfish production in Nigeria: An analysis involving input quality and COVID-19 effects.

Paper III: Farm strategies and characteristics influencing profitability in Nigerian catfish aquaculture: Lessons on resilience during economic crisis and COVID-type shock.

Paper IV: Teach me to fish: policy options for profitable and sustainable aquaculture.

Data Article: A national survey data for the technical and economic assessment of African catfish production in Nigeria before and during the COVID-19 period.

Since the major papers are self-contained with each having its background, method and findings, this introductory chapter has been structured to provide a broader background and context to the aquaculture sector in Nigeria, the critical role of catfish farming and how tackling the challenges being faced by the catfish farming sector can ultimately contribute to the growth of aquaculture in Nigeria. The next chapter (Chapter 2) summarizes this study's aims and the specific objectives of each of the papers published. The materials and methods used and limitations of the study are presented in Chapter 3. Chapter 4 gives a broad and scale-wise description of the socioeconomic characteristics of the catfish farmers and draws together the findings from the different studies discussing their relevance and implications. The conclusions, recommendations and suggestions for future research are presented in chapter 5. The original publications are then provided after the references in the appendix.

2 Aims

The aquaculture sector of Nigeria, though offers numerous benefits to the country both economically and in terms of food and nutrition security, is encountering numerous challenges that are hampering its growth and development. The performance of the aquaculture sector has mainly been driven by the catfish farming industry. Understanding the catfish farming industry of Nigeria is therefore a major step towards addressing the challenges facing the aquaculture sector of Nigeria. Using various economic and econometric tools, this dissertation therefore aims to assess the economic performance of catfish farmers in Nigeria, identifying their challenges and providing recommendations on ways to address them, thereby promoting the sustainable growth and development of the aquaculture sector in Nigeria.

Specifically, the dissertation seeks to answer the following questions:

i. What is the economic status of the catfish farming industry in Nigeria technically and financially?
ii. What are the available strategies that farmers can adopt to address current challenges?
iii. What policy options are available and can be the most effective to address the challenges being faced by the catfish farmers?

To answer these questions, we first conducted a preliminary study using the Federal Capital Territory as a case study to characterise the technical and financial performance of the farmers while also testing our hypothesis of differential performance among farmers based on scale and other factors. We followed this up with a national study of the catfish farming industry to explore the issues more deeply and to be able to draw nationally relevant conclusions and make recommendations. All these were addressed in the four main papers that make up this dissertation. The specific objectives of each paper are as follows:

Paper I: To assess the economic performance of catfish production in Nigeria across different scales of operation using the Federal Capital Territory as a case study

Paper II: To assess the technical efficiency and its determinants in African catfish production in Nigeria considering the impact of input quality and the effects of COVID-19.

Paper III: To assess the profitability dynamics of catfish production in Nigeria before and during COVID-19, drawing lessons on strategies that contribute to resilience.

Paper IV: To identify effective policy options that can enhance the profitability and sustainability of aquaculture, particularly catfish farming in Nigeria.

3 Materials and Methods

3.1 Study Area and Sampling

Nigeria is divided into 36 states and one Federal Capital Territory. Catfish farming takes place in every state of the country but at varying degrees. The Federal Capital Territory was selected for the preliminary study. It was selected for its centrality and availability of farms of different sizes. For the national study, a multi-stage sampling technique was employed. Firstly, ten states were selected purposively: five from the Northern region and five from the Southern region. These states were chosen based on their production capacities, agroecological characteristics and the need to ensure comprehensive national coverage (Figure 3). In the second stage, simple random sampling was used to select farmers from collated farmers lists from each state. The lists of farmers were obtained from both governmental and private sources to include unregistered but practising farmers, minimizing potential survivorship bias. This was done in both the preliminary and national studies.

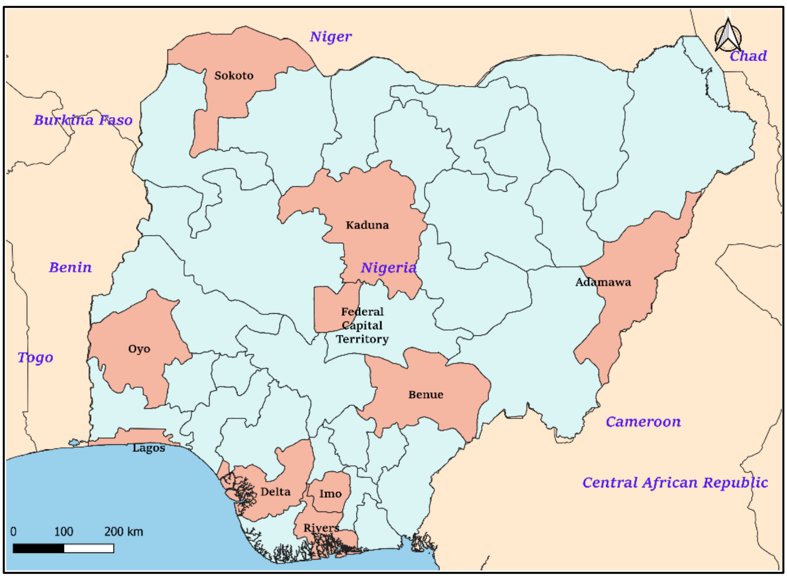


Figure 3. Geographical map of Nigeria showing the ten sampled states.

3.2 Data Collection

The data collection was conducted in two phases. The preliminary study was carried out from July to August 2019 and in January 2020, involving 30 farms for analysis. The national study, covering a broader scope, was conducted between May 2021 and

February 2022. This national survey included 609 farms, capturing a total of 1,118 production cycles: 609 cycles from the pre-COVID period and 509 cycles during the COVID-19 pandemic. To enhance data quality and facilitate effective data cleaning, data were collected using an electronic questionnaire on the Open Data Kit (ODK) platform. This approach allowed for real-time data entry and validation. Enumerators involved in the national data collection received comprehensive training to ensure accuracy and consistency in data collection. The data collection was primarily conducted on-site, ensuring that enumerators could gather precise and context-specific information. Farm photos and geo-locations were obtained to verify the authenticity and location of each farm, further enhancing the reliability of the data.

The collected farm data include a wide range core production and economic data, including input quantities and costs, harvest details, prices, stocking and harvest dates, farm management practices, socioeconomic and other farm information. Specifically, the socioeconomic and other farm data included information on gender, age, education, years of experience, scale of operation, market type, pond type, source of fingerlings, farm type, main occupation, feed usage, ownership, and labour characteristics (hired/household). Some of the data have subcategories are self-explanatory, but the subcategories under the "operation scale" category are defined in Table 2. Harvest data included not only the fish sold but also the stocks retained, and fish removed for gifts and personal consumption. All surveyed farms practised intensive farming and produced mainly for the market.

Table 2. Scale characterization of sampled catfish farms

Operation scales	**No. of farms (Pre-COVID)**		**No. of farms (COVID)**		**Production capacity (tonnes/year)**
	Freq.	**Perc.**	**Freq.**	**Perc.**	
Micro Scale	314	52%	272	53%	< 5
Small Scale	183	30%	162	32%	5-10
Medium Scale	97	16%	66	13%	>10 - 30
Large Scale	15	2%	9	2%	>30
Total	**609**	**100%**	**509**	**100%**	

Source: Field survey (2021/2022).

3.3 Analytical Methods

3.3.1 Descriptive Analysis

The descriptive analysis involves summarizing the data to provide a clear understanding of the general patterns and characteristics of the dataset. Key variables such as farm size, experience, input usage, output levels, and economic parameters were summarized using measures of central tendency (mean, median) and dispersion (standard deviation, range). The analysis was used in Papers I, III and IV. They were sometimes used together with other analysed variables. For instance, in Paper III, the technical efficiency estimate obtained from Paper II and profit per kilogram estimated from budgetary analysis alongside other technical and financial variables were descriptively analysed with the socioeconomic characteristics of the farms. This approach helps to highlight the overall trends and variations within the data collected from catfish farms in Nigeria.

3.3.2 Budgetary Analysis

Budgetary analysis was used to assess the financial performance of the farms in Papers I, III and IV. The cost and returns, as well as the different measures of profitability used, include net farm income (NFI), return on investment (ROI), and operating profit margin (OPM) ratio. These provide wide coverage of economic assessment (Dauderis & Annand, 2014). In Paper IV, the NFI (Profit= Total revenue – Total cost), is further broken down to the various technical and financial components for deeper analysis. In most of the calculations, the per unit output estimate is used, which is an effective measure of performance commonly used in economics (Engle, 2010; Kay et al., 2015). The component of profit is further simplified as Revenue = output x price and Cost = ∑(input quantity x price). If both sides of the profit expression are divided by the total harvest, the profit per kg will be as follows:

$$\frac{\pi}{y} = P_y - P_f(FCR) - P_s(SR) - P_l(LR) - \frac{O_{cost}}{y}$$

Where $\frac{\pi}{y}$ is the profit per kg and $\frac{O_{cost}}{y}$ is other costs per kg harvest, while other variables include Feed Conversion Ratio (FCR), Seed-to-Harvest Ratio (SR), Labour to Harvest Ratio (LHR), Price of 1kg feed (Pf), Seed price (Unit price of fingerlings) (Ps), Price of labour (in man-day) (Pl), Other costs per kg fish (Oc) which also includes the fixed cost, and Product price (Price per kg of fish) (Py).

3.3.3 Stochastic Frontier Analysis

Stochastic Frontier Analysis (SFA) was used in Paper II to evaluate the technical efficiency of catfish farms. The stochastic production frontier model incorporates a composed error term that includes both random errors and inefficiency effects. The stochastic production frontier model for cross-sectional data is written as:

$$Y_i = f(X_i; \beta) \exp(V_i - U_i)$$

where Y_i is the output of the *i*th farm; X_i is the vector of inputs of the *i*th farm; β is the vector of the parameters to be estimated; V_i is the random error beyond the farmer's control and it is assumed to be independently and identically distributed $N(0, \sigma_v^2)$; U_i is the random variable (non-negative) associated with the technical inefficiency effects. The U_i is presumed to be independently and identically distributed as truncations of the $N(\boldsymbol{Z}_i\delta, \sigma_u^2)$ distribution. According to Battese and Coelli (1995), the U_i can be expressed as follows:

$$U_i = \boldsymbol{Z}_i\delta + Wi$$

where $\boldsymbol{Z}_i$ is the variable associated with inefficiencies on farm *i*, δ is a vector of unknown parameters to be estimated, and Wi is the random variable defined by the truncation of the normal distribution with mean 0 and variance σ_u^2, such that the point of truncation is $-\boldsymbol{Z}_i\delta$, meaning $Wi \geq -\boldsymbol{Z}_i\delta$. Accordingly, the TE of the *i*th firm is defined as the ratio of the output of the *i*th firm in comparison to the output of the frontier (if there were no inefficiency). That is,

$$TE_i = \exp(-U_i) = \exp(-\boldsymbol{Z}_i\delta - Wi) = \frac{Y_i}{f(X_i;\beta), \exp(V_i)}$$

In SFA, two common functional forms are used: the Cobb-Douglas and the translog models. The Cobb-Douglas model is simpler and imposes a specific functional form, while the translog model is more flexible, allowing for interactions between inputs. After conducting the LR test, the translog form was deemed more appropriate than the Cobb-Douglas model and was therefore adopted. The empirical model for the translog functional form is as follows:

$$ln\, Y_i = ln\, f\,(X, \beta) = \beta_0 + \sum_{j=1}^{n} \beta_j\, ln\, X_{ji} + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} \beta_{jk}\, ln\, X_{ji}\, ln\, X_{ki} + V_i - U_i$$

The frontier is expressed with one output (*Y = Harvest*) and five input variables (*X*): *fingerlings, feed, labour, pond size,* and *other inputs* (Table 2). *i*, refers to the *i*th farm operation while X_{ji} and X_{ki} are the amount of inputs *j* and *k* used respectively; *ln* is the natural logarithm; and β, U_i and V_i are already defined.

3.3.4 Regression Analysis

Regression analysis was utilized to investigate the relationships between dependent and independent variables, specifically focusing on profitability and performance metrics in Nigerian catfish aquaculture. In Paper III, a stepwise regression model was employed to select the variables that most significantly influence profit across two different periods. In Paper IV, linear regression was used to determine the direction and magnitude of the effect of various factors on performance variables and profit. The key difference between the two papers is that while both included profit as a dependent variable with influencing factors as independent variables, Paper IV also incorporated other performance variables as dependent variables. This approach in Paper IV provided a deeper understanding of how these factors separately influence performance variables, ultimately affecting profit, thus offering insights into how policy interventions could enhance farm performance and profitability of the aquaculture sector.

The general multiple linear regression model used specified is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon$$

Where Y represents the dependent variable (e.g., profit, performance metrics), β_0 is the intercept and β_1, β_2,..., β_n are the coefficients for the independent variables $X_1, X_2, \ldots, X_n$ and ϵ is the error term, representing the variability in Y not explained by the independent variables.

3.3.5 Effect Size Measurement

Analysis of Covariance (ANCOVA) was used to evaluate the impact of policy-related factors on profit while controlling for the effects of other covariates in Paper IV. This method allowed for the assessment of the main effects and interactions of policy-related factors, providing estimates of the effect size through Eta Squared (η^2) and Partial Eta Squared ($\eta^2 p$). Eta Squared reflects the proportion of total variance in profit attributed to the policy-related factors, while Partial Eta Squared measures the proportion of variance explained by each factor after accounting for other covariates. Effect size measurement is a critical component of the analysis, providing insight into the practical significance of the results beyond mere statistical significance. By utilizing these effect size metrics, Paper IV offers a comprehensive view of how various factors influence performance and profitability, enabling a better understanding of the practical significance of the findings.

3.4 Software and Tools

The statistical applications employed in the research spanned several tools and software to ensure comprehensive data analysis. Descriptive and budgetary analyses across all the papers were carried out using both Excel and various R packages. For instance, in Paper II, the Stochastic Frontier Analysis was performed using the *frontier* package in R. In Paper III, stepwise regression was conducted using the *Stats* package in R, while the Student's t-test and Mann–Whitney test were executed using the JASP statistical package. Additional analyses, such as ANCOVA and effect size measurements, were conducted using PROC GLM in the SAS statistical package. Geospatial data visualization was done with Google Earth while QGIS was used to generate all maps included in the papers. All data collection was done electronically, but the tools used varied based on the study phase. National data collection was carried out with Open Data Kit (ODK) and its counterpart, KoboToolbox. For the preliminary study (Paper I), data was collected using both the FMARD data app and Google Forms.

3.5 Methodological Contributions of this Research

This study introduces several methodological approaches that are either novel to aquaculture or represent pioneering techniques with broader applicability in the field and related industries. We highlight the following key innovations:

i. **Analytical Insights:** In Paper I, we utilized both analytical and graphical methods to explore the interconnections between profit, scale, and experience in aquaculture. This multifaceted analysis not only enhances our understanding of these factors within aquaculture but also offers a framework that could be adapted to other industries where scale and experience play crucial roles.

ii. **Quality Input Assessment:** Paper II evaluated the impact of quality inputs on farmers' technical efficiency. Given the challenge of defining quality, we used price as a proxy, with the rationale for this choice clearly articulated. This approach can be applied to various fields where direct measures of quality are difficult to obtain, potentially offering new insights into efficiency and performance.

iii. **Multi-Analytical Approach:** Paper III employed a detailed multi-analytical approach that combined budgetary analysis, stepwise regression, and colour scaling to characterize the profitability of different categories of farmers. This comprehensive method offered deep insights into profitability. The Rmarkdown file and other supporting materials detailing the steps used in the stepwise regression to select profit-influencing groups are available online (Olagunju, 2024b) and accessible through https://doi.org/10.7910/DVN/NOUCOG.

iv. **Effect Size Measurement:** As far as we are aware, Paper IV is the first aquaculture study to use effect size measurements for policy analysis. This method, which is well-established in psychology and sociology, was applied here to provide evidence-based policy recommendations for the aquaculture industry, demonstrating its potential value in this field. Its application in this context demonstrates its potential for broader use in evaluating the impact of interventions across various fields. The SAS codes and associated Excel files for methodological reproduction have been provided in the online archive Havard Dataverse (Olagunju, 2024a) and accessible through https://doi.org/10.7910/DVN/VXWBPE.

v. **Sampling Methodology:** To capture a comprehensive range of catfish farmers, including both registered and unregistered ones, we supplemented the government-provided list with additional data from feed sellers and farm associations. This approach minimized survivorship bias and improved sample representativeness, which could be valuable for similar studies in other agricultural sectors.

The methodological innovations introduced in this study not only advance aquaculture research but also provide valuable techniques with broader applicability. These approaches have the potential to significantly enhance research and policy evaluation across various sectors. By improving our understanding of aquaculture and establishing adaptable methodologies, this study sets a precedent for applying these techniques to other industries with similar challenges, thereby broadening their impact and utility.

3.6 Limitations of the Study

One notable limitation of this study concerns the collection of household size, age and experience data. In this research, the household size, age and experience of catfish farmers were collected as range data rather than as continuous data. While categorizing into ranges can simplify data collection and analysis, it also introduces several drawbacks. Collecting data in ranges limits the precision and granularity of the analysis. Continuous data would allow for an in-depth understanding of how incremental increases in the variable impact outcomes and to detect non-linear relationships or thresholds where the variable might have a disproportionate impact. Continuous data collection would facilitate the use of more sophisticated statistical techniques and models that could reveal these subtleties. Future studies should aim to collect related data as a continuous variable to enhance the accuracy and depth of the analysis.

With respect to farm types by location, three primary locations were considered: backyard, farm site, and cluster. To achieve a more diverse and representative sample, the study adopted the purposive exclusion principle by limiting the number of farms that could be sampled within any particular cluster. This approach was necessary because farmers within cluster farms tend to be more numerous, and without regulation, they could disproportionately dominate the data, skewing the overall findings. For a deeper understanding of cluster farms and their performance, a separate, dedicated survey could be conducted. This focused survey would allow for a more detailed examination of cluster farms without the risk of overrepresentation in a broader study.

In the regression analysis used in Paper 4 to evaluate the impact of different factors on performance variables, the R-squared values were relatively low. Although this does not affect the relevance and interpretation of the findings, it suggests that there may be some unexplained variation that still needs to be accounted for. This may be due to other possible factors not included in this study either because they are immeasurable such as the personal intelligence of individual farmers or they were not captured during data collection. Future studies should consider additional potential policy-related factors and their effect on profit through the performance variables.

4 Results and Discussion

4.1 Descriptive Analysis

4.1.1 Socioeconomic Characteristics of Catfish Farmers in Nigeria

The socioeconomic characteristics of catfish farmers varied across different scales of operation, which included micro, small, medium, and large farms. Broadly, the catfish farming sector in Nigeria can be said to consist predominantly of small-scale producers (Table 3). In the preliminary study, the farms were broadly classified as large and small with small covering farmers producing 10 tonnes and below (Olagunju et al., 2022). However, an important sub-group of the small-scale farmers was identified in the national survey – the micro, farmers producing 5 tonnes and below (Table 2). This group comprises 52% of catfish farmers, and when combined with the parent small-scale group, they together account for 82% of all catfish producers. This underscores the significance of considering the various sub-groups of different scales in characterizing and evaluating catfish farming and the aquaculture sector in Nigeria as a whole, as well as conducting comparative studies among them. While valuable insights have been gained from previous studies, including those with large sample sizes (Alawode & Ajagbe, 2020; Falola et al., 2022; Mukaila et al., 2023), greater attention to these sub-groups could further enhance our understanding of the sector.

The majority of catfish farmers were male, accounting for 82% of the total sample. Female farmers constituted 18%, with a relatively consistent distribution across all scales of operation. The relatively consistent distribution of females among the scale groups further signifies the increasing involvement of women in catfish farming across different levels of production. This trend highlights a positive shift towards gender inclusivity in the sector, as female farmers participation is not limited by scale. The dominance of male in the catfish production sector is consistent with other studies (Falola et al., 2022; Gbigbi & Achoja, 2020; Iruo et al., 2019; Sogbesan et al., 2015). However, women play a larger role in other aspects of the catfish value chain, especially processing and marketing (Okeke & Nwoye, 2019; Omeje et al., 2022). Catfish farming has attracted a diverse age group, although younger farmers (30 and below) make up only 6% of the total. The most dominant age groups are those between 31-40 years (37%) and 41-50 years (32%). The low participation of younger operators can be attributed to limited financial capacity. Similar age group pattern was also reported by Iruo et al. (2019) with 31-40 and 41-50 years being the dominant age groups. The 31-40 age range had the highest representation in micro operations, while the 41-50 age group was more prevalent in medium-scale farms.

Table 3. Catfish farm socioeconomic and operational characteristics by scales.

	Micro		Small		Medium		Large		Grand Total	
	Freq.	**Perc.**	**Freq.**	**Perc.**	**Freq.**	**Perc.**	**Freq.**	**Perc.**	**Freq.**	**Perc.**
Count	314	100%	183	100%	97	100%	15	100%	609	100%
Gender										
Female	62	20%	29	16%	18	19%	3	20%	112	18%
Male	252	80%	154	84%	79	81%	12	80%	497	82%
Age										
30 and below	31	10%	6	3%		0%		0%	37	6%
31-40	132	42%	66	36%	22	23%	5	33%	225	37%
41-50	82	26%	66	36%	41	42%	6	40%	195	32%
51-60	48	15%	36	20%	23	24%	3	20%	110	18%
>60	21	7%	9	5%	11	11%	1	7%	42	7%
Education										
No Education	27	9%	15	8%	16	16%	5	33%	63	10%
Primary	9	3%	8	4%	2	2%		0%	19	3%
Secondary	48	15%	42	23%	12	12%		0%	102	17%
Tertiary	230	73%	118	64%	67	69%	10	67%	425	70%
Experience										
5 and below	165	53%	51	28%	19	20%	3	20%	238	39%
6 to 10	108	34%	81	44%	42	43%	3	20%	234	38%
11 to 15	21	7%	26	14%	18	19%	6	40%	71	12%
16 and above	20	6%	25	14%	18	19%	3	20%	66	11%
Household size										
5 and below	217	69%	93	51%	45	46%	8	53%	363	60%
6 to 10	88	28%	75	41%	46	47%	6	40%	215	35%
11 to 15	8	3%	15	8%	6	6%	1	7%	30	5%
16 and above	1	0%	0	0%	0	0%	0	0%	1	0%
Pond type										
Concrete pond	138	44%	57	31%	33	34%	5	33%	233	38%
Earthen pond	92	29%	91	50%	41	42%	6	40%	230	38%
Mobile pond	84	27%	35	19%	23	24%	4	27%	146	24%
Farm type										
Cluster	27	9%	33	18%	21	22%	2	13%	83	14%
Farm Site	115	37%	101	55%	55	57%	11	73%	282	46%
Backyard	172	55%	49	27%	21	22%	2	13%	244	40%
Fingerlings Source										
On Farm	45	14%	48	26%	33	34%	6	40%	132	22%
Other farms or hatcheries	269	86%	135	74%	64	66%	9	60%	477	78%
Feed usage										
Adds local feed	40	13%	51	28%	25	26%	4	27%	120	20%
Only commercial	274	87%	132	72%	72	74%	11	73%	489	80%

Source: Field survey (2021/2022).

Most of the farmers were well-educated, with 70% having tertiary education. Secondary education was the second most common educational level at 17%, while those with no formal education accounted for 10%. Other studies have reported a high level of literacy among fish farmers in Nigeria (Gbigbi & Achoja, 2020; Iruo et al., 2019; Ume et al., 2016). The highest educational attainment was most notable among micro scale farmers with 73% having tertiary education. Experience levels among catfish farmers varied but was mostly within 10 years, with 39% having five or fewer years of experience and 77% having 10 years of experience and below. Falola et al. (2022) also reported that 82.5% of catfish farmers have experience of ten years and below. However, micro farmers had the highest percentage of less experienced farmers (53%), whereas larger farms had a relatively even distribution of experience levels. Household size among catfish farmers predominantly consists of small to medium households, with 60% having between 1 to 5 members, and 95% of households having 10 members or fewer. Similarly, Iruo et al. (2019) and Amachree et al. (2019) reported 85% and 86% of the fish farmers having between 1 to 10 members, respectively, while all the farmers surveyed by Inoni et al. (2017) fell within this group. Micro-scale farmers predominantly have smaller households, with 69% having 5 or fewer members. In contrast, 41% of small-scale and 47% of medium-scale farmers have larger households of 6 to 10 members. Large-scale farmers, however, tend to maintain smaller household sizes, with 53% having 5 or fewer members, mirroring the pattern seen in micro scale operations. This has implications for labour dynamics as smaller households, which are more prevalent among micro and large-scale farmers, could indicate less labour-intensive farming practices or a reliance on external labour.

Farmers utilized a variety of different types of ponds. Concrete ponds are the most common, accounting for 38% of the total, closely followed by earthen ponds, also at 38%. Mobile ponds make up 24% of the total. Other studies have reported the dominant use of concrete ponds among catfish farmers (Issa et al., 2014; Sogbesan et al., 2015). This may have been due to their ease of construction and less reliance on water from natural sources like rivers, streams and springs as is common with earthen ponds. Despite their smaller share, the adoption of mobile ponds is increasing among catfish farmers, indicating a growing interest in this technology. They have been reported among the common pond types used in raising catfish to table size (Amachree et al., 2019; Anetekhai, 2013; Ogidi, 2016). The type of ponds used varies across the different scales. Micro-scale operators mostly used concrete ponds, while small and medium-scale farms used a mix of earthen and concrete ponds. Larger farms showed a similar preference but with a slightly higher use of earthen ponds. This is expected considering their scale of operation which could be more cost-saving with earthen ponds.

Farm operations were categorized mainly into three types based on location: cluster, farm site, and backyard. Overall, a significant portion of farms (46%) are located on dedicated farm sites, while 40% are situated in backyards. The location of catfish farms is strongly influenced by the scale of the farming operation. Backyard farming is the most common practice among micro farms (55%). However, as the scale of farming increases, there is a shift towards the use of more dedicated farm sites. This pattern implies that while backyard farming is convenient and accessible for many, it inherently limits the scale of the operation. Larger-scale operations require more space and resources than what a backyard can typically provide, necessitating the use of farm sites as the scale grows. Thus, while backyard farming is an entry point for many cafish farmers, those looking to expand are likely to transition to larger, dedicated farm sites to accommodate increased production needs. The proportion of cluster farms in the study should be interpreted with caution, as farmers from cluster farms were deliberately restricted during sampling. This means that while the data collected from cluster farms can provide valuable insights into their performance, it is not suitable for estimating the proportion of cluster farmers relative to other farmers in the sample. The purposive exclusion was intended to prevent cluster farms from disproportionately influencing the overall results. Nevertheless, cluster farming has become a common practice used by farmers to optimize resources, share knowledge, and reduce costs (Achoja & Enwa, 2019; Enwa et al., 2024; Folorunso et al., 2021).

Most farmers sourced their fingerlings from other farms or hatcheries (78%), while 22% produced their fingerlings on-farm. This generally agrees with the report of Amachree et al. (2019) where 84% of farmers sourced fingerlings from private farms. This reliance on externally sourced fingerlings could be attributed to the farmers' belief that they will be of better quality (Olaoye et al., 2013). Moreover, production of fingerlings requires relatively high investment cost and level of specialist skills and knowledge, making it unfeasible for small and new operators to engage in. The tendency to source fingerlings on-farm increases with operation scale, indicating that larger-scale farms are more likely to invest in their own hatchery facilities as part of their production strategy. Regarding feed usage, 80% of the farmers relied solely on commercial feed, while 20% used a combination of commercial feed and local feed. Sogbesan et al. (2015) also reported a similar proportion of farmers (21%) including locally compounded feed in their production. The reliance on commercial feed was particularly high among micro farmers, reflecting a possible preference for quality feed. Moreover, the decision to incorporate compounded feed typically depends on the farmer's knowledge and experience, as it requires understanding not only the formulation of the feed but also the appropriate stages of the production cycle to use it. Microscale farmers, who often have less experience, may find it challenging to manage these complexities and therefore tend to rely solely on commercial feeds.

4.1.2 Usage Patterns of Commercial Feed Types by Catfish Farmers

Most farmers (80%) rely solely on commercial feeds, highlighting a significant market opportunity for these products in the country. In the survey, the catfish farmers were asked to provide three major commercial feed brands that they use. Commercial feeds used in the country constitute of both in-country produced and imported. The in-country produced ones are produced by both international companies and indigenous companies. Among the commercial feed used, Blue Crown, in-country-produced feed by OLAM-Crown Flour Mills, stands out as the most widely used feed, accounting for 27.1% of usage (Figure 4). This indicates a strong preference for Blue Crown, likely due to its perceived high quality, effectiveness and favourable price. Other major feeds include Coppens and Aller Aqua, which are imported, making up 15.0% and 10.3% of the market, respectively. Despite their foreign origin, these brands have secured substantial market shares, highlighting their competitiveness in terms of quality and performance.

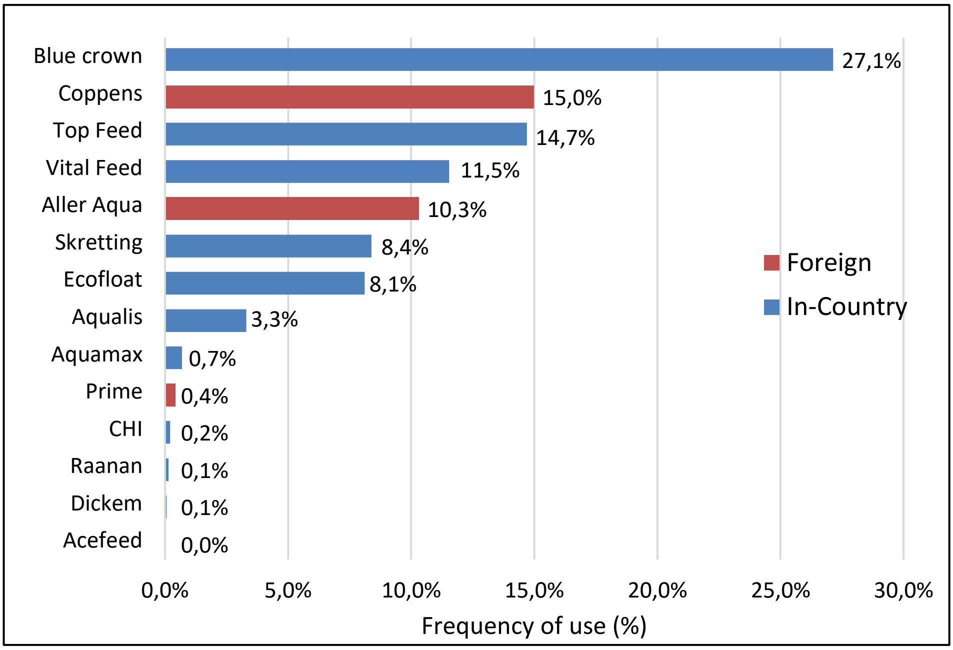


Figure 4. Frequency of use of commercial feed types by catfish farmers.

Source: Field survey (2021/2022).

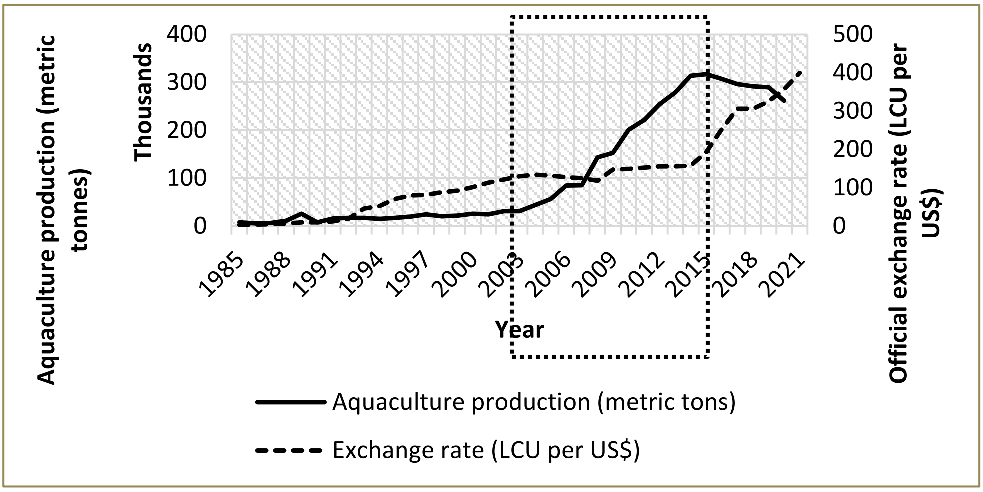
OLAM-Crown Flour Mills also produces Ecofloat and Aqualis feeds, which are used by 8.1% and 3.3% of farmers, respectively. The dominance of OLAM-Crown Flour Mills in the market is further evident as their products collectively hold a significant portion of the market share, underpinned by their commitment to quality and innovation as seen in their product differentiation. In addition to quality, price is a major factor influencing farmers' choice of feed. Many farmers consider OLAM brands to be among the best options for low-priced, high-quality feed. Other notable feeds include Top Feed (14.7%), Vital Feed (11.5%), and Skretting (8.4%). These in-country brands are favoured for their accessibility and potentially lower costs compared to imported brands. Farmers acknowledge the quality of Skretting feed, but its relatively high price likely contributes to its absence from the top market share rankings. Overall, in-country feeds dominate the market, with Blue Crown leading by a significant margin. Imported feeds like Coppens and Aller Aqua also have substantial usage but do not surpass the leading in-country brands. This distribution reflects a strong preference for locally produced commercial feeds among catfish farmers.

Although many studies have indicated that the aquaculture industry in Nigeria has historically relied on imported feeds (Adewumi A. A. & Olaleye F. V, 2011; Anetekhai, 2013; Gabriel et al., 2007), the situation is now changing. Over time, the reliance on imported feeds has decreased as international companies and indigenous companies have ramped up local production. This is also due to a hike in prices of imported goods, particularly since 2016 as a result of the devaluation of the local currency (Edema-Sillo et al., 2017). This shift has increased the availability of commercially produced quality feed in Nigeria, reducing the dependence on imports. While imported feeds still hold notable market shares, the trend towards local production is driven by factors such as price, accessibility, and improvements in feed quality. Despite the increase in local production of commercial feeds, a significant portion (20%) of farmers continue to use locally compounded (non-commercial) feeds to supplement commercial feeds and reduce production costs. However, issues such as inconsistent quality and difficulties in sourcing reliable products have led some farmers to avoid these feeds altogether. In contrast, the consistency and perceived quality of commercial brands like Coppens, Blue Crown, Aller Aqua, and Skretting are likely to maintain their market dominance and drive competition between locally produced and foreign feeds.

4.2 Economic Status of the Catfish Farming Industry in Nigeria

4.2.1 The Macroeconomic Basis

Our desk studies indicate that the trajectory of Nigeria's aquaculture sector has been closely linked to the country's macroeconomic conditions. Challenging economic climate, exacerbated by a devaluation of the Naira, has made it increasingly difficult for farmers to maintain profitability. The sector experienced steady growth during a period of relatively stable exchange rates from 2004 to 2014; however, this growth began to falter with the onset of rapid Naira depreciation (Figure 2). Research by Obekpa et al. (2020) has shown that Naira devaluation adversely affects Nigeria's fisheries and aquaculture production. Additionally, Djomo et al. (2017) found that a stable exchange rate positively impacts agricultural growth more broadly, largely due to its influence on production costs. Catfish farming, which is highly capital-intensive, is particularly vulnerable to fluctuations in the exchange rate. This is primarily because fish feed, which constitutes over 70% of production costs, is sensitive to currency devaluation. Even domestically produced commercial feeds are affected by exchange rates, as they rely heavily on imported ingredients, especially protein sources. Numerous studies have identified the high cost of fish feed, alongside poor market prices for fish, as major challenges for the industry (Dauda et al., 2018; Itam et al., 2014; NAERLS and



FDAE, 2015; Sogbesan et al., 2015; Ume et al., 2016). These factors have a major impact on the profitability of the aquaculture sector, underscoring the need for greater efficiency and competency among farmers to navigate the current economic downturn.

Figure 5. Trends in aquaculture production and official exchange rates in Nigeria[2].
The dotted box represents the period of the relatively stable exchange rate. Source: Olagunju et al. (2024)

4.2.2 The Impact of COVID-19

The economic analysis provided in Table 4 complements the findings published in Papers II and III by offering more focus on performance across scales. It assesses the technical and financial performance of the farmers across operational scales before and during the pandemic. Largely, it shows the farmers remained profitable both before and during COVID-19. The COVID-19 period induced an additional increase in production cost as the variable cost per kilogram increased from 627.80 NGN to 765.25 NGN and the total cost per kilogram from 638.19 NGN to 778.15 NGN. However, the price per kilogram saw a significant increase from 764.78 NGN to

[2] "The DEC alternative conversion factor is the underlying annual exchange rate used for the World Bank Atlas method. As a rule, it is the official exchange rate reported in the IMF's International Financial Statistics. Exceptions arise where further refinements are made by World Bank staff. It is expressed in local currency units per U.S. dollar" (World Bank, 2023)

937.63 NGN during the pandemic, which can be attributed to market price adjustments and increased demand for food products during the crisis. This adjustment in product price allowed the farmers to achieve profit as profit per kilogram rose from 126.60 NGN to 159.48 NGN, although this increase was not uniform across different scales of operation. Large-scale farms continued to enjoy higher profitability, with profit margins indicating a strong return on investment (ROI).

However, when adjusted for inflation and currency devaluation, the overall profit value for the pre-COVID stood at $0.42 per kilogram, while during the COVID period, it slightly decreased to $0.41 per kilogram. This implies that despite the challenges and increased costs brought on by the pandemic, the profitability per kilogram remained relatively stable when expressed in dollar terms. The slight decrease suggests that while the farmers were able to largely maintain their profit margins, the real value of these profits was somewhat eroded by inflation and currency devaluation. Nevertheless, several farmer-led strategies, such as price flexibility, market adaptation, and product complementarity, proved helpful during this time. For instance, the relative profit that was maintained during the pandemic despite rising production costs was because catfish farmers, working through their associations, managed to raise the product price. This emphasizes the importance of collective action and strong farmer associations in negotiating better market terms, stabilizing income, and ensuring profitability even in challenging economic conditions. Additionally, targeting diverse market and having alternative agricultural products to offer also sustained profitability for farmers during this period (Olagunju et al., 2024).

Moreover, the difference in the technical efficiency of the farmers during the periods could not be considered a performance improvement but could mainly be attributed to the withdrawal of farmers during the COVID period, especially the less efficient ones (Olagunju et al., 2023). This was demonstrated by estimating separate models with the same specification and variables for the two periods and comparing the coefficients of the parameters of the two independent translog models, but it showed no significant difference. This implies there was no change in the relative technical performance of the farmers during both periods. Moreover, a significantly higher median technical efficiency obtained for the COVID period indicates there were more highly technically efficient farmers producing during the period (Olagunju et al., 2023). Nevertheless, the average production per farmer during the COVID period reduced both overall and across the different operational scales which reflects a contraction in overall production capacity due to the challenges posed by the pandemic. This underscores the need for government support for the sector at such a period as it has significant implications for food security.

4.2.3 The Profitability and Efficiency Status of the Farms

Broadly, the industry performs slightly below optimal efficiency level and shows potential for increased efficiency and output. The average technical efficiency of catfish production stands at 85.4%, indicating that there is room for a 14.6% increase in production using existing technology which can contribute an additional 42,273 metric tons of fish to Nigerian aquaculture production (Paper II). The study also shows that the use of quality inputs is crucial for enhancing technical efficiency. The performance however depends on operational scale as the study shows that producing less than 5 metric tons annually (micro-scale) increases inefficiency. The economic landscape of the catfish farming industry in Nigeria reveals a significant disparity between large-scale and small-scale operations.

Table 4. Average technical and financial estimates of catfish production by scale of operation for the pre-COVID and COVID

	Indicators	Pre-COVID (n = 609) Period Average	Pre-COVID Micro	Pre-COVID Small	Pre-COVID Medium	Pre-COVID Large	COVID (n = 509) Period Average	COVID Micro	COVID Small	COVID Medium	COVID Large	Grand Total
Technical	Production per farmer (kg)	*3681.12*	1212.02	3782.92	9063.35	19320.47	*2831.64*	1117.50	3345.13	7191.70	13420.11	3294.37
	Technical Efficiency	*0.85*	0.82	0.86	0.88	0.90	*0.86*	0.84	0.88	0.89	0.88	0.85
	Feed Conversion Ratio (FCR)	*1.25*	1.31	1.20	1.16	1.15	*1.22*	1.27	1.17	1.15	1.12	1.24
	Fingerlings per kg (Seed Ratio)	*1.74*	2.02	1.50	1.34	1.19	*1.66*	1.85	1.48	1.34	1.36	1.70
	Labour per kg (Labour Ratio)	*0.33*	0.50	0.18	0.09	0.04	*0.37*	0.55	0.20	0.10	0.06	0.35
Financial	Variable cost/kg	*627.80*	682.48	578.97	557.13	536.10	*765.25*	818.30	718.61	673.60	673.95	690.38
	Fixed cost/kg	*10.38*	14.79	6.58	4.24	4.10	*12.90*	17.15	9.54	4.51	6.38	11.53
	Total cost/kg	*638.19*	697.27	585.55	561.37	540.20	*778.15*	835.44	728.15	678.10	680.33	701.91
	Price (Revenue per kg)	*764.78*	768.59	750.03	776.24	790.79	*937.63*	947.97	926.96	928.97	880.68	843.47
	Profit/kg	*126.60*	71.32	164.48	214.87	250.59	*159.48*	112.52	198.80	250.87	200.35	141.57
	Return on Investment	*0.29*	0.19	0.34	0.45	0.50	*0.28*	0.22	0.33	0.42	0.32	0.28
	Operating Profit Margin (OPM, %)	*14.84*	7.37	20.08	26.71	30.29	*12.11*	3.97	19.86	25.39	21.23	13.60

Financial estimates were in ₦/kg harvest (pre-COVID, $1 = ₦306; COVID $1 = ₦393 average exchange rates for the periods reported (Central Bank of Nigeria, 2023))

Financial estimates were in ₦/kg harvest (pre-COVID, $1 = ₦306; COVID $1 = ₦393 average exchange rates for the periods reported (Central Bank of Nigeria, 2023))

Financially, catfish farming can be considered profitable across all the different profitability indices assessed – Profit (NFI), ROI and OPM, which agrees with the findings of many studies in the sector (Alawode & Ajagbe, 2020; Falola et al., 2022; Gbigbi & Achoja, 2020). However, across all these indices, profitability increased with the scale of operation. Specifically, during the pre-COVID period, the large-scale operators earned nearly four times as much profit as the micro-scale operators, with 71.32 ₦/kg compared to 250.59 ₦/kg. Aside from indicating that profitability varies across different operational scales, this further raises the question of "How profitable is a profit?" While a group might be considered profitable as long as the average profit per kilogram is positive, this level of profit may not be sufficient to make the enterprise attractive or sustainable for an individual. The decision to engage in or continue an enterprise often depends on whether the profitability is high enough to justify the risks, efforts, and resources invested (Engle, 2010). These 'unprofitable profits' may have contributed to the withdrawal of many farmers from the catfish farming business (Paper I). This is also evident in the study of Alawode & Ajagbe (2020) who reported that catfish farming is profitable while the major complaint reported in the same study is low profitability.

In an attempt to assess the relative worth of profit by a particular group, we carried out further analysis using the relative average of profit (Paper III). This indicates the relative closeness or deviation of profit from the overall average estimate. The production scales alongside many other factors were ranked. Micro-scale producer which accounts for 52% of the farmers ranked least profitable while those producing between 5 to 10 tonnes are just slightly above the average (Paper III). This underscores that, despite the overall positive outlook, smaller-scale farmers are facing profitability challenges. Ragasa et al. (2018) similarly found that costs and profits varied across different scales of tilapia farmers in Ghana. Likewise, Ali et al. (2018) reported that production costs and profitability differed among various operational scales of fish farms in Bangladesh. This further establishes the differential response of scale to profitability variables. Notwithstanding, small-scale aquaculture has been said to have more favourable economic spillovers than large-scale farms, playing an important role in rural development and poverty reduction (Filipski & Belton, 2018). Considering the importance of the small-scale group of producers, it is crucial to identify and address the challenges mitigating their profitability.

4.3 Strategies for Addressing Current Challenges

In Paper III, the farmers were further characterised to understand the different factors that result in the profitability of farms or lack of it and identified channels that farmers could adopt to achieve profitability. The large-scale catfish farms demonstrate higher profitability compared to their smaller counterparts, largely due to economies of scale that result in lower production costs per kilogram of fish. Small-scale farmers, on the other hand, face increased costs and diminished profitability. This can be attributed to suboptimal management practices as seen from their comparatively low efficiency, limited experience and high operational expenses. Large-scale operators have been shown to have market advantage not only in the output but also in the input market creating a form of market imperfections among firms that belong to different scales. Using a Cost Disadvantage Ratio (CDR), the study of Sleuwaegen & Goedhuys (2003) on the technical efficiency, market share and profitability of manufacturing firms in Cote d'Ivoire assessed the negative impact of small-scale operation in the existence of economies of scale. The study found high inefficiency among small-scale firms. This inefficient practice usually leads to higher unit cost of production which translates to small market share and eventually lower profitability.

Nevertheless, our study further suggests that profitability in catfish farming is not limited by the size of the operation or the farmer's level of experience, as long as they utilize effective strategies tailored to their specific business. The first key strategy that favours profitability which farmers could adopt is cost-saving strategies. Limited by scale, small-scale producers may not be able to achieve cost reduction through scale. However, the study identified other means of saving costs through the incorporation of cheaper quality local compounded feeds as feed accounts for a major proportion of production costs. This however requires knowledge as the study shows that this practice is more common among experienced farmers.

Farmers who lack the experience to reduce costs by incorporating locally formulated feed might instead focus on using high-quality commercial feeds. This is buttressed by the findings in Paper II, which showed that technical efficiency is increased with the use of quality feed. However, this approach carries significant financial implications, and government support would be crucial to help these farmers afford the procurement of quality inputs. Availability of high quality feeds has been reported as one of the main factors that enhanced the growth of tilapia value chain in Ghana (Ragasa et al., 2018). However, efficient management of feed is highly critical when using high quality commercial feed as they are more expensive. Paper III shows that the unprofitable groups are mostly technically inefficient which is often associated with waste or abuse of inputs. To save cost in this regard, the farmers could learn to be more efficient in their use of input by cutting down wastage, using only the needed amount of inputs.

The other strategy channel identified is through price maximization. This could work by being selective on the type of market targeted. Targeting high-value markets, such as individuals and restaurants, can help smaller and less experienced farmers achieve better product prices and offset cost disadvantages. Also, to achieve a good price, the dependence on middlemen has to be minimized. Farmers who rely on retailers as a major market option are highly unprofitable. To minimize the role of middlemen, farmers can develop platforms such as cooperatives or markets that can effectively link them to customers directly. Diversifying into other agricultural enterprises can also provide additional revenue streams and bolster the market for fish products. During crises like COVID-19, adjusting product prices and exploring diverse market options become essential for maintaining profitability.

The ability to be dynamic and adjust to changing economic conditions is crucial for profitability and survival, especially during challenging situations like those currently experienced in the country. The higher median technical efficiency during the COVID period further supports the notion that only the more efficient and resilient farmers continued operations, while those less able to adapt were forced to exit the market. This scenario highlights the selective pressure exerted by difficult economic or challenging situations, where only the most technically proficient farmers were able to sustain their production, albeit at a reduced scale.

4.4 Policy Options for Aquaculture Development

The future of commercial aquaculture particularly catfish farming in Nigeria is tangent on its profitability. Policy interventions are crucial for addressing the multifaceted challenges facing the profitability of catfish farming in Nigeria. In Paper IV, we used a multi-analytical approach to assess various policy-relevant factors that the government could consider in improving the profitability of the sector. This is to enable the government to make evidence-based policy decisions that will positively impact the aquaculture sector, supporting its growth and sustainability. The policies identified in this section build upon and complement the recommendations provided in Papers I through III.

Key policy options were categorized into knowledge/learning-based, tactical decision-based, and infrastructure-based policy options. Among these, knowledge-based policies had the most significant and positive impact on profitability. Training and capacity-building initiatives proved particularly effective, as they enhanced farmers' technical management skills, leading to improved technical efficiency and profitability. Access to extension services also contributed to better farm management practices, but because the farmers accessing this service could not secure better product prices, it did not directly translate into increased profits. Access to both training and extension services has been reported to improve the technical efficiency of the farmers in Paper II. The impact of training could be significantly enhanced if financial management was more thoroughly integrated into training and extension services (Paper IV).

Formal education did not impact profit or any of the farm management variables significantly, highlighting the importance of sector-specific training. The importance of specificity of training was further revealed when it showed training could not improve the impact of policies (tactical decision) about inclusion of local feed and production of own fingerlings on profit. This means for farmers to be able to take advantage of the cost minimisation benefit of the inclusion of local feed, the training dedicated to such would be more relevant. Many of the challenges identified with unprofitable farmers, particularly the micro and small-scale farmers could be addressed with focused sector-specific training and further reinforced through the service of extension agents. A study comparing small-scale carp farmers in Bangladesh who received long-term training and extension services with those who did not find that those who received the support achieved greater profitability and efficiency over time (Murshed-E-Jahan et al., 2008).

Infrastructure-related policies are second in importance only to knowledge-based ones. Among these, the use of earthen ponds has the most significant impact on profit among pond types, while backyard farming stands out as the most beneficial farm type. The economic advantages of farming in earthen ponds have been widely documented (Olaoye et al., 2013; Oluwatayo & Adedeji, 2019; Omobepade et al., 2014) and backyard farming is known to offer cost-reduction benefits, such as utilizing home-available services and facilities (Gbigbi & Achoja, 2020). Although the use of mobile ponds also contributes positively to profit, its impact is not significant. The rise of mobile ponds in recent decades has further supported the viability of backyard farming. Policies that promote technologies like mobile ponds, which support backyard farming, should be encouraged. To fully leverage the benefits of earthen ponds, policies favouring farmland ownership, such as designating land specifically for fish farming, should also be implemented. Additionally, promoting the development of fish farming estates could combine the advantages of both backyard farming and earthen pond farming, offering a comprehensive approach to enhancing profitability and sustainability in the sector.

The tactical decisions to use local feed and on-farm-produced fingerlings did not directly enhance profitability, which likely reflects concerns over input quality. Local feeds, often questioned for their quality, tend to result in higher Feed Conversion Ratios (FCR), leading to increased costs (Mustapha et al., 2014). Similarly, in addition to doubts about the genetic quality of African catfish raised in Nigeria, poor broodstock management practices have been reported among fingerling producers, which can produce lower-quality fingerlings (Ibiwoye & Thorarensen, 2018; Iwalewa et al., 2017). Our results further indicate that adequate knowledge is crucial for maximizing the cost-reducing potential of local feeds, as effective use involves not only the FCR but also the Economic Conversion Ratio (ECR). Studies from Malaysia and Uganda found that, despite a lower FCR, local feeds yielded a better ECR compared to commercial diets, thus supporting their cost-effectiveness under informed management (Farahiyah et al., 2016; Limbu, 2015). However, knowledge sources did not significantly improve the profitability of on-farm fingerling production. These findings emphasize the urgent need for training in effective broodstock management and, as a long-term approach, the establishment of a catfish breed improvement program to enhance seed quality across Nigeria.

As part of knowledge sources, we also identified the significant role of social media access in enhancing profitability through improved access to information, highlighting the importance of developing internet infrastructure. Social media use helped farmers secure higher prices for their products, thereby increasing their profits. Similarly, Olukemi et al. (2022) reported that catfish farmers who utilize ICT tools are more profitable than those who do not. Policies to improve internet infrastructure and access across the country need to be developed to ensure that farmers can fully leverage digital tools and platforms, such as social media, for accessing market information, securing better prices, and enhancing profitability.

4.5 Additional Note: The Nexus of Profitability and Sustainability

It is often perceived in ecological economics that prioritizing profitability can undermine environmental and sustainability goals (Rees, 2003). This perception stems from traditional profit-maximizing practices that often neglect environmental costs, leading to over-exploitation and degradation of natural resources. Then the question is, can pursuing aquaculture profitability result in sustainability? The findings from this study have demonstrated that this is possible. This study demonstrates that efficiency—using fewer resources and reducing costs while maintaining the same level of output—can lead to increased marginal profit and reduced waste, thereby minimizing environmental impacts. Profitability and sustainability can therefore go hand in hand. This approach not only supports environmental goals but also provides strong incentives for sustainable practices. Encouraging sustainability from a profitability perspective can be an effective way to achieve environmental goals more rapidly. This concept is not limited to aquaculture but applies to other industries as well. For example, in capture fisheries, managing for Maximum Economic Yield (MEY) has been shown to have less impact on resources than managing for Maximum Sustainable Yield (MSY) (Grafton et al., 2012). Thus, addressing sustainability through appropriate economic strategies can accelerate the achievement of environmental goals across various sectors. This encapsulates the concept of "doing well by doing good," emphasizing that businesses can achieve financial success by integrating sustainability into their operations. Such approach not only helps the environment but also enhances the establishment's long-term viability and reputation.

5 Conclusion

5.1 Summary

This dissertation aimed to conduct a comprehensive economic assessment of catfish farming in Nigeria, identifying the factors mitigating its growth and proposing actionable recommendations to revitalize the industry. The study's overarching goal is to enhance the sustainability of catfish farming and its contributions to the nation's economy and food security. This study provides a broad socioeconomic description of the catfish farming industry of Nigeria and shows their disparities across different operational scales while also highlighting the growth in the fish feed sector. The research synthesized findings from four key papers, each providing critical insights into different aspects of catfish farming in Nigeria.

The analysis indicates that Nigeria's aquaculture sector is highly sensitive to macroeconomic conditions, particularly the devaluation of the Naira. The sector experienced steady growth during a period of relatively stable exchange rates, but this growth faltered as the Naira began to depreciate rapidly making it increasingly difficult for farmers to maintain profitability, underscoring the need for greater efficiency and competency in navigating the current economic downturn. The research revealed that profitability in catfish farming is significantly influenced by the scale of operations, with larger farms benefitting from economies of scale. Key factors such as experience, training, and access to information were identified as crucial for improving profitability. Additionally, the study highlighted the importance of technical efficiency, showing that the use of high-quality inputs and effective management practices are essential for maintaining productivity, particularly during economic crises and periods of shock like the COVID-19 pandemic.

There is a need for adaptive strategies and comprehensive management skills to navigate economic challenges. It underscored the significance of market flexibility and the role of farmers' associations in sustaining profitability. Policy recommendations focused on enhancing capacity through targeted training and improving infrastructure, such as internet facilities and technologies that favour backyard farming for their cost-reducing benefits, were deemed essential for sustainable development. Improving technical efficiency—achieving more with fewer resources—can increase profitability while reducing waste and environmental impact. This synergy between profitability and sustainability is achieved through practices such as using high-quality inputs and effective management, which not only boost marginal profits but also minimize resource depletion and ecological degradation. Overall, the dissertation proposes a multifaceted approach involving strategic support for small-scale farmers, targeted training, financial aid, and policy interventions to revitalize Nigeria's catfish farming industry, thereby contributing significantly to the nation's economy and food security.

5.2 Overall Conclusions and Recommendations

This research highlights the economic performance and primary challenges facing Nigeria's catfish farming sector, suggesting underlying issues that need to be addressed to enhance its sustainability and contributions to the nation's economy and food security. The key issues identified include poor management practices, lack of experience, high operational costs, and the impact of economic crises including the COVID-19 pandemic.

To revitalize the catfish farming industry in Nigeria, the following actionable recommendations are proposed:

i. Training and Capacity Building: Implement specialized training programs that encompass financial and economic management to improve farmers' skills and resource management.

ii. Improve Access to Quality Inputs: Support the development and regulation of input markets to ensure the availability of high-quality inputs and provide financial support for small-scale farmers to procure these inputs.

iii. Support Infrastructure Development: Enhance internet infrastructure to improve access to critical information, facilitate better decision-making and innovation, and promote technologies favouring backyard farming due to its cost-reducing benefits and its role as a valuable small-scale venture contributing to food security, economic, and livelihood benefits.

iv. Promote Market Flexibility and Diversification: Facilitate access to diverse markets and encourage diversification into complementary agricultural enterprises to provide additional income streams and reduce financial risks.

v. Strengthen Farmers' Associations: Support the formation and strengthening of farmers' associations to enhance their capacity for collective bargaining, price control, and knowledge sharing.

vi. Implement Crisis Support Mechanisms: Establish emergency funds, technical assistance, and input support during periods of crisis to mitigate negative impacts on production.

vii. Adopt Scale-Based Evaluations and Support: Recognize the impact of scale on profitability and provide tailored support for small, medium, and large-scale farms to address their unique challenges.

viii. Provide immediate training for farmers on effective broodstock management practices and implement a comprehensive breed improvement program as a long-term strategy to enhance catfish seed quality.

By addressing these key areas through strategic policy interventions and targeted support, the Nigerian government and stakeholders can foster a more sustainable and profitable aquaculture sector. The findings of this dissertation provide a comprehensive foundation for informed decision-making, aimed at enhancing the economic performance and resilience of catfish farmers in Nigeria, ultimately contributing to the nation's economy and food security.

5.3 Further Research

This study provides insights into the economic performance and challenges of catfish farming in Nigeria, yet several areas warrant further investigation to deepen understanding and enhance the sector's sustainability.

Conducting longitudinal studies to track changes in profitability and technical efficiency over time would be highly valuable. This approach will help in understanding long-term trends and the impact of various interventions on catfish farming, providing a clearer picture of the sector's dynamics and the sustainability of different practices. There is also an opportunity to apply advanced econometric techniques. While the study adopted a mixed-methods approach combining quantitative and qualitative data, utilizing methods such as panel data analysis, structural equation modelling (SEM), or machine learning algorithms can help identify complex relationships between variables and predict future trends. These advanced techniques can provide deeper insights and more robust predictions, enhancing the decision-making process for policymakers and stakeholders.

Comprehensive value chain and supply chain analyses using both quantitative and qualitative data is essential. This research should include mapping all stakeholders, processes, and value additions along the chain to identify inefficiencies and opportunities for improvement. A thorough understanding of the entire value chain will allow researchers to pinpoint critical areas where interventions could lead to significant improvements in efficiency and profitability.

While the technical efficiency study indicated that inefficiency increased in female-managed farms, there is a need for a deeper investigation of the roles and contributions of women and youth in catfish farming. Future research should assess barriers to entry, challenges faced, and the impact of targeted support programs on their participation and success. Understanding these dynamics can help design more effective policies and programs to support these groups, ultimately contributing to the overall sustainability and growth of the aquaculture sector.

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Original Publications

Paper I

Aquaculture 555 (2022) 738192

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Profitability assessment of catfish farming in the Federal Capital Territory of Nigeria

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ARTICLE INFO

Keywords:
Aquaculture management
African catfish
Profitability
Small-scale
Fish farming
Nigeria

ABSTRACT

This study assesses the current economic performance of catfish production in Nigeria using profitability analysis taking the Federal Capital Territory as a case study. Aquaculture production in Nigeria has grown significantly in the last two decades. The farming of catfish accounts for more than half of the total national aquaculture production. However, a decline in production has been observed since 2015 and it has been reported that some catfish farmers are abandoning fish farming. A survey was carried out using a structured questionnaire and oral interviews. The farms sampled were categorised into small and large-scale farms for analysis of their profitability and operational management. While the overall assessment of most of the performance indicators portrayed catfish farming in the study area to be profitable, large-scale farms perform better than the small-scale farms in all the indicators assessed with Net Farm Income (NFI), Benefit Cost Ratio (BCR), Operating Profit Margin (OPM) and Gross Ratio (GR) of ₦2,611,811, 1.25, 18.5 and 19.5 respectively for large-scale farms and ₦-17,247, 0.97, −11.06 and − 6.93 respectively for small-scale farms. Management of inputs affected the profitability of the farmers with small-scale farmers expending on average ₦703 per kg fish produced against ₦598.5 kg^{-1} fish produced by large-scale farms. Profitability of the farms was influenced by farmers' years of experience. The majority of small-scale farmers (84%) had less than 10 years of experience. Aside from the operational cost, poor fish performance was also considered a major constraint by the farmers. There is a need to improve broodstock management and carry out a feasibility of establishing a broodstock production programme that will facilitate an adequate supply of quality fingerlings. Effective training and improved extension services are also recommended to ensure profitable and sustainable catfish farming in Nigeria.

1. Introduction

Nigerian aquaculture produced 148,000 MT of African catfish (*Clarias gariepinus*, Burchell, 1822) in 2017 which was about 2/3 of global production that year (Fig. 1) (FAO, 2020a). The African catfish is the most farmed fish in Nigeria due to high tolerance towards adverse environmental conditions, disease resistance and low Food Conversion Ratio (FCR) (Miller and Atanda, 2011; Nwachi and Toritseju, 2014). Fast-growth allows for up to two grow-out cycles in a year. Catfish is popular among "point and kill" restaurants in Nigeria as the fish can be kept alive until ready to be prepared.

Nigerian aquaculture dates back to the 1950s when the extensive culture of catfish, carp and tilapia was introduced to different parts of the country (Anetekhai, 2013). However, at that time, aquaculture did not make a significant contribution to the overall national fish production (Miller and Atanda, 2011). Aquaculture growth was improved by the further promotion of the production of the African catfish in the early 1980s with the training of government extension agents on its artificial propagation (Anetekhai, 2013). Most of the established government farms at the time were not only producing fingerlings but also served as technology transfer centres for catfish production. By the early 90s, an increased number of farmers had adopted the culture of the species at a small-scale level. In 2003, African catfish farming took off due to the increased availability of commercial protein-rich fish feeds

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https://doi.org/10.1016/j.aquaculture.2022.738192
Received 20 April 2021; Received in revised form 20 March 2022; Accepted 24 March 2022
Available online 28 March 2022

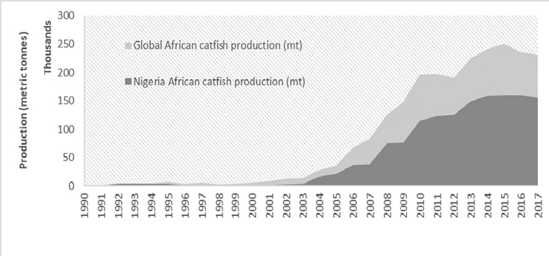

Fig. 1. Global production of the African catfish (*Clarias gariepinus*, Burchell, 1822).
Source: FAO FishStat (FAO, 2020a)

(Anetekhai, 2013).

The increasing population and high consumer preference also created a large market for catfish. This led to an intensification of culture with high growth in small-to-medium-sized farms and the establishment of large-scale intensively managed catfish farms. During the last decade, the farming of catfish has played a pivotal role in the growth of Nigerian aquaculture and accounts for more than half of the total national aquaculture production.

The contribution of aquaculture to domestic fish production (both capture and culture) has increased over the years from 5.1% in 2001 to 30.8% in 2015 (FAO, 2020a, 2020b). Aquaculture, and in particular catfish farming, has been recognised as a major way to boost fish production in Nigeria and is considered capable of moving the country towards self-sufficiency in fish supply (Ugwumba, 2005). Catfish aquaculture involves the production of seed and the on-growing of fingerlings/juveniles to table size catfish which take place in different culture systems such as earthen ponds, concrete ponds, cages, or mobile ponds including plastic and fibre glass tanks, iron- or wood-framed tarpaulin and any container that can stock the desired number of catfish. Sources of water can be through underground seepage, rainfall, borehole or reservoir depending on the culture system used. Pond preparation involves liming, fertilizing, detoxifying in concrete ponds before the ponds are ready for stocking with fingerlings/juveniles. Mobile pond preparation mainly involves leakage inspection. Catfish is then stocked into the pond and fed of appropriate pellet size and composition until they reach the desired size.

Earlier studies in Nigeria have reported good profitability of catfish farms, with 60 to 90% Return on Investment (Bassey et al., 2013; Issa et al., 2014; Kudi et al., 2008; Olukotun et al., 2013; Tunde et al., 2015). However, production declined from 2015 to 2017 and catfish farmers have been reported to abandon fish farming in favour of other agricultural ventures due to poor quality of fingerlings and fish feed and reduced profitability (Digun-Aweto and Oladele, 2017; Edema-Sillo et al., 2017).

Several authors have indicated that the profitability of catfish farming has been affected by increasing cost of production without a commensurate increase in farm gate price (Bassey et al., 2013; Kingsley et al., 2014; Sogbesan et al., 2015; Ume et al., 2016), but this was not reflected in the outcome of their studies, possibly because most of them only reported averages for all farms studied. Performance of larger profitable farms may have masked any loss occurred by smaller farms. Ali et al. (2018) have shown that production cost and profitability varies among different operational scales of fish farms in Bangladesh. It is therefore important to look at what the farms' profitability would be if analysed based on their scales of operation (Michael, 2009).

The objective of this study was to assess the current economic performance of catfish production in the Federal Capital Territory of Nigeria across different scales of operation, using profitability analysis. The following section describes the methods used in this analysis, while section 3 provides results and analysis. The conclusions and recommendations are provided in section 4.

2. Methodology

2.1. Study area

The survey was conducted among fish farmers in the Federal Capital Territory (FCT) of Nigeria (Fig. 2). The FCT, including the city of Abuja and its environs, covers an area of approximately 7315 square km having a population of 3,564,126 (2016 estimates) in the North Central part of Nigeria between latitudes 8°25` and 9°25′ N and longitudes 6°45′ and 7°45′ E (National Population Commission (NPC), 2006). The climate is tropical and there are two major seasons, a dry season (from November to March) and a rainy season (from April to October) with rainfall ranging from 305 to 762 mm. Temperature ranges from 12 to 40 °C (Abubakar, 2014). Owing to its abundant rainfall, fertile soil and the location within the Guinea-Savanna vegetation zone, the region is agriculturally productive with the population engaging in crop, fisheries and livestock production. It comprises of six (6) area councils viz.: Abuja Municipal, Abaji, Bwari, Gwagwalada, Kuje and Kwali. The FCT, like most other parts of the country, has experienced growth in fish farming in recent years. In addition, the FCT was selected as the study area due to its centrality and availability of farms of different sizes.

2.2. Data collection

As it is not mandatory for farmers to register with the government or associations, official registries are likely to over-represent well established and larger farms. To capture unregistered but practising farmers and to reduce potential survival bias, lists of farmers were obtained not only from government sources but also from major fish feed dealers as most fish farmers rely on commercial starter feeds (Emmanuel et al., 2017).

Random sampling method was used to select farmers from compiled list in line with Bluman (2019). Continuous random numbers generated in Excel were used to select farmers from the collated list of 339 catfish farms out of which 53 consented to participate in the survey. Out of the 53 farmers selected, only 30 were able to provide data that could be used

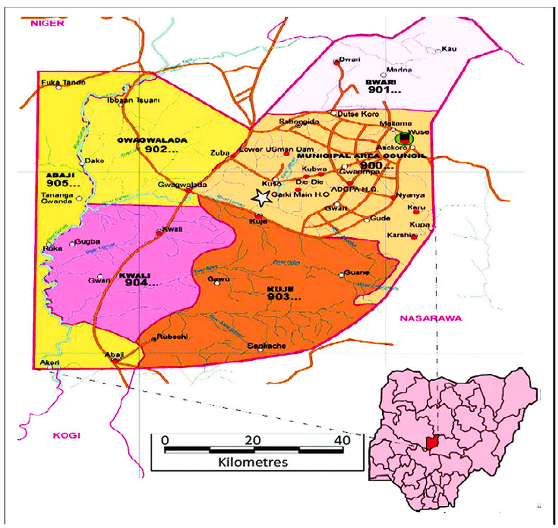

Fig. 2. Map of the Federal Capital Territory of Nigeria.
Source: (Ozioma et al., 2017)

for analysis (Table 1). Farm visits and interviews were conducted from July to August 2019 and in January 2020. A structured questionnaire was administered in addition to interviews and the researcher's on-farm observations. The data were recorded electronically to allow for consistency and quality. Feed dealers and government fishery officers were also interviewed on the performance of the sector and assessment of the key indicators.

The farms were categorised as small or large based on their labour engagement and estimated annual production (Table 2). Annual production capacity was estimated based on the farm's production per cycle and average monthly harvest. Data collected included input quantities and costs, harvests, prices, farm management practices and socioeconomic information. Cases of retained stocks and fish removed for gifts and personal consumption were factored into the harvest data. All the farms involved in the study practise intensive farming and products are mainly market oriented.

It was difficult to get reliable production and economic data from some farmers due to poor record-keeping. Also, being a primary agricultural production sector and mostly dominated by small-scale operators, the farmers are not obliged to provide any accounting record to the government, as such their information is not available to the public. The data collection, therefore, focused mainly on the most recently completed production cycle whose data could be very easily remembered. Care was also taken to corroborate the qualitative and quantitative data with the price of inputs provided by suppliers and knowledge of sector practices. Farmers who did not keep records tended to overestimate their production. However, after consultations and clarifications, farmers usually provided more credible data. Such data quality assurance was also adopted by Rahman et al. (2020).

2.3. Data analysis

Budgetary analysis was used to assess the economic performance of the farms. Multiple measures of profitability including Gross Margin (GM), Net Farm Income (NFI), rate of Return on Investment (ROI) and Operating Profit Margin (OPM) ratios were calculated (Table 3). These provide for a wide coverage of economic assessment and financial performance (Dauderis and Annand, 2014; Engle, 2010). All data obtained and estimates were for a single cycle of production. The production management characteristics of the farms were assessed through the estimation of the cost or input per kg of harvest. The data analysis was carried out in Microsoft Excel.

The sample sizes for the two groups were small and unequal with non-normal distribution, hence, a non-parametric test, the Kruskal Wallis Test (KWT) was used to test for differences in key production management indicators across scales of operation (Bluman, 2019). The tests were carried out using the dplyr package in R software.

The number of labourers provided was for those engaged full-time. Household labourers who were not engaged full-time were excluded and their cost was not estimated. This is mostly applicable to the smallest farms. Labour in man-days was estimated from the total number of days of the culture period (Jadhav, 2009).

The total labour cost was provided as the sum of the monthly wages paid to hired workers pro-rated per production cycle. For the small-scale farmers who mostly managed the farm by themselves or engaged family labour, labour cost was treated as an opportunity cost (Ali et al., 2018).

Table 1
Sample size of catfish farms involved in the study.

Farmers selected for the study	Farmers with no available record (part or complete)	Farmers that had abandoned catfish farming	Incomplete and unreliable data after further verification	Valid data included in the study
53	7	8	8	30

Source: Field survey (2019/2020).

Table 2
Classification and characteristics of catfish farms included in the study (adapted from Veliu et al. (2009)).

Features	Small	Large
n=	26	4
Annual production capacity (ton/year)	< 10 t	>10 t
Labour and Management	Owner-managed or Partial/ Fully paid labour	Fully paid labour/ Dedicated farm manager

Table 3
Equations used to calculate the cost and return of catfish farming in the FCT, Nigeria.

Costs estimates	
Total cost	= Variable costs + Total Fixed costs
Variable costs	= Cost of fingerlings, feed, labour, others (transport, treatment, water, maintenance, electricity, etc.)
Fixed costs	= Cost of depreciation* + Land lease (Rental value of land)
Cost kg^{-1}fish	= Cost/total harvest
Revenue	= Total harvest x farm gate price
Revenue kg^{-1} fish	= Revenue/ Harvest = Price
Returns and Profitability Ratios	
Gross Margin	= Total revenue – Total variable cost
Net Farm Income (NFI)	= Total revenue – Total cost
Benefit Cost Ratio	= Total revenue/Total cost
Rate of Return on Investment	= Net Farm Income/Total cost
Operating Profit Margin Ratio	= ([Total revenue - Total cost]/ Total revenue) x 100
Operating Expense Ratio	= Total Fixed cost/Revenue
Gross Margin Ratio	= ([Total revenue - Total variable cost]/ Total revenue) x 100

* Prime cost depreciation rate was estimated for owned ponds based on two cycles a year, annual depreciated value was divided by two to account for cycle value (Igwe and Mgbaja, 2014).

3. Results and discussion

3.1. Socioeconomic characteristics of farms

Of the 30 farms included in the study, 26 (87%) were small scale and 4 (13%) large scale. The prevalence of small farms may be due to limited access to funds. About 62% of small-scale farmers were males whereas all the large-scale farms were owned by males (Table 4). Three out of the four managers of large-scale farms had more than 10 years of experience

Table 4
Fish farm socioeconomic characteristics by scales of operation.

	Operation Scale Categories					
	Small		Large		All Farms	
	Freq	%	Freq	%	Freq	%
Gender						
Female	10	38			10	33
Male	16	62	4	100	20	67
Grand Total	**26**	**100**	**4**	**100**	**30**	**100**
Fish Farming Experience						
Less than 5	11	42		0	11	37
Btw 5–10	11	42	1	25	12	40
Btw 11–15	4	15	1	25	5	17
Above 15		0	2	50	2	7
Grand Total	**26**	**100**	**4**	**100**	**30**	**100**
Highest Educational Level						
MSC and above (Grad-studies)	9	35	2	50	11	37
Degree	12	46	1	25	13	43
ND/NCE	4	15		0	4	13
Secondary	1	4	1	25	2	7
Grand Total	**26**	**100**	**4**	**100**	**30**	**100**

Source: Field survey (2019/2020).

in catfish farming, while the majority (84%) of small-scale farmers had ≤10 years of experience out of which 42% had less than 5 years of experience. Farming practices improve with experience and experienced farmers were also able to understand the market and as such could secure good prices for their products. Small scale farming is characterised by several new entrants who may not have much experience in farming and as such are exposed to many risks which they may not be able to manage in their early days. Eight of the farmers reached during this survey had already given up fish farming at the time they were contacted and resorted to other enterprises due to lack of profit from their attempt at catfish farming. Expectations of most new entrants are usually unrealistic due to inaccurate information obtained from self-proclaimed consultants and trainers who exaggerate the profitability of the venture.

All the farmers surveyed had at least a secondary school certificate with 28 out of 30 possessing tertiary education. Such a high level of education among fish farmers is not uncommon in Nigeria (Bassey et al., 2013; Ebukiba and Anthony, 2019; Ideba et al., 2013), and it makes the farmers open to knowledge.

Three out of the four large-scale farms depended on training for technical support while the small-scale farmers sourced technical support mainly from other farmers (38%) and social media (31%). Only one of the farms surveyed indicated extension service as a major source of technical support (Table 5). This is not because of lack of interest in the extension service from the farmers but the inadequate number of trained extension officers in the agricultural sector in general. With the extension officer to farmer ratio being as high as 1:10,000 (FMARD, 2013), there is a dearth of extension service delivery in the country and the catfish farming sector is not excluded.

A major constraint considered by the large-scale farmers was poor fish performance (75%) while funding/high cost of operation (58%) and poor fish performance (19%) were considered as major constraints by small-scale farmers. Majority (96%) of the small-scale farmers surveyed sourced their fingerlings from other farms while only two large-scale farmers (50%) produced fingerlings on-farm. However, as this could not adequately meet their requirements, they had to source fingerlings from other farms as well, the quality of which they find questionable most of the time.

Ali et al. (2018) also found that larger operators were more likely to produce fingerlings in their hatcheries. Fingerling production requires a high degree of specialisation and investment in expensive equipment and facilities. The lack of an adequate supply of quality fingerlings has been a major challenge in catfish production. The government policy must be geared towards addressing this supply gap.

Table 5
Fish farm socioeconomic characteristics by scales of operation.

	Operation Scale Categories					
	Small		Large		All Farms	
	Freq	%	Freq	%	Freq	%
Technical Support Source						
Other Farmers	10	38		0	10	33
Training Courses	7	27	3	75	10	33
Social Media	8	31	1	25	9	30
Extension Agent	1	4		0	1	3
Grand Total	**26**	**100**	**4**	**100**	**30**	**100**
Major constraints						
Fund/Operational Cost	15	58	1	25	16	53
Poor Fish Performance	5	19	3	75	8	27
Marketing	3	12		0	3	10
Inadequate Technical Knowledge	2	8		0	2	7
Animal Interference	1	4		0	1	3
Grand Total	**26**	**100**	**4**	**100**	**30**	**100**
Fingerlings source						
On-Farm	1	4	2	50	3	10
Other Farms	25	96	2	50	27	90
Grand Total	**26**	**100**	**4**	**100**	**30**	**100**

Source: Field survey (2019/2020).

3.2. Cost and return analysis

The cost and return analysis was carried out using the production cycle estimates collected (Tables 6 & 9). The analysis was taken further by estimating the costs per kg harvest (Tables 7 & 8) in order to examine the production management characteristics of the different farm categories and the role of economies of scale on the profitability and efficiency of the enterprise (Engle, 2010; Michael, 2009; Tisdell, 2019). The cost estimates are provided in Nigerian Naira (US$1 = ₦306; average exchange rate during the survey period; (Central Bank of Nigeria, 2020)). The average total cost incurred by all the farms was ₦2,331,701 which increased from ₦638,546 on small farms to ₦13,337,213 for the farms producing more than 10 tons year^{-1} (Table 6). Average total cost kg^{-1} was considerably higher for small farms (₦703.5 kg^{-1}) than large farms (₦598.5 kg^{-1}) (Table 7) and appear to follow observations elsewhere (Ali et al., 2018). This indicates that economies of scale are pronounced in catfish farming.

The variable cost for the large farms accounted for 99% of the total cost of production while it was 96% for small farms. High variable cost of 88% to 94% has also been reported by others (Ibeun et al., 2018; Oluseye and Damilola, 2019; Umar et al., 2017). Feed cost accounted for 74% and 86% of the total cost for small- and large-scale farms respectively. Feed cost has been reported to account for the largest proportion in the cost of production in Nigeria; Olaoye et al. (2013) reported feed to contribute 75% to the total production cost in Oyo State; Umar et al. (2017) reported 66% in Borno State.

A study on farming of Pangasius catfish in India showed a higher proportion of feed cost for large (80%) than for small farms (76%) (Mugaonkar et al., 2019). This was attributed to the tendency of small-scale farmers to use supplementary feeds to save cost. On average, the cost of feed kg^{-1} harvest for large and small farms were ₦509.2 kg^{-1} and ₦499.2 kg^{-1} respectively (Table 7). The higher feed cost of large farms is primarily due to the larger harvest size they target which is reflected in the slightly higher FCR in large farms (Table 8). FCR of catfish increases with size (Bosma et al., 2017), but additional feed cost is not proportional as the cost of feeds used at later stages of growth is usually less. This additional cost of feeding eventually paid off for the large-scale farmers as they were able to attract a better price for their harvest (Table 7).

Though the difference observed among the scales in feed cost per kg was not significant ($p > 0.05$), the difference expressed as percentage was high – 85% and 71% in large- and small-scale farms, respectively. This is due to lower amounts spent by large-scale farmers on other variable components. Fingerlings in small farms accounted for 13% of the total cost while large-scale farmers spent only about 3% (Table 6). Overall, fingerling cost accounted for 6% of the total production cost which is in line with findings from Oyo State (Oluseye and Damilola, 2019). Moreover, while the large-scale farmers utilise 1.3 fingerlings kg^{-1} of fish produced, the small-scale farmers utilised 3.8 fingerlings kg^{-1} (Table 8).

Average fingerling cost for the small-scale farmers was ₦99.2 kg^{-1}, while it was significantly lower at ₦32.1 kg^{-1} for large farms and a couple of small-scale farms spent more than ₦300kg^{-1} (Fig. 3). Excluding their figures from the sample, however, did not significantly improve the performance of the small-scale farmers. Excessive stocking is common when the farmers stock their ponds based on the advice of fingerling producers. This further underscores the importance of adequate training and extension service. While feed certainly accounts for a significant part of production cost, the observed difference in production cost per kg fish produced across scales was more influenced by the cost of fingerlings with a resultant effect on the farm's profitability.

Though there are prevailing issues on the fingerlings quality which could affect the survival rates of the fingerlings, it was observed that

Table 6
Average production costs for catfish for different size categories of farms.

Cost Items	Operation Scale Categories					
	Small		Large		All Farms	
A. VARIABLE COST	₦	%	₦	%	₦	%
Feed	470,903	*73.75*	11,492,625	*86.17*	1,940,466	*83.22*
Fingerlings	83,875	*13.14*	445,831	*3.34*	132,136	*5.67*
Labour	34,000	*5.32*	1,084,782	*8.13*	174,104	*7.47*
Maintenance & other costs	26,156	*4.10*	247,625	*1.86*	55,685	*2.39*
Total Variable cost	614,934	*96.30*	13,270,863	*99.50*	2,302,391	*98.74*
B. FIXED COST						
Depreciation cost	6823	*1.07*	43,850	*0.33*	11,760	*0.50*
Rent (Lease)	16,788	*2.63*	22,500	*0.17*	17,550	*0.75*
Total Fixed cost	23,612	*3.70*	66,350	*0.50*	29,310	*1.26*
C. TOTAL COST-TC (A + B)	638,546	*100.00*	13,337,213	*100.00*	2,331,701	*100.00*

Source: Field survey (2019/2020).

Table 7
Cost and profitability estimate per kilogramme (kg^{-1}) of harvest across operation scales.

	Small		Large		All Farms	
		%*		%*		%*
n=	26		4		30	
Fingerling cost	99.2	14.1	32.1	5.4	90.3	13.1
Feed cost	499.2	71.0	509.2	85.1	500.5	72.6
Labour cost	46.9	6.7	34.2	5.7	45.2	6.6
Maintenance & other costs	32.56	4.6	16.0	2.7	30.3	4.4
Variable cost	677.8	96.4	591.5	98.8	666.3	96.6
Total Fixed cost	25.6	3.6	7.0	1.2	23.1	3.4
Total cost	703.5	100.0	598.5	100.0	689.5	100.0
Profit (NFI)	−62.9		143.2		−35.4	
Revenue (Price)	640.6		741.7		654.0	

* percentages were estimated within each group. All costs provided in ₦ per kg.

Table 8
Input estimates per kilogramme (kg^{-1}) of harvest across operation scales.

	Small		Large		All Farms	
		%*		%*		%*
n=	26		4		30	
Fingerlings	3.8		1.3		3.5	
FCR	1.3		1.4		1.3	
Labour (man-days)	0.3		0.1		0.3	

some farmers stocked more fingerlings than required which resulted in increased cost per unit output. The utilisation of fingerlings could be a good indicator of efficient management practice and profitability prospects of a fish farmer.

The average labour cost decreased as the scale increased with small and large farms having ₦47 and ₦34.2 kg^{-1} output, respectively. Small-scale farmers engage household labour whose cost is usually minimal when accounted for, but due to economies of scale, the average cost of labour for large farms was lower (Shang, 1985). Ali et al., 2018 also reported a comparatively lower labour cost for large-scale farms.

Of the total cost of production, the total fixed cost was about 2%. Cost of renting the farms was higher than the cost of owning the ponds. Mugaonkar et al. (2019) also observed that the rental cost was the highest among the fixed cost components. All the large-scale farmers owned their ponds. On average, the total fixed cost kg^{-1} output of the large-scale farms was ₦7 while for the small-scale farm it was ₦26. In the long run, it is better to own a pond than to rent it although ownership attracts a higher initial investment cost.

Gross revenue for all the farms averaged ₦2,664,996, and averaged ₦621,299 and ₦15,949,024 for small- and large-scale farms respectively (Table 9). Overall GM and NFI for all farms were ₦362,605 and ₦333,295 respectively. The GM indicates the profit of the farm before the deduction of total fixed costs while the NFI indicates the profit of the farm after total fixed costs deduction. The average for both profit indices for all farms showed the ventures to be profitable and appears to follow observations of others in Nigeria (Busari, 2018; Olaoye et al., 2013; Olukotun et al., 2013; Ucha et al., 2018). When assessed across the different scales of operation the average GM for both large- and small-scale farms was positive at ₦6.365 and ₦2,687,161 respectively, while

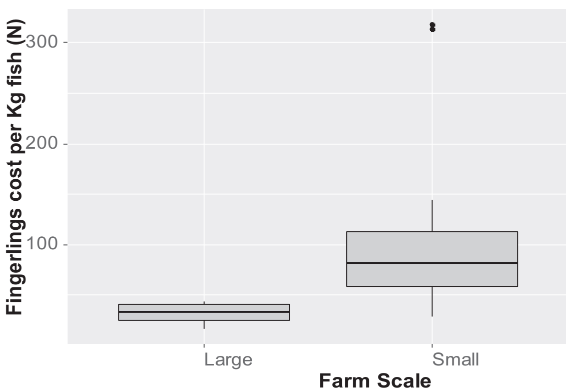

Fig. 3. Fingerlings cost per kilogramme of fish (₦) across operation scale ($P < 0.05$, KWT).

Table 9
Return and economic indicators of catfish farms by operation scales.

Performance indicators	Operation Scale Categories		
	Small	Large	All Farms
n=	26	4	30
Variable cost	614,934	13,270,863	2,302,391
Total Fixed cost	23,612	66,350	29,310
Total cost	638,546	13,337,213	2,331,701
Revenue	621,299	15,949,024	2,664,996
Gross Margin (GM)	6365	2,678,161	362,605
Net Farm Income (NFI)	-17,247	2,611,811	333,295
Benefit Cost Ratio	0.97	1.25	1.01
Rate of Return on Investment	−0.03	0.25	0.01
Operating Profit Margin	−11.06	18.53	−7.11
Expense Ratio	0.04	0.01	0.04
Gross Ratio	−6.93	19.52	−3.40

the average NFI for small scale farms was, however, negative (₦ −17,247), but positive for the large-scale farms (₦2,611,811). The positive GM and negative NFI for small scale farms indicated the farms appeared to be performing well when the total fixed cost of operation is not factored in. This also shows how the fixed costs could affect the profitability outlook of a farm and how economies of scale in large farms reduced the impact of fixed costs on the farm's profit.

3.3. Profitability indicators and ratios

Overall, BCR was greater than 1 indicating profit, while there was a positive, though low, rate of return on investment (1%) which implies only ₦1 will be gained on every ₦100 of invested capital. The average expense ratio for all the farms was 0.04 which implied that 4% of the total cost of production was made up of fixed components. This low figure is however good for farm operation as the lower the total fixed cost the higher the rate at which variable cost will increase total revenue (Ucha et al., 2018).

However, these profitability ratios look different when the farm scales were compared as the BCR was lower than 1 and RoI negative for the small farms indicating the cost outweighs the benefit. The positive overall profitability of the farms indeed masked the losses experienced by some of the small-scale farmers as it appears to have been the case in a number of previous studies.

Similarly, while the values for the operating profit margin (OPM) and Gross Ratio (GR) were negative on average for all the farms, the scale-wise result of the farms, however, showed that large-scale farmers had an average OPM of 18.5% which implies that the income realised can cover the operating expenses. A good OPM is usually above 10–12% and the higher the percentage, the more viable the investment (Umar et al., 2017). Different values of operating profit margin have been reported by different authors for fish farming in Nigeria. While Umar et al. (2017) reported high OPM (57%) in the Northern part of Nigeria, Busari (2018) reported a low OPM (8.1%) in the Southern part. Though the margins from both studies are wide, this disparity could be clarified if the scales of operation were taken into consideration. Like for the OPM, the GR was also positive for large scale farms at 19.5%. This means for every ₦100 revenue, ₦19.5 is returned while 80.5% is attributed to the cost of producing that product. Higher GR indicates the farm is selling the product at a higher profit percentage which is usually achieved by a reduced cost of production or higher sales price (Corporate Finance Institute, 2020). These two conditions were fulfilled by the large-scale farms: a low average total cost kg^{-1} fish of ₦598.5 compared to ₦703 in small-scale farms and a higher average sales price kg^{-1} fish (₦741.7) than the smaller farms which had ₦640.7. On the other hand, the OPM and the GR for the small-scale farms were negative at −11.06 and − 6.93 respectively. The ability of large-scale farmers to manage the cost of production may relate to their years of experience as most of them (75%) have more than 10 years of experience. Iruo et al. (2019) attested that farmers' years of experience can influence their knowledge of management practices.

3.4. Key factors to profitability

A scale-wise approach to the assessment of production management and profitability is important especially when the influence of scale on profitability is suspected. In this study, the large-scale farms had the advantage of economies of scale as their staff was more productive and the average cost of labour, fingerlings and maintenance were lower than for small-scale farms. They also had access to capital which enabled them to finance their operation at that scale. Also, being a more dependable supplier guaranteed good market prices for the large farms.

The large farms were managed by personnel with many years of experience in fish farming which played out in their knowledge of good production management practice. There is a wide variation in the profit of farmers with low levels of experience with the majority making losses especially among the small-scale farmers (Fig. 4). Profitability increased with experience. The more experienced farmers were able to maximise profits by either cost reduction or revenue increase through better market price. This further demonstrates the role of experience in contributing to efficiency and profitability as established by other authors. Iruo et al. (2019) reported that years of experience leads to increase in the knowledge of management practices. Mugaonkar et al. (2019) asserted that years of experience of fish farmers in Andra Pradesh, India contributed to their increase in expertise in the sector. Rahman et al. (2020), in their findings, also emphasized that small scale aquaculture in developing countries can be more economically viable given increased knowledge of management practices.

High fingerling costs, especially by the small-scale farms can only to a small extent be attributed to smaller harvest sizes. Poor fingerling quality and large variation in size reported by some of the respondents also lead to high mortality. This is not unexpected as the genetic strength of most of the parent stocks in use has been questioned over the years (Anetekhai, 2013). This is further compounded by poor broodstock management practices by fingerling producers. While there are provisions in the recently endorsed Inland Fisheries (Aquaculture) Regulation of Nigeria to promote the availability of healthy fingerlings and broodstock, attention is not paid to the practices of fingerling producers, and several farmers fall victim to poor fingerlings.

Not only the small-scale farmers, but the majority of large-scale farmers (75%) reported fingerling quality to be a major constraint. Other parallel studies within this project also indicated a lack of genetic diversity, poor growth, and high mortality in growth trials of catfish selected from different parts of the country (Bassey, 2020; Olalere, 2020). There is a need to enhance the catfish parent stock in the country. The use of quality fingerlings from good parent stock will result in reduced mortality, improved growth rate and thus better FCR, more cycles of production and better returns. This would be an effective cost-

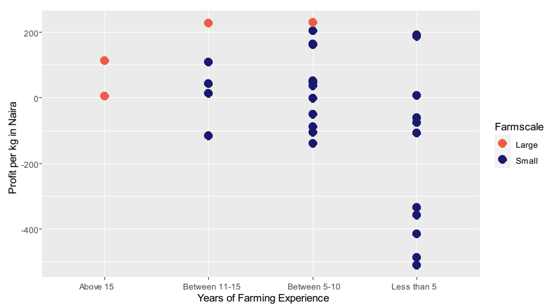

Fig. 4. Profit (NFI) per kg against years of experience by operation scale (Colour).

saving strategy and would boost the profitability of catfish farming in the country.

4. Conclusions

This study assessed the current economic performance of catfish production in Nigeria using profitability analysis across different operational scales. While the overall assessment of most of the performance indicators portrayed catfish farming to be profitable in the study area, the scale-wise result showed that the large-scale farms perform better than the small-scale farms in all the indicators assessed. Fish farming can indeed be profitable if managed appropriately and cost-effectively. The majority of small-scale farmers were facing difficult challenges exacerbated by lack of experience resulting in poor management practices. There is therefore a need for effective training and extension service for the small-scale farmers, who constitute the highest proportion of all the farmers. Fish farming is also capital intensive. Increased access to finance would aid the farmers to scale up their operations and be able to take advantage of economies of scale. The small-scale farmers that are profitable could benefit from this. However, the small-scale farmers who are making losses need to improve on their Operating Profit Margin ratio before they can get the advantage of economies of scale by maximising their Gross Margin. Small-scale farms could as well form effective clusters that are corporately managed and as such could operate in a manner closer to large-scale farms and reap the benefits. The sustainability and profitability of the catfish farming industry are also dependent on an adequate supply of quality fingerlings. To achieve this, an effective broodstock management program should be in place. This will improve the genetic virility and strength of the broodstocks as well as prevent inbreeding.

While the current study assesses the production performance of fish farmers in the study area, it is however limited in terms of sample size and geographical coverage. A wider study of national scope is required to assess the performance of the sector and make recommendations of national significance. Further study could also look into the assessment of the potential impact of adopting improved catfish breed on the profitability of catfish farming in Nigeria.

CRediT authorship contribution statement

Olanrewaju Femi Olagunju: Conceptualization, Methodology, Writing – original draft, Formal analysis, Data curation, Writing – review & editing. **Dadi Kristófersson:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Tumi Tómasson:** Conceptualization, Writing – review & editing, Supervision. **Theódór Kristjánsson:** Formal analysis, Writing – review & editing, Supervision.

Declaration of Competing Interest

Olanrewaju Olagunju reports financial support, administrative support, and travel were provided by UNESCO GRO-Fisheries Training Programme, Iceland.

Acknowledgements

This study was funded by the UNESCO GRÓ-Fisheries Training Programme, Iceland as part of a series of studies to identify key challenges of the catfish farming industry in Nigeria covering aspects of broodstock management, fingerling production, feed quality and economic assessment of the industry. We acknowledge all the government officers, fish farmers and fish feed suppliers who provided information through questionnaires and interviews. The authors thank anonymous reviewers for their insightful and constructive comments.

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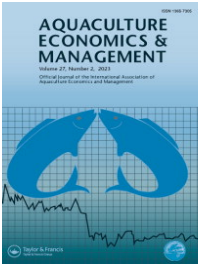
Paper II



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ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uaqm20

Technical efficiency of African catfish production in Nigeria: An analysis involving input quality and COVID-19 effects

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AQUACULTURE ECONOMICS & MANAGEMENT
https://doi.org/10.1080/13657305.2023.2222687

Technical efficiency of African catfish production in Nigeria: An analysis involving input quality and COVID-19 effects

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ABSTRACT

The technical efficiency of the African catfish production in Nigeria was assessed. A total of 609 farms were sampled, and 1,118 operations were recorded covering both the pre-COVID and COVID periods. A translog stochastic frontier modeling approach was used to simultaneously assess the technical efficiencies and the determinants of technical inefficiency of the catfish farmers. The mean technical efficiency for the catfish production in Nigeria is 85.4% indicating a scope of increasing production by 14.6% given the current technological state, which could contribute an additional 42,273 metric tons of fish to Nigeria's aquaculture. Comparative analysis showed that catfish producers during the COVID-19 period and producers from the Southern region were more technically efficient. The effect of management-dependent determinants is presented. Beyond management approaches, technical efficiency is seen to be improved significantly through the use of quality inputs. Based on these, measures for successful catfish production in Nigeria are recommended.

KEYWORDS

Catfish farming; COVID-19; farm management; input quality; stochastic frontier analysis; technical efficiency

Introduction

Fish is an essential protein source for human consumption, accounting for more than 20% of globally consumed animal protein by about 3.3 billion people (WorldFish et al., 2020). In Sub-Saharan Africa, it is an important source of protein as most staple foods are cereal or rice-based, which are deficient in essential amino acids, such as lysine and methionine (HLPE, 2014). Nigeria, despite having a relatively lower per capita protein intake, has a high percentage of seafood in animal protein consumption compared to many other countries. Fish and seafood constitute the major source of

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animal protein in Nigeria, accounting for 44% of the per capita animal protein intake (FAO, 2018).

The total fish consumption in Nigeria is estimated to be about 1.7 million metric tons, of which 1.2 million metric tons are produced locally (FAO, 2022b). Despite the important role of fish in food security and nutrition in Nigeria, per-capita fish consumption in Nigeria has been declining in recent years from 13.5 kg in 2013 to 9.1 kg in 2017 (FAO, 2020). Nigeria's fish requirement is expected to continue to increase, with the population growing at more than 3% per year (Subasinghe et al., 2021) and the need to constantly satisfy the food and nutrition security of the populace. To meet the challenge of reduced fish supply, the nation needs a strategy to substantially increase fish production. Capture fisheries contribute about 70% of Nigeria's fish production, but catches have been declining over the years (FAO, 2022b) and there are indications of overfishing (Asche et al., 2021). The only option is then to increase aquaculture production. This is in line with what can be observed globally in terms of production growth for seafood (Garlock et al., 2020) as well as seafood consumption (Garlock et al., 2022).

Aquaculture production in Nigeria has primarily been driven by the culture of catfish, which accounts for more than half of the total national aquaculture production (Olagunju et al., 2022). The African catfish (*Clarias gariepinus*) has been widely cultured due to its hardiness, disease resistance, and fast growth. The culture of catfish has been promoted by governments and aid organizations over the years, which has favored its culture in many countries (Anetekhai, 2013; de Graaf & Janssen, 1996; Miller & Atanda, 2011). In Nigeria, the species is considered a delicacy consumed smoked, dried, fried, barbecued, or in soup, and it is marketed throughout the country. The catfish industry has mainly been driven by private operators, who were drawn by the economic prospects in catfish aquaculture (Anetekhai, 2013). The industry has therefore made significant contributions toward food security in Nigeria. Various culture systems are being used in the culture of the species, ranging from earthen ponds, concrete ponds, floating cages, and mobile ponds. The use of mobile ponds has further encouraged backyard catfish farming in the urban areas as access to land is not a critical factor, which has allowed many to be able to participate in the venture. Catfish farming has therefore been a major source of economic empowerment in the country.

However, aquaculture production in Nigeria has been declining in recent years and Nigeria no longer stands among the top three African countries in the annual growth rate of both aquaculture and catfish production (Olagunju et al., 2022; Ragasa et al., 2022). Given the importance of catfish farming in Nigeria, it is important to investigate the causes. It is well-known that productivity growth and adaption of new technology have been key factors in fostering growth in the aquaculture production globally (Asche et al., 2022). Given the diverse structure of the Nigerian aquaculture industry, we will therefore in this paper assess the technical performance of catfish production to identify the scope for expansion in production and make recommendations that could guide food security policies. Technical efficiency measurement considers the ability of a farmer to produce the highest level of output given a specified number of resources. It is an assessment of resource use and productivity at the farm level. Improvement in the use of resources by farmers will lead to an increase in the efficiency and productivity of the fish farms. Technical efficiency measurement has therefore been noted to result in considerable resource savings, which may have important implications both for policy formulation and farm management (Bravo-Ureta & Rieger, 1991).

Many studies have assessed the technical efficiency of fish production in Nigeria.[1] However, the majority of them have been limited to a specific state or region (Busari, 2018; Ekunwe & Emokaro, 2009; Inoni et al., 2017; Ogunmefun & Achike, 2018) or focused only on small-scale farmers (Akegbejo-Samsons & Adeoye, 2012; Kingsley et al., 2014; Onoja & Achike, 2011). A preliminary part of the current study, however, demonstrated that the scale of production could influence farm operations and production management (Olagunju et al., 2022). However, the study was limited in respect of sample size and geographical coverage. Therefore, to have a broader scope of assessment of catfish production in Nigeria, the current study is taking a national perspective by assessing the technical efficiency of catfish farming operations across the country. In addition, due to the possible influence of the COVID-19 pandemic on the farmers' operations at the time of the study, operational data was obtained for both pre-COVID-19 and COVID-19 periods. The earlier study reported on the poor performance of inputs used by the farmers (Olagunju et al., 2022). This, however, could be due to bad management or the quality of the inputs. Hence, in light of these observations, when assessing the technical efficiencies of catfish farms in Nigeria, this study also assessed, as part of the determinants of technical inefficiencies, the influence of factors, such as the scale of operation, region, input quality, and COVID-19. A stochastic frontier modeling approach was used to simultaneously assess the technical efficiencies and the determinants of the technical inefficiency of catfish farmers in the country.

Methodology

Study area, sampling, and data collection

Nigeria comprises 36 States and one Federal Capital Territory grouped into six geopolitical zones, three in the Northern region, and three in the

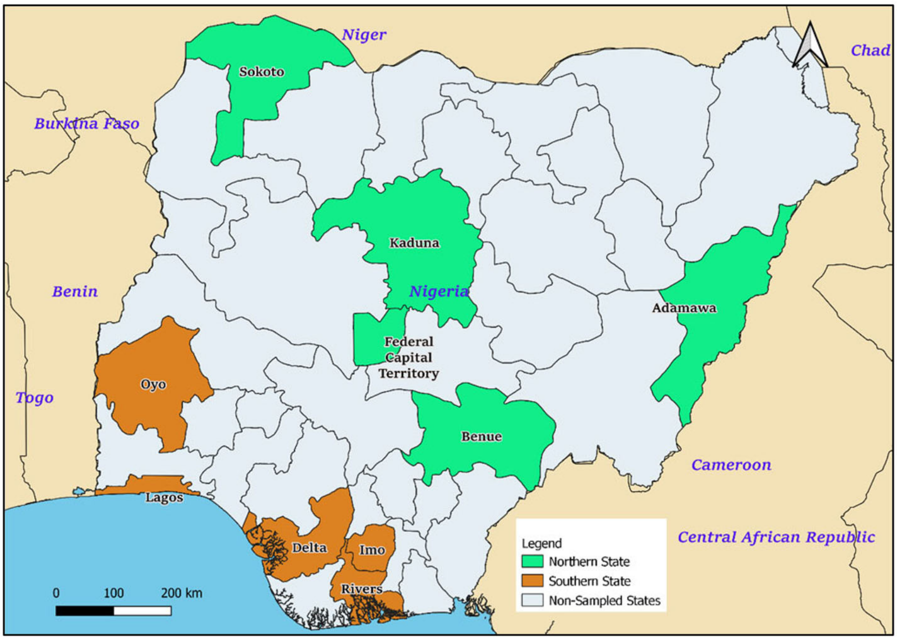

Figure 1. Geographical map of the Federal Republic of Nigeria highlighting the states included in the study.

Southern region *viz*: North-Central, North-East, North-West, South-East, South-South, and South-West. A multi-stage sampling technique was used in the study (Bluman, 2019). In the first stage, representative states who share close production and agroecological characteristics with other states in the zone were purposively selected from each geo-political zone. Aquaculture is practiced in every state of the country but not to the same degree. The selection, therefore, also took into consideration both the production capacity of the different states and the need for national coverage. In total, 10 states were selected for the survey: five from the Northern region and five from the Southern region (Figure 1). Lists of farmers were obtained from both governmental and private sources in all the states covered by the study to capture unregistered but practicing farmers and to reduce potential survivorship bias.

In the second stage, farmers were selected from the list using simple random sampling. Data collection was conducted from May 2021 to February 2022. The most recent operational data was collected from the farms. The anticipated limitation of the data for this study was the implausibility of using only the 2020/2021 production data of the farms as a basis for assessment of the sector owing to the shock created by COVID-19. This, however, provided an additional opportunity to assess the impact of COVID-19 on the sector's performance. The farm operations' data was therefore collected to cover both the COVID-19 and pre-COVID-19 periods. Some of

Table 1. Catfish operation data was sampled from different states in Nigeria.

Region/state	pre-COVID-19	COVID-19	Total
North	281	235	516
Adamawa	64	52	116
Benue	52	34	86
FCT	62	59	121
Kaduna	57	44	101
Sokoto	46	46	92
South	328	274	602
Delta	72	60	132
Imo	46	44	90
Lagos	74	57	131
Oyo	72	55	127
Rivers	64	58	122
Grand total	609	509	1118

Source: Field survey (2021/2022).

the farmers did not produce during the COVID-19 pandemic and in this case, only their pre-COVID-19 production data was obtained. As for the pre-COVID period data, the nearest pre-COVID production cycle data was obtained from the farms for ease of recollection and based on available records. The production data during the COVID period was then obtained where available. A total of 609 farms were sampled across the country and 1,118 production operations were captured covering both the pre-COVID-19 and COVID-19 periods (Table 1).

Considering the spread of the operations sampled as well as the need to improve the quality of the data collected and allow for effective data cleaning, an electronic questionnaire through the Open Data Kit (ODK) was used. Meetings and training sessions were held with enumerators across the states pre-collection for hands-on training, then mid- and post-collection to monitor and assess the whole process. The data collection was done mainly on-site with the farm photo and geo-location obtained for data verification and cleaning. All data were validated based on sectoral knowledge and comparison with related data from each state. In cases where data seemed unreliable, the farmer was contacted for further consultation and clarification. Collected farm data were input quantities and costs, harvests, prices, date of stocking and harvest, farm management practices, and socioeconomic information. Stocks retained and fish removed for gifts and personal consumption were included in the harvest data. All the farms that were surveyed practiced intensive farming and produced mainly for the market.

Output and input variables included in the model

The output variable involved in the stochastic frontier model is the harvest (Table 2). Input variables included the number of fingerlings stocked, feed, labor, pond size, and other inputs. Feed constitutes more than 70% of the costs of operations. Some farmers thus supplemented the commercial feeds

Table 2. Description of the variables used in the model.

Variables in the model	Unit	Description
Dependent variable		
Harvest	Kilogram	Total quantity of fish harvested
Independent variable		
Fingerlings	Number	Total number of fingerlings stocked
Feed	Kilogram	Total quantity of feed used
Labor	Mandays	Total number of days family or hired labors spent on the farm
Pond.Size	Sq. meter	Size of the pond stocked
Other Input	Naira	Cost incurred on other inputs
DumOth.InpNIL	Dummy	Farms with zero cost for other inputs (1 = yes, 0 = otherwise)
Inefficiency determinants		
Dgenderm	Dummy	Male farm managers (1 = yes, 0 = otherwise)
Downers	Dummy	Owners of pond used (1 = yes, 0 = otherwise)
Dtrainingorextension	Dummy	Engaged in training or utilized extension service (1 = yes, 0 = otherwise)
Dsouth	Dummy	Farm located in the South of the country (1 = yes, 0 = otherwise)
Dcovid	Dummy	Production operation carried out during covid (1 = yes, 0 = otherwise)
Dlocalfeed	Dummy	Included local (locally compounded, non-commercial) feed as part of the fish feed (1 = yes, 0 = otherwise)
Donfarmfingerlings	Dummy	Used on-farm produced fingerlings (1 = yes, 0 = otherwise)
Dmicrosmallscale	Dummy	Have an annual production of 5000 kg and below (1 = yes, 0 = otherwise)
Deductertiary	Dummy	Have a tertiary education (1 = yes, 0 = otherwise)
Fingerlings Quality (FingQual)	Price/g	Continuous variable
Feed Quality (FeedQual)	Price/kg	Continuous variable

with cheaper alternatives, including locally compounded feed, chicken waste, and trash fish. The dry weight equivalent of these alternatives was used, and in cases where the amount was unquantifiable, such data was not included.

Labor is expressed as the total number of days family or hired labor spent on the farm. Some of the labor quantity data provided by the farmers was zero and/or unrealistic. Discrepancies in the reporting of labor data in agricultural surveys in developing countries' have been well-reported (Dammert & Galdo, 2021; Gaddis et al., 2021). Due to the endogeneity of the labor input, a 2-stage least squares method was used to obtain the labor estimates (predicted labor value in man-days) included in the study. The independent variables used included the major production factors, such as feed, fingerlings, number of workers, and pond size, as well as other labor-influenced characteristics, such as whether it was paid or unpaid, household or hired, backyard farm or otherwise, farm ownership and pond type. To avoid endogeneity bias, the length of the culture cycle (days) was excluded from the independent variables as it is highly correlated to the dependent variable. The pond size is measured in square meters. Different pond types that were used included earthen ponds, concrete ponds, and various forms of mobile ponds. Other inputs used in production were provided as cost estimates, and these included the costs of maintenance, medication, probiotics, water supply, and electricity. Some farmers reported no costs for this section. This is possible, especially among small-scale producers who may not require much to run their operations. To deal with these zero observations, an arbitrary small number (0.1) was added to all the observations in the variable, and a dummy variable (*DumOth.InpNIL*) was provided to reflect the observations with zero value. As only 10 out of the 1,118 observations were affected, using this method did not create a bias in the model estimation because the affected number was not significant (Battese, 1997).

Farm-specific variables that may affect technical efficiency were included in the inefficiency function. The production scale of the farmers (annual production capacity) was estimated based on farm production per cycle and the number of cycles covered in the year or the average monthly harvest, where applicable. All the variables in the inefficiency model were expressed as dummies and their definitions are provided in Table 2, except fingerling and feed quality which were expressed as continuous variables. The prices of the affected inputs were used as a proxy for quality. The suitability of price as a proxy for quality has been affirmed in earlier studies (Makasi & Govender, 2014; Wolinsky, 1983). These values were deflated with the average unit price. However, given the implicit impact of the pandemic on prices, the average price for each period (pre-COVID-19 and COVID-19) were applied for production from the different periods.

Theoretical framework: the stochastic frontier production function

Efficiency measurements using a frontier approach usually assess the farms' relative closeness to or deviation from an optimal performance benchmark. The Stochastic Frontier Production Function (SFPF) approach involves an econometric estimation of the parametric function and decomposes the error term into a random error and an inefficiency component. The SFPF has been widely used in assessing the technical efficiencies (TE) of developing countries' agriculture, where the data are often affected by measurement errors and stochastic factors, such as weather, diseases, and other natural causes (Coelli et al., 1998; Dey et al., 2000; Singh et al., 2009). Hence, this study uses the SFPF approach to evaluate the TE and their determinants on the operations of catfish farms in the study area (Coelli et al., 1998). The stochastic frontier production function for cross-sectional data is written as:

$$Y_i = f(X_i; \beta)\exp(V_i - U_i) \tag{1}$$

where Y_i is the output of the ith farm; X_i is the vector of inputs used by the ith farm; β denotes the vector of the parameters to be estimated; V_i is the random error outside the farmer's control assumed to be independently and identically distributed $N(0, \sigma_v^2)$; U_i is the non-negative random variable associated with the technical inefficiency effects, which are presumed to be independently and identically distributed as truncations of the $N(\boldsymbol{Z}_i\delta, \sigma_u^2)$ distribution. According to Battese and Coelli (1995), the U_i can be expressed as follows:

$$U_i = \boldsymbol{Z}_i\delta + Wi \tag{2}$$

where $\boldsymbol{Z}_i$ is the variable associated with inefficiencies on farm *i*, δ is a vector of unknown parameters to be estimated, and Wi is the random variable defined by the truncation of the normal distribution with mean 0 and variance σ_u^2, such that the point of truncation is $-\boldsymbol{Z}_i\delta$, meaning $Wi \geq -\boldsymbol{Z}_i\delta$. Accordingly, the TE of the *i*th firm is defined as the ratio of the output of the *i*th firm in comparison to the output of the frontier (if there were no inefficiency). That is,

$$TE_i = \exp(-U_i) = \exp(-\boldsymbol{Z}_i\delta - Wi) = \frac{Y_i}{f(X_i;\beta),\ \exp(V_i)} \tag{3}$$

Empirical models

The translog stochastic production function has been widely used in other production frontier studies in aquaculture (Alam et al., 2012; Begum et al., 2013; Crentsil & Essilfie, 2014; Iliyasu et al., 2016). The translog functional form is written as follows:

$$\ln Y_i = \ln f(X,\beta) = \beta_0 + \sum_{j=1}^{n} \beta_j \ln X_{ji} + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} \beta_{jk} \ln X_{ji} \ln X_{ki} + V_i - U_i \tag{4}$$

The frontier is expressed with one output ($Y = Harvest$) and five input variables (X): *fingerlings, feed, labor, pond size,* and *other inputs* (Table 2). The subscript, *i*, refers to the *i*th farm operation in the sample and X_{ji} and X_{ki} represent the amount of inputs *j* and *k* used, respectively; *ln* is the natural logarithm; and β, U_i and V_i are as defined earlier.

According to Battese and Coelli (1995), the technical inefficiency distribution parameter, U_i, in Equation (2) can be specified as:

$$U_i = \delta_0 + \sum_{j=1}^{n} \delta_j Z_{ij} + W_i \tag{5}$$

where Z_{ij} are operational and farm-specific variables that determine technical inefficiency as shown in the lower part of Table 2, while δ and W are as defined earlier.

The technical inefficiencies Equation (5) can only be estimated if the technical inefficiency effects, U_i, are stochastic and have particular distribution properties (Coelli & Battese, 1996). Hence, it is important to test the following null hypotheses:

1. Whether the second order and interaction terms in the translog functional form were insignificantly different from zero;
2. The inefficiency effects are absent from the model, H_0: $\gamma = 0$;
3. The coefficients of the determinants of the inefficiency model are equal to zero, H_0: $\delta_1 = \ldots. = \delta_{10} = 0$.

These hypotheses were tested using generalized likelihood-ratio test statistics defined by:

$$\lambda = -2\left[ln\left\{L(H_0)\right\} - ln\left\{L(H_1)\right\}\right] \tag{6}$$

where $L(H_0)$ and $L(H_1)$ represents the values of the likelihood function under the null and the alternative hypotheses, respectively.

The definition of TE in Equation (3) with respect to U_i can be expanded further as follows:

$$TE_i = \exp(-U_i) = \exp\left(-\left(\delta_0 + \sum_{j=1}^{n} \delta_j Z_{ij} + W_i\right)\right) \tag{7}$$

where TE_i is the relative technical efficiency of the ith firm which lies between zero and unity, i.e. $[0 < TE < 1]$. A TE_i equal to 1 implies a fully efficient farm. Since the coefficients (β) of the translog stochastic frontier in Equation (4) do not have a direct interpretation, the translog stochastic production frontier in this study was estimated using mean-scaled input variables. Therefore, the output elasticity of the ith farm operation is given as follows:

$$\varepsilon_i = \frac{\partial lnY}{\partial lnX_i} = \beta_i + \sum_j \beta_{ij} \ln X_j \tag{8}$$

where Y and X_j are the means of output and all input variables, respectively. By centralizing the data using means, the expression is simplified, and the parameter estimate for β_i becomes an estimate of the elasticity at the mean. The elasticity of scale is then estimated as the sum of output elasticities (ε_i) for all the inputs (Henningsen, 2020; Jueseah et al., 2021; Sesabo & Tol, 2010). The measure of return to scale is determined as increasing, constant, or decreasing returns to scale if the estimate is greater than, equal to, or less than 1, respectively.

The maximum likelihood estimation method is used to estimate the unknown parameters in the equations with the stochastic frontier, and the inefficiency effects are estimated simultaneously using the FRONTIER 4.1 "frontier" package in "R" (Coelli & Battese, 1996; Coelli & Henningsen, 2013). The comparative analysis of the TE satisfies the assumptions of a non-parametric test, hence Mann–Whitney *U* test was adopted using the "ggstatsplot" package in R (Patil, 2021).

Results and discussion

Summary statistics

The average harvest (output) produced is 3,294 kg, with minimum and maximum values of 33 and 40,000 kg, respectively (Table 3). On average, 4,112 fingerlings were stocked. The average feed quantity used by the farms was 3,815 kg. The labor value was estimated in man-days and ranged from 47 to 3,029, with an average of 340. The average pond size used in production was 108 m^2 and minimum and maximum sizes were 1 and 4,176 m^2, respectively. The smallest ponds (1 m^2) were cube-shaped plastic tanks often used by backyard fish producers due to their mobility. The average cost of other inputs was 94,872 Naira. Most of the standard deviations of the variables are considerable, which is mostly a reflection of the large variations in output among operators.

Hypotheses tests and choice of model and specification

The first null hypothesis, H_0: $\beta_{jk} = 0$, was performed to determine whether a Cobb-Douglas specification provided a better representation of the frontier production function than the translog functional form. The null hypothesis was rejected in favor of the translog functional form (Table 4). The second null hypothesis, H_0: $\gamma = 0$, was also rejected, showing that inefficiency effects are present in the model. This indicates that there are technical inefficiencies in the operations of the catfish farmers. The gamma (γ) value of 0.936 (Table 5) is very close to one and significantly different from zero, showing a high level of inefficiencies in the operations of the catfish

Table 3. Summary statistics of the variables used in the model.

Variables	Unit	Mean	Standard deviation	Minimum	Maximum
Harvest	Kilogram	3294	4464	33	40,000
Fingerlings	Number	4112	4784	100	60,000
Feed	Kilogram	3815	5188	56	65,000
Labor	Man-days	340	247	47	3,029
Pond size	Sq. meter	108	256	1	4,176
Other input	Naira	94872	142554	0.1	1,353,750
Dummy variables	Dummy	–	–	0	1
Fingerlings quality	Price/g	3.26	2.50	0.4	20
Feed quality	Price/kg	452	101	200	879
Number of observations = 1,118					

Table 4. Likelihood ratio test of the hypothesis of the stochastic production frontier model.

Null hypothesis	$L(H_0)$	$L(H_1)$	*df*	Test statistics	Decision
The production function is Cobb-Douglas, H_0: $\beta_{jk} = 0$	261.44	289.55	15	56.22***	Reject H_0
The technical inefficiency effects are absent from the model, H_0: $\gamma = 0$	230.42	289.55	1	118.25***	Reject H_0
The coefficients of the determinants of the inefficiency model are equal to zero, H0: $\delta_1 = \dots = \delta_{10} = 0$	230.42	387.31	14	313.77***	Reject H_0

p-Value: *** denotes statistical significance at the 0.001% level.

Table 5. The maximum likelihood estimates of the translog production frontier model.

	Parameters	Estimate	Std. error
Stochastic frontier			
Constant	β_0	0.1534***	0.0108
*Ln*Fingerlings	β_1	0.0943***	0.0218
*Ln*Feed	β_2	0.8966***	0.0207
*Ln*Labor	β_3	0.0250(*)	0.0129
*Ln*Other.Inputs	β_4	0.0222**	0.0069
*Ln*Pond.Size	β_5	−0.0000	0.0063
DumOth.InpNIL		0.2653	0.4305
0.5*(*Ln*Fingerlings)^2	β_{11}	−0.0700(*)	0.0374
0.5*(*Ln*Feed)^2	β_{22}	−0.0354	0.0401
0.5*(*Ln*Labor)^2	β_{33}	−0.0216	0.0319
0.5*(*Ln*Other Inputs)^2	β_{44}	0.00074	0.0049
0.5*(*Ln*Pond Size)^2	β_{55}	0.0031	0.0073
(*Ln*Fingerlings**Ln*Feed)	β_{12}	0.0291	0.0347
(*Ln*Fingerlings**Ln*Labor)	β_{13}	−0.0029	0.0284
(*Ln*Fingerlings**Ln*Other.Inputs)	β_{14}	−0.0024	0.0090
(*Ln*Fingerlings**Ln*Pond.Size)	β_{15}	0.0493***	0.0133
(*Ln*Feed**Ln*Labor)	β_{23}	0.0320	0.0284
(*Ln*Feed**Ln*Other.Inputs)	β_{24}	0.0172(*)	0.0101
(*Ln*Feed**Ln*Pond.Size)	β_{25}	−0.0468***	0.0132
(*Ln*Labor**Ln*Other.Inputs)	β_{34}	−0.0138	0.0093
(*Ln*Labor**Ln*Pond.Size)	β_{35}	−0.0061	0.0085
(*Ln*Other.Input**Ln*Pond.Size)	β_{45}	−0.0014	0.0041
Variance			
σ^2		0.1696***	0.0466
γ		0.9364***	0.0177
λ		3.8379***	0.5715
$\gamma/[\gamma+(1-\gamma)\pi/(\pi-2)]$	γ^*	0.843	
Log likelihood value		387.3	
Mean technical efficiency		0.854	

Note: (*), *, **, and *** denote statistical significance at the 10, 5, 1, and 0.1% levels, respectively.

farmers who were sampled. The proportion of the total variance that is due to inefficiency (γ^*) is estimated as 0.843. This indicates that 84.3% of the total variance is due to inefficiency. The third hypothesis, that the coefficients of the determinants of the inefficiency model (δ-parameters) are equal to zero, was also rejected, which implies that the inefficiency determinants included in the model explain the technical efficiencies of the farmers.

Technical efficiency analysis and resource productivity

The estimated coefficients of fingerlings, feed, labor, and other inputs all have a positive impact on the output of catfish production, with fingerlings, feed, and other inputs statistically significant at $<5\%$ level and labor at 10% while the coefficient of pond size is negative and insignificant (Table 5). The first-order parameters were interpreted as the output elasticities since the data included in the analysis were mean-scaled (Coelli et al., 1998). Overall, the return to scale (RTS) estimated as the summation of the output elasticities of the first-order parameters is 1.04 at the sample mean with a standard deviation of 0.034. This indicates that an average catfish farm in Nigeria has a slightly increasing return to scale. In related studies, the returns to scales of 1.15 and 1.06 were reported for Ondo and Oyo states, respectively (Fapohunda et al., 2005; Ogundari & Ojo, 2009) and 1.02 for pangasius production in Bangladesh (Ali et al., 2018).

The output elasticity of *feed* was the highest (0.897) followed by *fingerlings* (0.10). This implies that every 10% increase in feed and fingerlings would result in $\sim$9 and 1% increase in output, respectively, *ceteris paribus*. Furthermore, this also establishes the critical role of feed and fingerlings in catfish production, and how their optimal utilization can increase production output. Feed and fingerlings were also reported to be the most significant factors that influence pangasius and tilapia production in Bangladesh (Ali et al., 2018; Rahman et al., 2019). The output elasticities of *labor* and *other inputs*, though comparatively lower, also contribute to production increases. The output elasticity of *pond size* was the least and insignificant, which indicates that increasing the size of a pond may not necessarily increase output. Alam et al. (2012) reported a negative influence of pond size on production output. The influence of *pond size* on output may be dependent on other co-inputs, as seen in the significance of its interaction with *feed* and *fingerlings* in the second-order parameters section of the model. The double interaction of *fingerlings* has a negative effect on the output. This expresses the non-linear relationship and diminishing effect that the number of fingerlings stocked has on the output which could be indicative of the negative effect of excessive stocking on output in poorly managed farms. The positive effect of the interaction between *pond size* and *fingerlings* shows ponds stocked at appropriate density would have a positive impact on output, while the negative effect of the interaction between *pond size* and *feed* implies increasing feed use due to an increase in pond size would have a countereffect on productivity. Hence, maximizing productivity through pond size is highly contingent upon the type of management. This implies that, when using a large pond, efficient management would be needed to minimize input waste while also ensuring the pond is not understocked. The interaction between *feed* and *other inputs* is positive and only significant at 10%.

Distribution of technical efficiencies

The mean technical efficiency (MTE) for catfish farming operations in Nigeria is 85.4%. The TE ranges from 32%, which is the least technically efficient, to 98%, the most technically efficient reported operation. Nevertheless, none of the farms are fully technically efficient. The MTE score of 85.4% indicates that the farmers have the scope to increase their production by 14.6% given the current technological state and input levels. If all the farms were fully technically efficient, this would result in a 14.6% production increase and an additional 42,273 metric tons of fish for Nigeria's aquaculture production based on the fish production estimate in 2019 (FAO, 2022a). Hence, by adopting the techniques used by the best practice farmer, Nigeria's aquaculture production would surpass the highest reported output of the year 2015. About 50% of the farmers have TE scores between 90 and 100% and ∼77% of them have a TE score above 80% (Figure 2). This implies that, while there is a need for improvement, most of the catfish farmers operate at the upper end of the technical efficiency range. Baruwa and Omodara (2019) and Kingsley et al. (2014) reported similar findings where ∼78% of farmers had a technical efficiency score of 80% or above.

Moreover, the MTE value in this study is close to the MTE of studies in Oyo (81%), Ondo (83%), Delta (87%), and Kaduna (85%) States in Nigeria (Ekunwe & Emokaro, 2009; Fapohunda et al., 2005; Inoni et al., 2017; Ogundari & Ojo, 2009), and also close to the nationwide average of MTEs

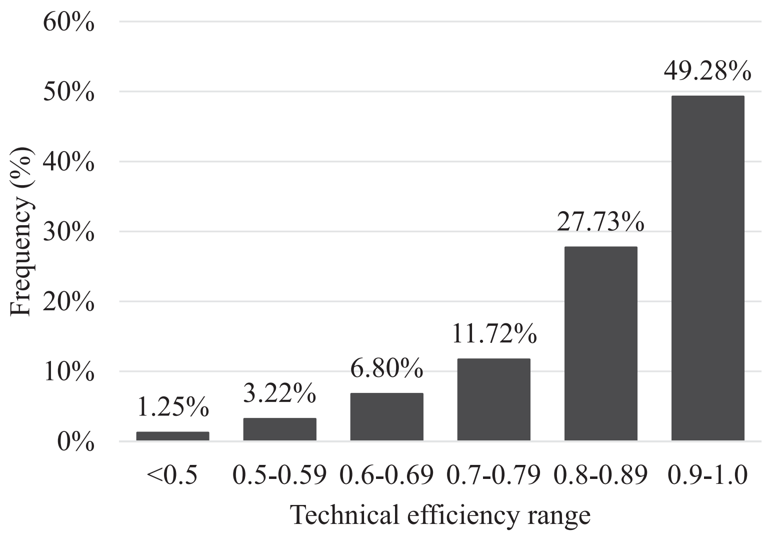

Figure 2. Distribution of technical efficiency scores.

Table 6. Review of technical efficiency studies in Nigerian aquaculture.

State	Region	Range	MTE*	References
Cross River	South	0.41–0.98	0.89	Kingsley et al., 2014
Delta	South	0.28–0.96	0.87	Inoni et al., 2017
Delta	South	0.46–0.71	0.53	Ikpoza et al., 2021
Ekiti	South	0.50–0.85	0.79	Omobepade et al., 2014
Kaduna	North	0.47–0.97	0.85	Ekunwe & Emokaro, 2009
Lagos	South	0.57–0.97	0.88	Ogunmefun & Achike, 2018
Niger	North	0.32–0.93	0.73	Ibeun et al., 2018
Ogun	South	0.30–0.90	0.99	Olayiwola, 2013
Ondo	South	0.63–0.99	0.83	Fapohunda et al., 2005
Oyo	South	0.82–0.97	0.81	Ogundari & Ojo, 2009
Oyo	South	0.41–0.90	0.74	Baruwa & Omodara, 2019
Oyo	South	0.51–0.99	0.91	Osawe et al., 2008
Rivers	South	0.52–0.99	0.76	Onoja & Achike, 2011
	Average MTE		0.81	

*Mean technical efficiency.

(81%) of some of the studies carried out across several states in the country using stochastic frontier production functions (Table 6). MTEs of 83% have been reported for tilapia production in the Philippines (Dey et al., 2000), 82.4% for shrimp farms in Bangladesh (Begum et al., 2013), 78% for tilapia production in Bangladesh (Alam et al., 2012) and 74% for pond fish production in Ghana (Crentsil & Essilfie, 2014).

Categorical analysis of technical efficiencies (production period, region, fingerling source, and pond ownership)

Farm operations during the COVID-19 period have a higher median TE than before COVID-19. The difference in the median TE for the periods, though significant at the 95% confidence interval, was however minimal. This higher median technical efficiency obtained for the COVID period indicates there were more highly technically efficient farmers producing during the period which may have been occasioned by the withdrawal of less technically efficient farms from operation during the COVID period (Appendix Figure A1). The higher TE also may have been influenced by the necessity to maximize the use of scarce resources during the period, which was occasioned by reduced access to resources experienced at the time.

There was also a significant difference in the median TE of catfish production in the different regions of the country, with the southern region being more technically efficient than the northern region. Until recent years, catfish farming was predominantly practiced in the southern part of the country and the technical knowledge of its production is believed to be well-entrenched in this region of the country (AIFP Project, 2004). This is in contrast with the findings of Rahman et al. (2019) where farms in region with large industry and more production were less efficient than those with a smaller industry. The study, however, suggested that industry size can only positively influence efficiency where technology and knowledge are communicated from farmers to farmers and in areas with high farm density (Rahman et al., 2019). This agrees with the findings of Hu et al. (2019) in Bangladesh aquaculture where regions with a high density of farmers were more efficient. A combination of these factors (knowledge and spill-over effect, and high density of farmers) in the Nigeria southern region may have, therefore, contributed to their higher technical efficiency.

Those who produce their fingerlings are less technically efficient compared to those who sourced their fingerlings externally. While this may be attributed to potential input abuse, as farmers who produce their fingerlings tend to stock more than the required number, it also poses questions about the quality of the fingerlings they produce. Ibiwoye and Thorarensen (2018) reported a prevalence of poor broodstock management practices among fingerling producers, especially those who utilized on-farm produced broodstock, which leads to poor fingerlings quality and thereby poor output. Owing to the questionable state of many local broodstocks in use, some fingerling producers opt for foreign-sourced improved broodstock, which comes at a cost but not all fingerling producers could afford this.

Another instance of inefficient use of input was among the farmers who rented their ponds. Owners of ponds used were more technically efficient and seemed to have appropriated a more proportionate amount of input to produce the resulting output. Conversely, the productivity and efficiency of cash tenant farms (non-owners) were significantly higher than self-owned farms in Bangladesh aquaculture (Mitra et al., 2022). The study attributed this to the effect of farm size as the efficiency of self-owned farms decreased as farm size increased. However, in Nigeria's case, the majority of owners are those who practice backyard farming and are therefore limited by size which may have favored their efficiency. Pond leasers should maximize the size of ponds leased such that they will be commensurate with the inputs deployed. The use of a relatively larger pond could lead to understocking, and this practice has been associated with the abuse of other inputs, such as feeds, which could make the operation not only technically inefficient but also expensive (Begum et al., 2013).

Inefficiency (model) estimates

In the inefficiency model, the positive coefficient of a farm-specific factor implies that such a factor increases inefficiency and vice versa (Table 7). The coefficients of dummies representing pond ownership, producers from the southern region, and production during the COVID period were all negative and significant in the technical inefficiency model, indicating that these factors increase technical efficiency. The coefficient of users of farm-

Table 7. The inefficiency model estimates the translog production frontier.

	Parameters	Estimate	Std. error
Inefficiency model			
Z_(Intercept)	δ_0	1.5542***	0.3634
Z_Dgenderm	δ_1	−0.2222**	0.0765
Z_Downers	δ_2	−0.2485**	0.0814
Z_Dtrainingorextension	δ_3	−0.3565***	0.1048
Z_Deductertiary	δ_4	0.1716*	0.0681
Z_Dlocalfeed	δ_6	0.2425***	0.0650
Z_Dsouth	δ_7	−0.4308***	0.1220
Z_Dcovid	δ_8	−0.1489**	0.0518
Z_Donfarmfingerlings	δ_9	0.2528***	0.0727
Z_Dmicrosmallscale	δ_{10}	0.4591***	0.1172
Z_Feed quality	δ_{11}	−1.7518***	0.5093
Z_Fingerlings quality	δ_{12}	−0.1824**	0.0613

Note: *, **, and *** denote statistical significance at the 5%, 1% and 0.1% level, respectively.

produced (on-farm) fingerlings was positive and significant, showing that the use of on-farm fingerlings decreases technical efficiency. These results agree with the comparative analysis of the TE discussed earlier. Moreover, the coefficient of the male gender was significantly negative. This implies that male farm owners are more technically efficient than female farm owners. Such a negative and significant coefficient for the male gender has been reported in other studies (Crentsil & Essilfie, 2014; Kingsley et al., 2014). However, the technical performance of the female gender may have been occasioned by additional factors. The dummy variable representing farmers that had training or access to extension services has a significantly negative coefficient, which implies that engagement in training and having access to extension services increases technical efficiency. Access to extension services and technical advice has been reported to improve the technical efficiency of fish farmers in the Kainji Lake basin and the Niger-Delta zone of Nigeria, and likewise among Ghanian fish farmers (Crentsil & Essilfie, 2014; Ibeun et al., 2018; Ikpoza et al., 2021).

The inefficiency model estimates also showed that the use of local feed reduces technical efficiency given the significantly positive coefficient of the factor. Farmers often opt for the use of locally compounded feed to reduce the costs of production. Relative to commercial feeds, a higher quantity of local feed and a longer time may be required to obtain the desired market size (Mogaji & Olafur, 2020). It is therefore a tradeoff between cost and quantity. The use of commercially produced, pelleted floating feeds was found to significantly increase technical efficiency in pangasius farming in Bangladesh (Ali et al., 2018). This also aligns with the effects of feed quality on technical efficiency—with feed price taken as an index of quality. The use of quality feed increased technical efficiency. The extra cost farmers pay for feed is to obtain the value in quality, which ultimately showed in their increased technical efficiency. This does not mean that quality local feed does not exist, but it will come at an additional cost.

The use of quality fingerlings also increased technical efficiency. Due to a lot of uncertainty expressed by farmers on the quality of fingerlings, as reflected by poor fish performance and low survival rates (Anetekhai, 2013; Digun-Aweto & Oladele, 2017; Olagunju et al., 2022), many farmers go the extra mile to procure fingerlings from sources deemed reliable but with a higher price. While the choice of paying for quality input could be based on management knowledge, it also depends on the farmer's access to finance. As the use of quality inputs has a significant positive influence on the farmers' technical efficiencies, their willingness and capacity to pay the extra cost for quality inputs could greatly affect their productivity. Government support could be targeted at assisting the farmers financially to be able to afford the procurement of quality inputs.

The coefficient of factor that represents farmers that produce below 5 metric tons of fish per annum was also positive and significant, indicating that farmers within this production range are less technically efficient and that economies of scale are important. Studies have shown that bigger farms enjoy scale benefits from several aspects of the value chain (Asche et al., 2013; Fernández Sánchez et al., 2022). Addressing the needs and capabilities of these low-scale producers has been considered a major challenge for policy makers especially in sub-Saharan Africa (Naylor et al., 2023). However, targeted training for producers within this category to increase their knowledge of management could be helpful as this would enable them to record more success and possibly increase their scale of operation, which could also contribute to the growth of the industry.

Having tertiary education did not positively impact technical efficiency. The reports on the impact of education on technical efficiency vary in studies. Some have reported a positive influence of education on technical efficiency in the farming of catfish (Ibeun et al., 2018; Olayiwola, 2013; Singh et al., 2009), while Alam et al. (2012) observed no significant effect on technical efficiency. Kingsley et al. (2014) found a negative influence in a study of fish farms in Cross River State, Nigeria. While education has the potential of increasing a farmer's openness to knowledge which may eventually impact efficiency, the current study indicates that having tertiary education may not necessarily impact production efficiency. The technicality of aquaculture, however, intimates that a basic level of education would be helpful for farmers to properly use their acquired practical skills.

Marginal effects of inefficiency variables

The estimated parameters of the inefficiency variables only provide the direction of inefficiency, but not the size of the effects of these variables. The marginal effects of the inefficiency variables were calculated using the

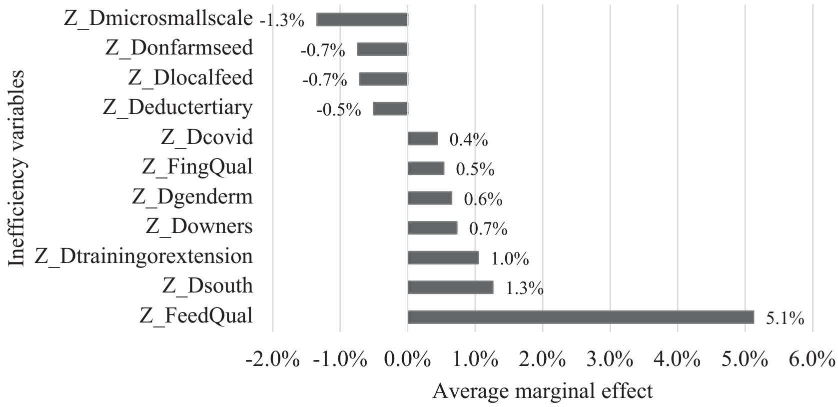

Figure 3. Average marginal effects of inefficiency variables.

formula given by Olsen and Henningsen (2011) estimated with the "frontier" package in "R" (Coelli & Henningsen, 2013). Variables, such as feed quality, farmers in the southern region, engagement in training or utilization of extension service, male farm managers, fingerlings quality, and production during the COVID period have a positive marginal effect on TE, while other variables produce negative effects (Figure 3). The group of catfish farmers that produces 5 metric tons and below (micro-small scale) has the highest negative marginal effect on TE. This indicates that, on average, a farm that belongs to this group achieves, *ceteris paribus*, 1.3 percentage points lower technical efficiency and, thus, at least 1.3% less output than a farm that does not belong to this group.

On the other hand, the use of quality feed has the highest marginal effect (5.1%) on TE. An increase in the use of quality feed will increase the technical efficiency of farms by 5.1%, *ceteris paribus*. This is followed by marginal effects of variables for farmers in the southern region (1.3%) and those who participate in training or utilize extension service (1%). Access to training or extension services features among the variables with the most positive impact on TE as these attributes improve the management skills and capacity of farmers. This high marginal effect of extension services on TE was also presented in a study of fish farmers in southern Nigeria (Oyo State), where it was reported to have the highest marginal effect (8%) on TE, followed by access to credit (5%) (Ogundari & Ojo, 2009). In the present study, the cumulative marginal effect of the use of quality input, calculated at the sample mean, takes 5.6% out of the total 9.8% cumulative marginal effect of variables with a positive impact on TE, *ceteris paribus*. This has important implications for catfish farmers given the magnitude of the effect of the use of quality input. It means that low-skilled farmers, who probably do not have access to extension services or training, can leverage the use of quality inputs to optimize their production. However, farmer's access to credit is critical to this as it will enhance the affordability of quality input. Empirical studies indicate that access to credit increased the productivity of aquaculture farmers in Bangladesh (Mitra et al., 2019), improved the technical efficiency of shrimp farmers in Vietnam (Long et al., 2020), and enhanced both the economic performance and productivity of Ghanian fish farmers (Ankrah Twumasi et al., 2023).

Conclusion and policy recommendations

An average catfish farm in Nigeria operates with a slightly increasing return to scale. This means that the deployment of more production resources by catfish farmers would increase the benefits that could be derived. Fingerlings, feed, labor, and other inputs have a significant and positive impact on the production of catfish, while increasing the size of a pond may not necessarily increase output. However, the second-order interaction shows that ponds stocked at an appropriate density and given proportionate use of other co-inputs would lead to increased outputs. This implies that a holistic management approach is needed to improve the efficiency of catfish farming operations. Generally, the farms are fairly efficient as the mean TE for the catfish farming operations in Nigeria is 85.4%, which implies the farmers could increase their production by 14.6% given the current technological state and input levels and contribute additional 42,273 metric tons of fish to Nigerian aquaculture production. Improving technical efficiency can thus serve to boost fish production.

Moreover, there is variation in the technical efficiencies of the different periods and regions compared. When separate models with the same specification and variables for the two periods (pre-COVID and COVID) were estimated and the coefficients of the parameters of the two independent translog models compared, it showed no significant difference. This suggests that the production processes of the farms were similar during both periods. However, a significant difference was observed when the median technical efficiency of both periods was compared. A significantly higher median technical efficiency obtained for the COVID period indicates there were more highly technically efficient farmers producing during the period. This was supported further by the result of the inefficiency model which showed production during the COVID period has a significant positive marginal effect on technical efficiency. Though this was associated with the withdrawal of mostly inefficient farms during the pandemic, it also implies that catfish farmers require more support during emergency periods, both technically and through input provision, since such interventions would minimize negative impacts on the food system and farmers' livelihoods.

Catfish farmers in the southern region are, on average, more technically efficient than in the northern region. Comparing our observations in the current study with the 2004 AIFP survey (AIFP Project, 2004) shows there is an increasing number of fish farmers involved in catfish production in the northern region (Appendix Figure A2). It is therefore important to further strengthen the skills and expertise of catfish producers from this region through capacity building.

Generally, the enhancement of the technical capacity of Nigerian catfish farmers will boost their efficiency and productivity. Engagement in training and access to extension services improved technical efficiency significantly and has a high marginal effect on the TE. The earlier growth of catfish farming in Nigeria was greatly driven by a series of training provided by the Federal Department of Fisheries with the support of partner organizations, which was accompanied by guides and manuals (Anetekhai, 2013).

Improvement of technical efficiency is not only a question of management approaches but also the use of quality inputs. The use of quality inputs significantly increased the technical efficiencies of the catfish farm operations under study and has the highest cumulative positive marginal effect on TE (5.6 out of 9.8%). The good implication of this to farmers is that low-skilled farmers, who probably do not have access to extension services or training, can leverage the use of quality inputs to optimize their production. However, the use of quality inputs comes at a price. Therefore, there is a need for increased access to finance for the farmers to afford these quality inputs and consequently increase their productivity (Ankrah Twumasi et al., 2023; Mitra et al., 2019). Farmers could also be assisted in this respect by providing these quality inputs through the input support programs of the government or by increasing their access to cheaper long-term loans.

For a sustainable supply of quality fingerlings, there is a need to initiate a breeding improvement program for the catfish industry to improve the quality of the broodstock. Currently, due to the poor quality of the local stocks, some of the high-value fingerlings that the farmers opt for are either produced from imported broodstock or crossbred with the local stocks. There is therefore an urgent need to commence a well-strategized breeding program for the African catfish of Nigeria that will have a broader long-term impact on the domestic and African industry.

Note

1. Numerous studies have also examined technical efficiency and productivity in aquaculture production in various other countries (Aponte, 2020; Aripin et al., 2020; Hukom et al., 2022; Kularatne et al., 2019; Mussa et al., 2020; Ngoc et al., 2023; Rahman et al., 2020; Sanchez et al., 2020).

Acknowledgments

We are grateful to the catfish farmers, fish feed suppliers, and government officers who provided farmers' lists and valuable information through questionnaires and interviews. We would like to thank the enumerators for their painstaking efforts in data collection. Comments from the editor and the two anonymous reviewers are gratefully acknowledged.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the UNESCO GRO-Fisheries Training Programme and Rannsóknasjóður Háskóla Íslands/The Doctoral Grants of the University of Iceland Research Fund.

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Appendix

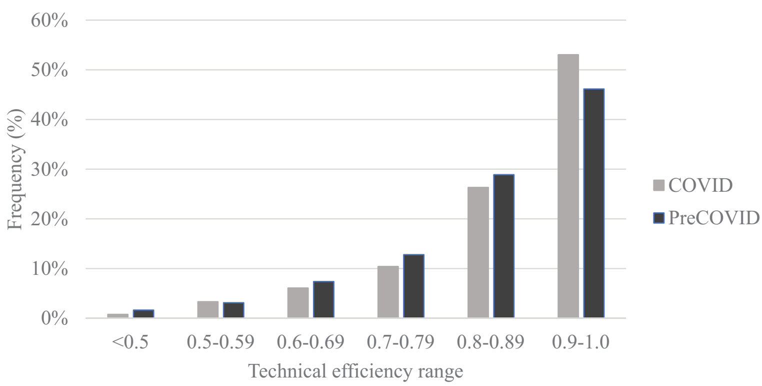

Figure A1. Technical efficiency range of farm operations during pre-COVID and COVID periods.

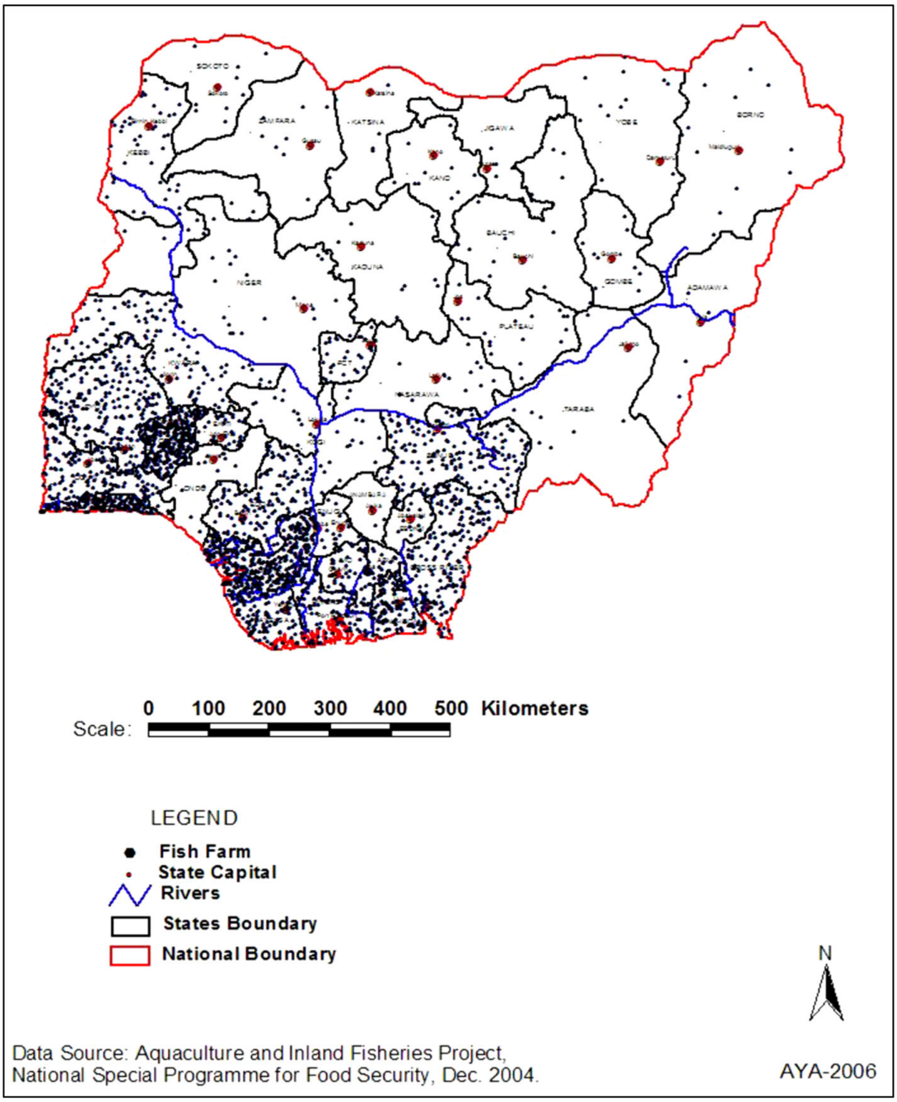

Figure A2. Fish farm distribution in Nigeria is based on a 2004 field survey of the AIFP project (Abdullah, 2007).

Paper III

Received: 10 November 2023 | Revised: 15 January 2024 | Accepted: 24 January 2024

DOI: 10.1111/jwas.13058

ORIGINAL RESEARCH

Journal of the World Aquaculture Society Open Access | WORLD AQUACULTURE Society | WILEY

Farm strategies and characteristics influencing profitability in Nigerian catfish aquaculture: Lessons on resilience during economic crisis and COVID-type shock

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Funding information
UNESCO GRO-Fisheries Training Programme, Iceland; the Doctoral Grants of The University of Iceland's Research Fund

Abstract

Since the early 2000s, aquaculture in Nigeria has grown exponentially. African catfish aquaculture was a major contributor to this expansion. However, a fall in output started in 2015, mostly due to challenging economic conditions which affected farmer's profitability. This challenge has been exacerbated by the COVID-19 pandemic. Notwithstanding, some catfish farms remained profitable. This study investigates the profitability strategies that aid farmers' resilience in times of both economic distress and COVID-type shock. Data from 609 randomly sampled farms across the country were verified and included in the study covering 1118 operations for the pre-COVID and COVID periods. Budgetary analysis was done, and stepwise regression was used to identify factors that most contribute to profitability. These factors were ranked by average profit per kilogram and grouped. The profitability during the periods was influenced by factors within the subcategories of scale of operation, experience, targeted markets, ownership, and pond type. Engagement in other agricultural ventures favored profitability during the COVID period. Profitable and non-profitable groups were further characterized based on their technical and financial indicators. Explored strategies for profitability, including the operation scale, marketing tactics, cost-cutting, and innovative production techniques all proved successful during economic distress and the pandemic.

KEYWORDS

catfish farming, COVID-19, economic crisis, market strategies, Nigeria, profitability, resilience

1 | INTRODUCTION

The expansion of aquaculture in Nigeria has largely been driven by the farming of African catfish (Figure 1a, FAO, 2022). It is the preferred species for most commercial farming because of its high consumer preference (Dauda et al., 2018). The African catfish (Figure 1b) is very tolerant to extreme environments and reared widely, from the southern rainforest to the middle savannah and the northern semi-arid region.

Catfish production has played a prominent role in various inter-governmental and national drives and policies aimed at boosting domestic fish production. These efforts include the resolutions of the NEPAD[1]-Fish for All Summit, which aimed to underscore the crucial role of fisheries and aquaculture in Africa's development, as well as the National Aquaculture Development Plan (2011), charting the course for Nigeria's aquaculture growth. Additionally, the Sustainable Aquaculture System for Nigeria (2010–2011) aimed to empower catfish farmers for increased productivity (Abdullah, 2011; NEPAD, 2005; Omonona, 2011). Notable subsequent programs included the Growth Enhancement Support Scheme (GESS) (2013–2014) an input support program, and the backward integration policy of the government, which encouraged fish importers to embark on fish farming as a mark of commitment to the government policy of increasing domestic fish production. Consequently, the aquaculture sector in Nigeria, particularly catfish farming, has witnessed substantial investments across all scales of operation, both domestic and foreign.

However, the influence of these initiatives on the sector's growth has been diminishing as aquaculture production started to decline from 2015. This can be attributed to several reasons, ranging from the increasing cost of inputs to issues with the quality of inputs, such as broodstock, fingerlings, and feed (Digun-Aweto & Oladele, 2017; Edema-Sillo et al., 2017). While all of these remain substantive, this production decline is not unconnected with the economic recession experienced between 2015 and 2016 in the country (Olomola & Nwafor, 2018).

Nigeria's aquaculture sector has been severely affected by the economic crisis and does not seem to have recovered from its effects. In Nigeria, this economic crisis was associated with a devaluation of the Naira, which significantly influenced the cost of production. The aquaculture sector experienced consistent growth during a period of a relatively stable exchange rate (2004–2014) and the decline began when a rapid depreciation of the Naira value set in (Figure 2). Naira devaluation has been shown to affect Nigeria's fisheries and aquaculture production negatively (Obekpa et al., 2020). Another study has established that a stable exchange rate positively impacts agricultural growth in general (Djomo et al., 2017). This is mostly because of the effect of the exchange rate on the cost of production. Catfish production is capital-intensive, and the cost of production is mainly influenced by fish feed prices as

[1]New Partnership for Africa's Development.

(a)

(b)

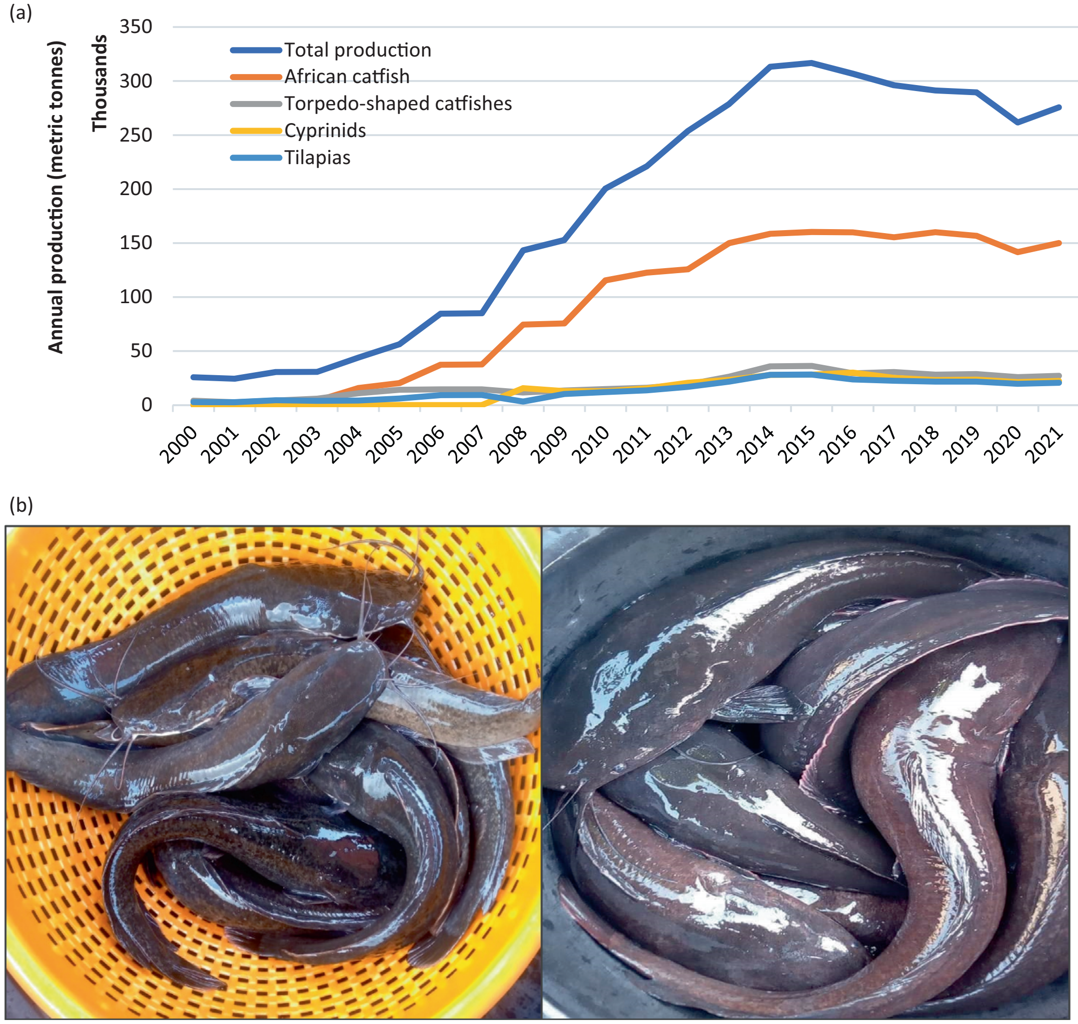

FIGURE 1 (a) Annual aquaculture production trend in Nigeria from 2000 to 2021 featuring top four species (FAO, 2022). (b) The African catfish. "Photo courtesy: Left – Oluwadamilola Adebayo, Oyo State; Right – Joseph Anteyi, Benue State".

it accounts for more than 70% of the cost of production. Like imported feed brands, prices of commercial feeds produced in Nigeria are also influenced by the exchange rate because they rely on importation for their major ingredients, particularly the protein components. The farm gate price of catfish was between 500 and 600 Nigerian Naira from 2011 to 2018, and farmers lamented this unchanging farm gate price over the years (Table 1) (Alagoa et al., 2011; Anetekhai, 2013; Dauda et al., 2018; NAERLS and FDAE, 2015). A surge in the exchange rate, not accompanied by a corresponding increase in product prices as observed in 2015, would negatively impact the sector, lowering farmers' profits. This shows that the catfish industry is highly susceptible to economic pressures that impact profitability and, eventually, farmers' production.

In recent years, the world has been faced with a series of stresses and shocks ranging from the Coronavirus Disease (COVID-19) pandemic to the spillover effect of the war in Ukraine, fuel price hikes, inflation, and increases in commodity prices, all with their attendant economic impact. All these emphasize the need to understand what

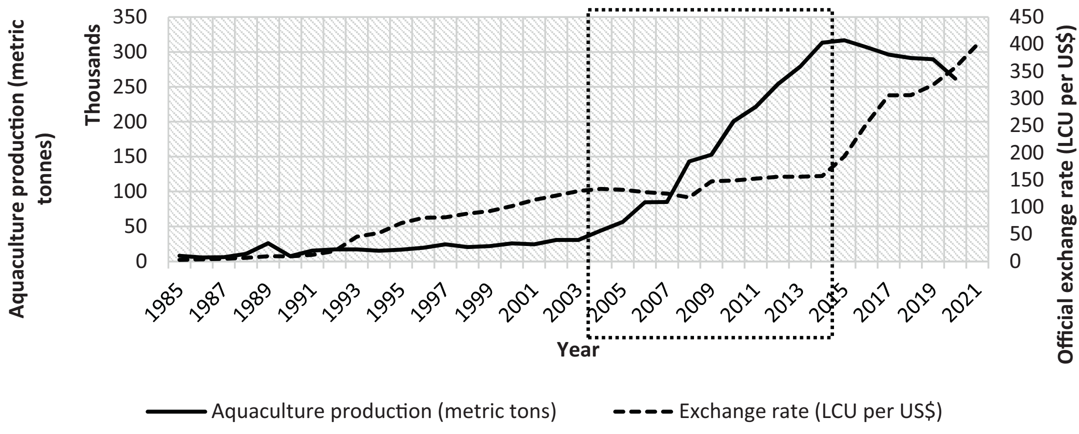

FIGURE 2 Trends in aquaculture production and official exchange rates in Nigeria. The dotted box represents the period of the relatively stable exchange rate (World Bank, 2023). "The DEC alternative conversion factor is the underlying annual exchange rate used for the World Bank Atlas method. As a rule, it is the official exchange rate reported in the IMF's International Financial Statistics. Exceptions arise where further refinements are made by World Bank staff. It is expressed in local currency units per U.S. dollar" (World Bank, 2023).

TABLE 1 Prices of catfish in Nigeria from 2009 to 2019.

Year	Farmgate price in naira	Retail price in naira	Literature
2009	340	400–450	(Veliu et al., 2009)
2011	500–550	700–1000	(Alagoa et al., 2011)
2013	500	–	(Anetekhai, 2013)
2017	–	700	(Dauda et al., 2018)
2019	550–650	700–800	(Olagunju et al., 2022)

strategy could be helpful to thrive in such a time as these for the world at large and the aquaculture sector specifically. Since the pre-COVID economic crisis, many Nigerian catfish farmers have been struggling in business, while some have left the business because of the unfavorable economic conditions. Nevertheless, a preliminary study conducted in 2019 indicated that there were still profitable farms within the system (Olagunju et al., 2022). The subsequent emergence of the COVID-19 pandemic posed a further shock to the system due to the lockdowns leading to disruptions in supply chains, fluctuating commodity prices, shift in market demand and uncertainty in planning and decision making which affected many businesses, including catfish farmers. The period also brought about lingering effects that many countries and establishments have yet to recover from. Therefore, using the pre-COVID period (post-2015 economy) in Nigeria to represent a distressed economy and the COVID period as an added shock, this study examines the different factors that aid farmers' profitability in times of both economic distress and shock and explores the strategies that contribute to the resilience of profitable farms during these times. Using socioeconomic factors, budgetary analysis, and profitability indicators, this study assessed the profitability dynamics of catfish production in Nigeria before and during COVID-19, drawing lessons on strategies that contribute to resilience during difficult times.

2 | METHODOLOGY

2.1 | Study area and data collection

A multi-stage sampling method was used. Ten states in Nigeria were purposively selected from different geopolitical zones, considering the production capacity of the different states and the need for national coverage (Figure 3). The collated lists of catfish farmers obtained from both government and non-government sources (farmers associations and fish feed marketers) in each state were utilized, and the farmers were randomly selected from the lists for survey. Data collection was carried out through pre-trained enumerators from May 2021 to February 2022, covering production data from both the pre-COVID and COVID economic periods using an electronic questionnaire–open-data-kit (ODK). The pre-COVID data covers the most recent production and economic data for the farms before 2020 while COVID period data were from 2020 and 2021. Data from 609 farms were verified and validated for inclusion in this study reporting 609 operations for pre-COVID and 509 for COVID-19 period (Table 2). The pre-COVID and COVID period data were collected in a single survey while farmers who did not produce during COVID only reported for the pre-COVID period. Although the survey data and feedback from enumerators indicate that a substantial number of farmers ceased farming activities during the COVID-19 pandemic, only 50 can be directly attributed to farmers' withdrawal during COVID-19. The rest of the reduction is due to the absence or incompleteness of data collected. Hence our data does not precisely suggest the percentage of farmers who either continued or stopped producing during COVID-19. The predesigned questionnaire in the preliminary study (Olagunju et al., 2022) was modified and improved to address the specific objectives of the current study. The questionnaire was pre-tested and improved accordingly. Other details on the data collection procedure have been reported (Olagunju et al., 2023, 2024).

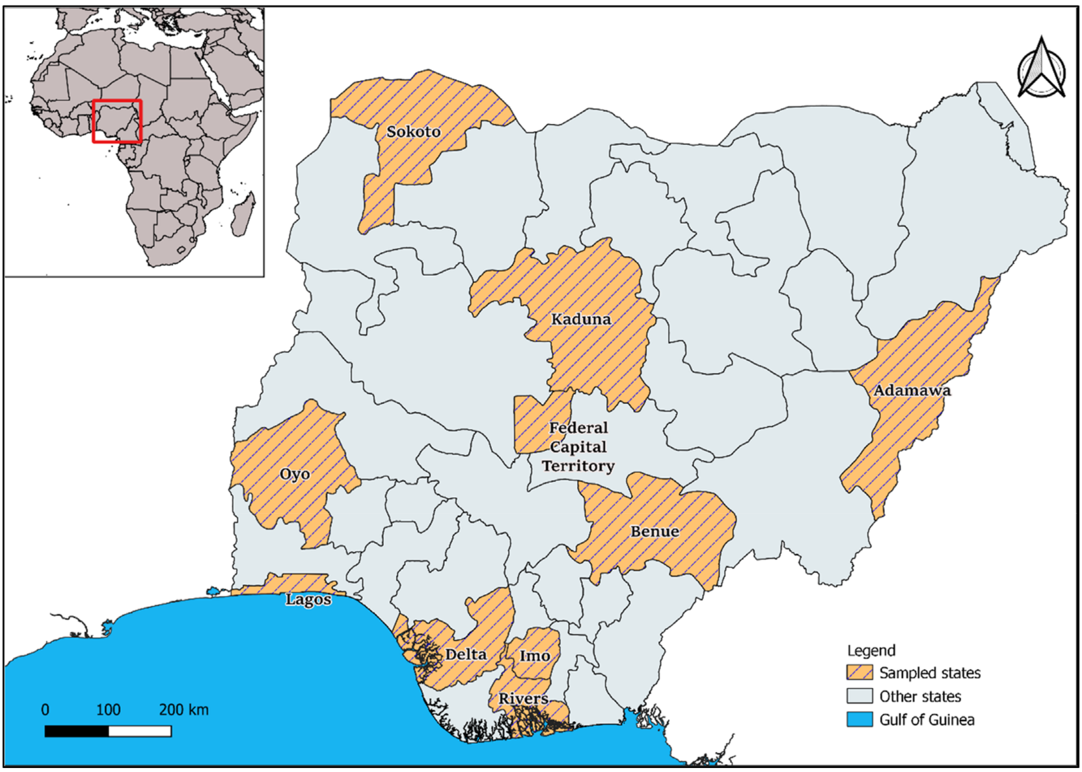

FIGURE 3 Geographical map of the Federal Republic of Nigeria showing the states included in the present study.

TABLE 2 Number of samples collected for the Pre-COVID and COVID periods in the states included in the study.

Region/state	Pre-COVID	COVID	Grand total
North	281	235	516
Adamawa	64	52	116
Benue	52	34	86
FCT	62	59	121
Kaduna	57	44	101
Sokoto	46	46	92
South	328	274	602
Delta	72	60	132
Imo	46	44	90
Lagos	74	57	131
Oyo	72	55	127
Rivers	64	58	122
Grand total	609	509	1118

Source: Field survey (2021/2022). Adapted from Olagunju et al. (2023).

2.2 | Data analysis

2.2.1 | Overall technical and financial assessment using budgetary analysis and technical indicators

The average technical and financial performance of catfish producers during the pre-COVID economic crisis and the COVID-19 (shock) period was assessed for an overall outlook of the sector's performance during these periods. The technical indicators assessed included the Feed Conversion Ratio (FCR), fingerlings per kg output, labor (in man-days) per kg output, and technical efficiency estimates of the farms obtained from the national study on technical efficiency from the same survey (Olagunju et al., 2023). Technical efficiency measurement evaluates a farmer's capacity to generate the maximum output with a given set of resources. Efficiency is typically rated on a scale from 0 to 1, with 1 representing perfect efficiency. Budgetary analysis was used to assess the financial performance of the farms for different periods. Table 3 shows the equations used to estimate the cost and returns, as well as the different measures of profitability used, including net farm income (NFI), return on investment (ROI), and operating profit margin (OPM) ratio. These provide wide coverage of economic assessment (Dauderis & Annand, 2014). All data obtained and their estimates were obtained for a single production cycle. The technical and financial indicators were estimated based on per kilogram of farm output. Student's *t*-test was conducted to test the difference of the means of the indicators across the two periods, and for indicators which did not satisfy the equal variance assumption of the Student's *t*-test, Mann–Whitney test was used.

2.2.2 | Identifying profit-influencing categories using stepwise regression analysis

The utilization of appropriate variable selection methods is paramount when constructing robust predictive models. Stepwise regression is usually used in such situations to select variables that significantly contribute to explaining

TABLE 3 Equations used in the cost and return estimates.

Costs estimates	
Total cost = Variable costs + Fixed costs	
Variable costs = Cost of fingerlings, feed, labor, and others (transport, treatment, water, maintenance, electricity, etc.)	
Fixed costs = Cost of depreciation[a], Land lease (Rental value of pond)	
Cost kg^{-1}fish = Cost/total harvest	
Revenue = Total harvest × farm gate price	
Revenue kg^{-1} fish = Revenue/ Harvest = Price	
Returns and profitability ratios	
Net Farm Income (NFI) = Total revenue–Total cost	
Return on Investment (ROI) = (Net Farm Income/Total cost) × 100	
Operating Profit Margin Ratio = ([Total revenue–Total cost]/Total revenue) × 100	

[a]Prime cost depreciation rate was estimated for owned ponds.

TABLE 4 Scale characterization of sampled catfish farms.

Operation scales	No. of farms: Pre-COVID	No. of farms: COVID period	Annual production capacity (tonnes/year)
Microscale	314	272	<5
Small scale	183	162	5–10
Medium scale	97	66	>10–30
Large scale	15	9	>30
Total	609	509	

Source: Field survey (2021/2022).

the variation in the dependent variable. In this study, stepwise regression was used to identify the main categories of variables that have a predominant effect on profit. To achieve this, several socioeconomic and operational variables were regressed against the profit per kilogram (using the NFI/kg) as the dependent variable in a stepwise regression. These variables are different subcategories of gender, age, education, years of experience, scale of operation, market type, pond type, source of fingerlings, farm type, main occupation, feed usage, ownership, labor characteristics (hired/household), and region (north/south). Most of the subcategories are self-explanatory, but those under the "operation scale" category are defined in Table 4. The most critical subcategories affecting profits were determined using a backward elimination method in a stepwise regression analysis that employed the Akaike Information Criterion (AIC) using the R statistical package. The significant level for removal of a variable from the model is $p < 0.05$ (Full model in Appendix 1). Backward stepwise regression is a useful method for refining models with an initial abundance of potential predictor variables. It begins with a comprehensive model and systematically eliminates variables that are extraneous and/or do not significantly contribute to explaining the dependent variable's variance. Through this it handles multicollinearity and facilitates the creation of a more parsimonious model while also addressing overfitting, a concern wherein a model exhibits an exceptional fit to the training data but falters in generalizing to new data (Heiberger & Holland, 2015; Heumann et al., 2016). This further enhances the stability and interpretability of the regression model. Backward stepwise regression was thus used to select the primary categories used for further analysis using the 49 predictors included in the full model.

2.2.3 | Ranking of factors by profit and characterization of factors based on technical and financial indicators

In the next step, having identified the main categories to be considered for further assessment, to differentiate the subcategories with high-profit value from those with low-profit value, all the subcategories (also referred to as factors) were ranked based on the average profit per kg from the highest to the lowest. To understand the technical and financial characteristics of these ranked factors, the average technical and financial indicators relating to each factor were provided alongside the ranked factors (Tables A1 and A2). Moreover, it is likely for a factor to be adjudged profitable so long the average profit per kg is positive, but this may not be high enough for a person to be willing to engage in an enterprise or consider such an enterprise to be performing well (Engle, 2010). Hence, the average profit per kg of each factor was assessed in comparison with the overall average by calculating the relative average. This indicates the relative closeness or deviation from the overall average estimate. In addition, the relative average of each technical and financial indicator for the factors was estimated. To detect the existing pattern in the technical and financial characteristics of the ranked factors, the table was further analyzed using the heat map (grayscale) gradients to indicate the degree of closeness and deviation from the relative average. Based on this, the technical and financial performance relating to the factors were assessed. All analyses were carried out for both the pre-COVID economic period and the COVID-19 (shock) period. The stepwise regression was carried out using the "Stats package" in "R" while other analyses were performed using Microsoft Excel.

3 | RESULTS

3.1 | Technical and financial performance of the farms in both periods

The average production per farmer during COVID-19 dropped to 2832 kg as compared to 3681 kg in the pre-COVID period (Table 5). The overall average technical performance of the COVID period, however, was better, as indicated by the comparatively lower FCR (1.22) and fingerlings per kg (1.66) and a comparatively higher mean technical efficiency of 0.86, whereas the FCR, fingerlings per kg, and technical efficiency for the pre-COVID period were 1.25, 1.74, and 0.85, respectively. However, the labor per kg for the pre-COVID period was lower (0.33) than that for the COVID period (0.37).

An analysis of the profitability of catfish production during the pre-COVID and COVID-19 economic periods reveals that the average NFI (Profit) for the pre-COVID period was 127/kg and the COVID-19 period was 159/kg. The average profit for the COVID period was higher despite the higher production cost of 778/kg as the average catfish price during the period was also higher (938/kg) compared with the pre-COVID values of 638/kg and 765/kg for total cost and catfish price, respectively. Notwithstanding, the business during the pre-COVID period could be reckoned to be better given the averagely higher ROI (29%) and OPM (14.84%) compared to the 28% ROI and 12.11% OPM of the COVID period. Similarly, when factoring in the different exchange rates of the periods, it was observed that despite the higher nominal NFI during the COVID period, the adjusted value indicated reduced profitability. The devaluation-adjusted profit value for the pre-COVID period stood at $0.42, while during the COVID period, this decreased to $0.41.

3.2 | Categories and factors with the most impact on profit

The factors that most impacted profit in different periods are listed in Table 6. During the pre-COVID economic crisis, the production scale, years of experience, farm ownership, major market targeted, and source of fingerling categories were critical to the profitability of the enterprise, given the selection by stepwise regression. Under these

TABLE 5 Average technical and budgetary estimates for the pre-COVID economic period and the COVID economic period.

	Pre-COVID ($n = 609$)				COVID ($n = 509$)			
Indicators	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**
Production per farmer (kg)	3681.12[a]	5031.53	38.5	40,000	2831.64[b]	3622.28	33	28,000
Technical Efficiency	0.85[a]	0.12	0.315	0.983	0.86[b]	0.11	0.345	0.976
Feed Conversion Ratio (FCR)	1.25[a]	0.32	0.59	3.57	1.22[a]	0.29	0.73	3.24
Fingerlings per kg	1.74[a]	1.14	0.28	11.54	1.66[a]	0.98	0.33	8.63
Labor (man-days per kg)	0.33[a]	0.56	0.01	5.91	0.37[a]	0.57	0.01	6.14
Variable cost/kg	627.81[a]	198.01	262.88	1942.86	765.26[b]	227.26	355.77	2096.97
Fixed cost/kg	10.38[a]	29.76	0.13	530.77	12.90[a]	35.64	0.22	541.18
Total cost/kg	638.19[a]	207.66	263.59	1953.17	778.15[b]	241.86	357.01	2172.73
Price (Revenue/kg)	764.78[a]	139.37	161.54	1300	937.63[b]	199.10	84.99	1941.56
Profit (Net Farm Income/kg)	126.60[a]	224.27	−1153.2	863.41	159.48[b]	295.82	−1221.8	933.71
Return on Investment (ROI) (%)	0.29[a]	0.39	−0.63	2.61	0.28[a]	0.37	−0.91	1.41
Operating Profit Margin (OPM) (%)	14.84[a]	28.75	−169.63	72.33	12.11[a]	57.81	−1075.5	58.52

Note: Mean values followed by different superscript letters indicate significant difference ($p < 0.05$). Financial estimates were in per kg harvest (pre-COVID, \$1 = 306; COVID \$1 = 393 average exchange rates for the periods reported (Central Bank of Nigeria, 2023)). For production per farmer, price and profit, Brown-Forsythe test was significant ($p < 0.05$), suggesting a violation of the equal variance assumption of the student t-test. However, using Mann–Whitney test, the difference between the groups was still significant ($p < 0.05$).

TABLE 6 Stepwise regression result to identify profit-impacting factors and the categories to be considered for further analysis.

Variables		Pre-COVID		COVID	
Category	Sub-category (factor)	Estimate	SE	Estimate	SE
	(Intercept)	131.77***	21.37	140.18***	30.29
Scale	Microscale	−119.05***	16.80	−110.81***	24.28
Experience	11–15 years	87.61***	25.66		
Experience	16 years and above	107.16***	27.28		
Farm ownership	Owned	79.67***	20.47	129.1***	30.49
Major market	Individuals	124.17***	29.11	127.21**	44.36
Major market	Retailers	−148.3***	20.68	−164.58***	30.30
Fingerlings source	On Farm	−56.57**	20.31		
Main occupation	Other Agric Ventures			154.28***	41.37
Major market	Restaurants or hotels			131.27*	51.33
Pond type	Concrete pond			−63.18*	25.09

Note: *, ** and *** denote statistical significance at the 5%, 1%, and 0.1% level, respectively.

categories, certain factors possess a positive influence on profitability, such as having more than 10 years of experience, owning a farm, and selling to individual buyers. Conversely, factors such as being a micro-scale producer, relying on retailers as a major market, and producing own fingerlings negatively impacted profitability. Moreover, years of experience and the source of fingerlings do not have a significant influence on the farm's profitability during the shock period. Other factors, such as having other agricultural ventures as the main occupation and use of concrete ponds, were shown to have significant positive and negative impacts on profit, respectively. Selling to restaurants and hotels under the market category was also seen to have a high and positive effect on profit during COVID-19.

3.3 | Ranking and clustering of factors into profitability groups

All the subcategories (factors) under the selected categories were ranked based on the average profit per kg. The factors are micro, small, medium, and large for production scale; 5 and below, 6–10, 11–15, and 16 and above for years of experience; owners and renters for farm ownership; bulk buyers, retailers, processors, individuals, and hotels & restaurants for major market targeted; and production on farm and other farms for source of fingerlings. The unique factors of the COVID period were added as additional factors for consideration in the ranking.[2] Based on this ranking, the factors can be grouped into three major groups according to their distance or closeness to the overall average: the very profitable group, the moderately profitable group, and the less profitable group (Table 7). In addition, for the pre-COVID economic period, the profitability of the farms decreased with a decrease in years of experience and operational scale, with the least experienced and lowest operational scale having an average profit far below the overall average (Figure 4a). Farmers targeting individual markets were most profitable, followed by those targeting restaurants and hotels, and then those selling to bulk buyers, processors, and retailers. Farm owners were also more profitable than those who rented, whereas those who externally sourced fingerlings were more profitable than those who produced their own. While profit still increased with experience and owners were more profitable during the

[2]Due to their observed significance during COVID period, only the "Other Agric Ventures" and "Concrete Pond" groups were included from Main Occupation and Pond Type categories. Other main occupations surveyed include fish farming, civil servant, private employee, personal business, and other non-agricultural enterprise, while other pond types surveyed include earthen pond and mobile ponds.

TABLE 7 Identified distinct groups from the ranked factors based on their profit in relation to the overall average and the pattern in the color scale.

Group	Ranking	Profit in relation to the overall average	Strategy characterization by color scale	Associated factors
A	Highly profitable	Far above average	Very diverse	Scale (Large, medium, and small), Experience (11 to 15 & 16 and above years), Market (Individual, Restaurants, and hotels), Main occupation (Other Agric Ventures)
B	Moderately profitable	Close to average	Less diverse	Market (Bulk buyers/off-takers, Processors), Ownership (Owners), Fingerlings source (On farm & Other farms), Experience (6–10 years)
C	Less or not profitable	Far below average	No diversity	Scale (Micro-scale), Experience (5 years and below), Market (Retailers), Ownership (Renters), Concrete Pond users

Note: The shock period created instability in the order of many of the ranked factors which made processor as a factor drop to the lowest profitability rank group during the shock (COVID) period.

COVID, the order was different for operational scale as the profit of the large-scale producers decreased below that of the medium-scale producers (Figure 4b). Similarly, farmers targeting restaurants and hotels were the most profitable, followed by those targeting individual markets. The order was also changed for fingerling producers, as those who produced their fingerlings were more profitable during this period. Being involved in other agricultural ventures ranked among the highest profit-determining factors, but only featured during COVID. In addition, during this period, users of the concrete ponds were less profitable. On average, those who targeted retailers as the main market had negative profits and remained negative the farthest away from the overall average during both periods.

3.4 | Characteristics of the different profitability groups

What then characterizes the profitable factors from the less or non-profitable factors in these two periods? Table 8a,b present the color-scale pattern for the relative average value of the technical and financial indicators for the different factors. Indicators such as FCR, fingerlings per kg, labor per kg, and all the cost indicators are expected to be below average for good performance, while for technical efficiency, profit, price, ROI, and OPM, values above 1 indicate good performance. As the grayscale pattern indicates, each of the 3 profitability groups shares a characteristic that associates them together. The highly profitable factors (group A) adopted different strategies to achieve profitability as expressed by the diverse color variations in their technical and financial indicators, while the moderately profitable group (B) are, however, less diverse, and the less or not-profitable factors lack varied patterns. The technical performance of the less or not-profitable factors (group C) was generally poor with the technical efficiency mostly below average and all the input management indicators above average. The financial performance of this group is also poor as they mostly incur high costs and average prices. Farms that share these characteristics include the producers that operate microscale, the least experienced, renters, and those that consider retailers as their major target market.

The technical and financial characteristics of the highly profitable group are, however, dynamic. Factors in this group include the high-scale producers (producing 5tonnes and above), highly experienced producers (11 years and above), those that sell their products mainly to individuals, those that sell mainly to restaurants and hotels, farm owners, and more specifically to the shock period is the factor representing those that have other agricultural ventures as their main occupation. The high-scale producers had a good technical performance with most of the input

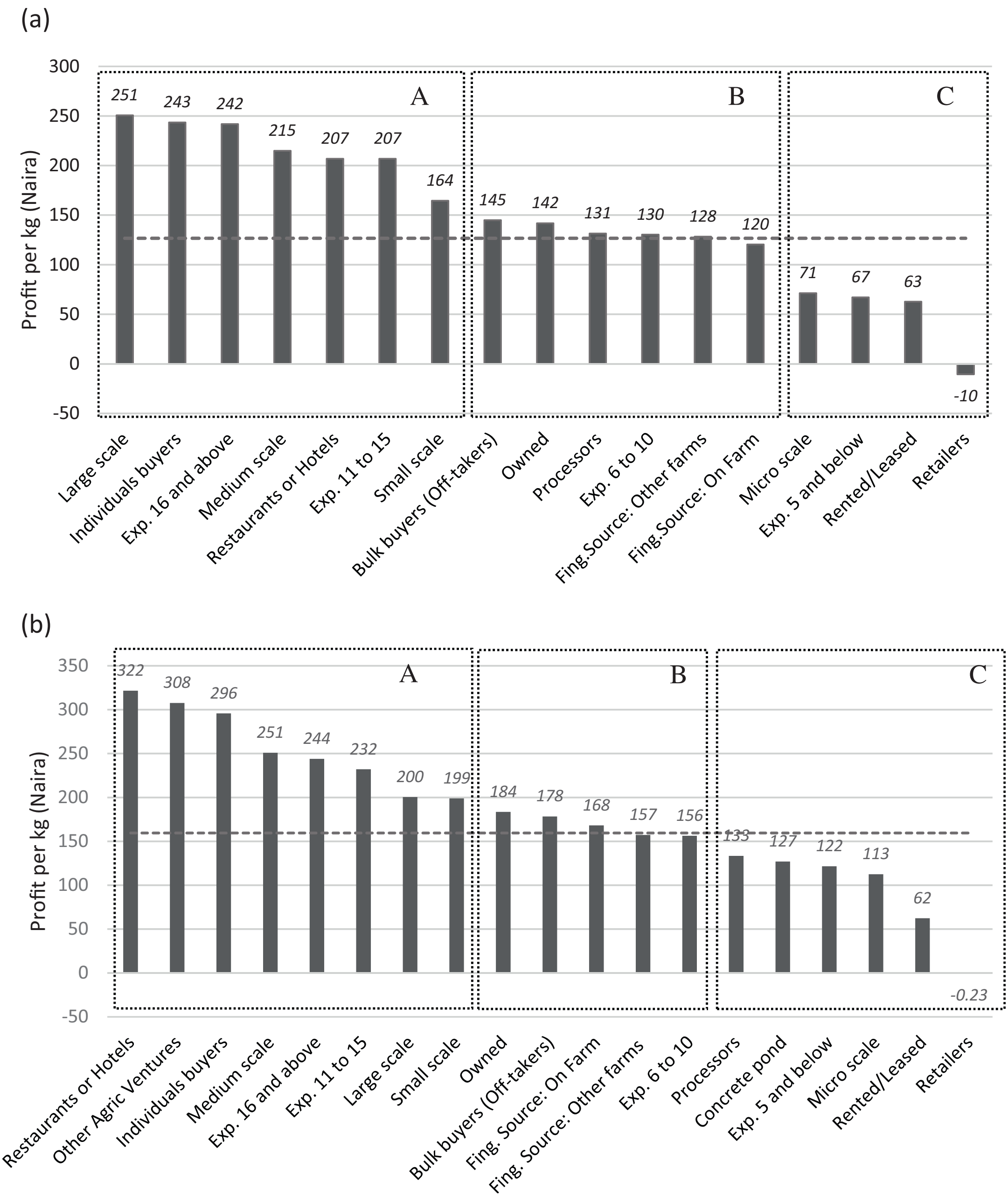

FIGURE 4 (a) Ranked average profit per kg estimates for the factors (pre-COVID). The broken horizontal line indicates the overall average value. The boxes are for different profitability groups (A = Highly profitable, B = Moderately profitable, C = Less or not profitable). (b) Ranked average profit per kg estimates for the factors (COVID). The broken horizontal line indicates the overall average value. The boxes are for different profitability groups (A = Highly profitable, B = Moderately profitable, C = Less or not profitable).

management indicators below the average, especially labor (was as low as 0.12 relative average), and the technical efficiency values were above average during both the period of economic crisis and the shock period. However, while the technical efficiency increased with operational scale during the economic crisis, the order was not maintained during the shock period. The high-scale producers also had profits that were above the relative average,

TABLE 8 Color scale showing the relative average of the technical and financial indicators for the ranked categories (a: pre-COVID; b: COVID). The color gradation is based on the relative average value in each cell; the progression of cells from gray to black shows how far below the average (which is 1) the value is, revealing the magnitude of the deviation.

(a)

GROUP			A							B						C			
	Pre-COVID	Value at average	Large Scale	Individuals	16 and above (Experience)	Medium Scale	Restaurants or Hotels	11 to 15 (Experience)	Small Scale	Bulk buyers (Off-takers)	Owned	Processors	6 to 10 (Experience)	Fing. Source: Other farms or hatcheries	Fing. Source: On Farm	Micro Scale	5 and below (Experience)	Rented/ Leased	Retailers
	Number of farms	609	15	54	66	97	32	71	183	395	492	10	234	477	132	314	238	117	118
	Profit/kg	1.00	1.98	1.92	1.91	1.70	1.63	1.63	1.30	1.14	1.12	1.04	1.03	1.01	0.95	0.56	0.53	0.49	−0.08
Technical	Technical Efficiency	1.00	1.06	1.04	0.98	1.04	1.02	1.02	1.02	1.00	1.01	1.03	1.01	1.01	0.97	0.97	0.99	0.96	0.99
	FCR	1.00	0.92	0.92	1.02	0.93	0.97	0.99	0.96	1.00	0.99	0.91	0.98	0.99	1.04	1.05	1.02	1.05	1.04
	Fingerlings/kg	1.00	0.69	0.78	0.80	0.77	0.77	0.86	0.86	0.99	0.99	1.03	0.95	0.99	1.04	1.17	1.15	1.06	1.20
	Labor/kg	1.00	0.12	0.87	0.59	0.28	2.23	0.49	0.54	0.74	1.00	1.04	0.71	1.07	0.73	1.53	1.55	1.01	1.59
Financial	Feed cost/kg	1.00	0.93	0.95	0.90	0.94	0.96	0.96	0.95	0.95	0.99	0.91	0.97	1.01	0.96	1.05	1.07	1.06	1.21
	Fingerlings cost/kg	1.00	0.67	0.83	0.70	0.70	0.54	0.76	0.78	0.91	0.96	0.91	0.94	1.01	0.97	1.24	1.21	1.16	1.50
	Labor cost/kg	1.00	0.45	0.67	0.95	0.73	1.13	0.86	0.98	0.97	0.93	1.33	0.92	0.98	1.07	1.12	1.14	1.28	1.18
	Other costs/kg	1.00	0.62	2.01	0.58	0.59	0.94	0.60	0.74	0.77	1.06	0.48	1.09	1.00	0.99	1.30	1.15	0.73	1.36
	Variable cost/kg	1.00	0.85	1.00	0.87	0.89	0.94	0.91	0.92	0.94	0.99	0.91	0.97	1.01	0.97	1.09	1.09	1.06	1.24
	Fixed cost/kg	1.00	0.39	0.55	0.62	0.41	1.28	0.55	0.63	0.80	0.37	1.26	0.98	0.94	1.22	1.42	1.26	3.64	1.76
	Total cost/kg	1.00	0.85	0.99	0.86	0.88	0.95	0.90	0.92	0.93	0.98	0.91	0.97	1.01	0.98	1.09	1.09	1.10	1.24
	Price	1.00	1.03	1.14	1.04	1.01	1.06	1.03	0.98	0.97	1.00	0.93	0.98	1.01	0.97	1.00	1.00	1.00	1.02
	ROI	1.00	1.74	1.50	1.86	1.57	1.64	1.53	1.21	1.08	1.07	1.02	0.97	1.01	0.98	0.67	0.63	0.72	0.33
	OPM	1.00	2.04	1.78	1.90	1.80	1.61	1.72	1.35	1.19	1.14	1.24	1.05	1.02	0.93	0.50	0.48	0.42	−0.19

(Continues)

TABLE 8 (Continued)

(b)

GROUP			A								B					C					
	COVID	Value at average	Restaurants or Hotels	Agric Ventures	Individuals	Medium scale	16 and above (Experience)	11 to 15 (Experience)	Large scale	Small scale	Owned	Bulk buyers (Off-takers)	Fing. Source: On Farm	Fing. Source: Other farms or hatcheries	6 to 10 (Experience)	Processors	Concrete pond	5 and below (Experience)	Micro scale	Rented/Leased	Retailers
	Number of farms	509	30	47	43	66	52	56	9	162	408	324	107	402	195	8	194	206	272	101	104
	Profit/kg	1.00	2.02	1.93	1.85	1.57	1.53	1.45	1.26	1.25	1.15	1.12	1.05	0.99	0.98	0.84	0.80	0.76	0.71	0.39	0.00
Technical	Technical Efficiency	1.00	1.06	1.02	1.01	1.03	0.97	1.02	1.02	1.02	1.01	1.00	0.99	1.00	1.02	1.02	0.99	0.99	0.98	0.98	0.96
	FCR	1.00	0.91	0.96	0.99	0.94	1.04	0.97	0.92	0.96	0.99	0.99	1.01	1.00	0.97	0.94	1.02	1.02	1.04	1.03	1.07
	Fingerlings/kg	1.00	0.76	0.76	0.86	0.81	0.87	0.82	0.82	0.89	0.97	0.95	0.98	1.00	0.99	1.17	1.10	1.09	1.12	1.12	1.28
	Labor/kg	1.00	1.92	1.05	1.13	0.27	0.84	0.63	0.16	0.55	1.01	0.72	0.79	1.06	0.70	1.38	0.99	1.43	1.47	0.96	1.52
Financial	Feed cost/kg	1.00	0.97	0.97	1.00	0.92	0.92	0.92	0.91	0.97	0.99	0.96	0.94	1.02	0.98	0.91	1.03	1.07	1.04	1.06	1.13
	Fingerlings cost/kg	1.00	0.63	0.80	0.88	0.73	0.74	0.68	0.72	0.82	0.94	0.87	0.88	1.03	0.93	1.29	1.11	1.21	1.18	1.24	1.55
	Labor cost/kg	1.00	0.92	0.90	0.63	0.68	0.87	0.97	0.51	1.00	0.92	0.98	1.15	0.96	0.97	1.00	1.00	1.07	1.09	1.33	1.24
	Other costs/kg	1.00	0.97	0.93	1.77	0.66	0.66	0.65	1.03	0.65	1.06	0.73	1.07	0.98	1.02	0.46	1.19	1.16	1.29	0.76	1.58
	Variable cost/kg	1.00	0.95	0.95	1.02	0.88	0.89	0.89	0.88	0.94	0.98	0.94	0.96	1.01	0.97	0.91	1.04	1.08	1.07	1.07	1.19
	Fixed cost/kg	1.00	1.09	0.71	0.70	0.35	0.76	0.55	0.49	0.74	0.36	0.70	1.31	0.92	1.07	2.07	1.14	1.12	1.33	3.59	1.95
	Total cost/kg	1.00	0.95	0.95	1.01	0.87	0.89	0.89	0.87	0.94	0.97	0.94	0.96	1.01	0.98	0.93	1.05	1.08	1.07	1.11	1.20
	Price	1.00	1.13	1.11	1.16	0.99	1.00	0.98	0.94	0.99	1.00	0.97	0.98	1.01	0.98	0.91	1.00	1.03	1.01	0.99	1.00
	ROI	1.00	1.59	1.64	1.66	1.50	1.42	1.39	1.15	1.17	1.10	1.02	1.09	0.98	1.00	1.07	0.88	0.79	0.77	0.59	0.50
	OPM	1.00	2.27	2.23	2.10	2.10	1.98	1.92	1.75	1.64	1.20	1.21	1.27	0.93	1.19	0.91	0.38	0.32	0.33	0.21	−0.45

but this came mostly because of reduced costs as the prices obtained were just above average and not significantly above it.

The highly experienced producers, however, could not be rated exceptional, technically, as the technical efficiency is just about average if considered together (i.e., for groups with experience of 10 years and above) and the most experienced producers had technical efficiency below average at both the economic crisis and shock periods. This is mostly affected by the usage of feed as the FCR is either above average or just a little below it at both periods. The relative average estimates for input usage for fingerlings and labor are well below average during both periods. However, the highly experienced producers were able to achieve profits that were far above average in both periods mainly due to the lower cost of production as the total cost is well below the average. Like the high-scale producers, their product prices were just about average.

Those that make the most profits based on target markets (Individuals and Restaurants or hotels) were also good performers technically; having good input management as evidenced by lower-than-average input management indicators and higher-than-average technical efficiency. Their profitability, however, stemmed mostly from the higher price (far above average) they obtained for the products as their costs were high and close to average compared to the other profitable groups in both periods. Those who had other agriculture as their main occupation during the shock period also achieved profitability through these means (high production cost but also higher product price). Selling to bulk buyers, however, only yielded a lower-than-average price but because of the slightly lower-than-average total cost, there were still some profits. Farm owners had average prices, but slightly lower production costs, influenced by very low fixed costs allowed for profitability. Factors such as having processors as the main market, having 6–10 years of experience, and sourcing fingerlings on-farm or externally were not significantly profitable and were easily affected by the shock as some that had profits slightly above average during the pre-COVID economy fell below average during the shock period. These factors do not seem to bear a strong influence on either cost or price and thus were very vulnerable during the shock period.

4 | DISCUSSION

Nigerian catfish farmers have faced many challenges in recent years ranging from the economic pressure induced by inflation and the devaluation of the Naira to the shock created by the COVID-19 pandemic. Despite this, several farmers have still been able to maintain profitability and remain in operation during these periods, a testament to their resilience. The characteristics of the three profitability groups (A = highly, B = moderately, and C = less profitable factors) did not change when the COVID pandemic struck. There is, however, a marked difference between the strategy adopted by the highly profitable and the least profitable groups.

4.1 | Least profitable farms were cost-disadvantaged and technically poor

During both periods, factors representing the least profitable farms were characterized by the high operational cost and constrained by an average price, rendering them unprofitable. These farms were also characterized by relatively lower technical efficiency. The microscale producers were disadvantaged by their size/scale of operation which made it difficult for them to reduce costs through bulk purchase. Unfavorable price-to-cost margin was reported to have caused the exit of smaller-scale fish farmers in the early years of aquaculture growth in the US (Engle et al., 2022); an incidence which is becoming prevalent among catfish farmers in Nigeria (Olagunju et al., 2022). The least experienced could not save cost where it is most needed—feed cost. They mostly had high feed costs which may have been occasioned by high dependence on commercial feed or poor feed management as indicated by their relatively high FCR and feed cost per kg. Pond leasers spent exorbitantly on rent and could not beat down on costs of other inputs as well. While there is a limit to how farmers can reduce the rental cost renters must consider how they can minimize expenses related to labor, feed, and fingerlings. Belonging to a farm cluster could provide such an advantage. Several fish farm clusters can be found across the different states in Nigeria where farmers can take advantage of their numbers to share other costs such as labor and leverage the production scale by buying inputs in bulk. Being in a cluster also portends the benefit of learning from the experience of other farmers. It would be of advantage to renters to consider clusters that practice this. Those who consider retailers as a major market are seen to be on the extreme side of mismanagement as they have generally high costs across all input sources and are pegged by average prices resulting in loss. The generally high operational cost accrued by this group could also be considered a result of poor management of input as indicated by the mostly poor technical performance. Saha et al. (2022) reported significantly more input usage by non-profitable farms than profitable farms. Non-profitable farms, therefore, must start learning efficient management of inputs either through shared knowledge of experienced farmers or avail themselves to training which will make their operation more economically viable (Rahman et al., 2020).

4.2 | Cost-saving strategies were adopted by high-scale and experienced farmers for profitability

Highly profitable farms achieved profitability through cost-saving strategies, and/or securing higher prices for their products. Experienced managers and high-scale farmers were both profitable by saving costs but through different means. High-scale farmers producing more than 5 tons per year saved cost through economies of scale which made them have characteristically low feed cost, labor cost and relatively low cost for other inputs. Many studies have established the important role of scale in reducing production costs and increasing farm efficiency (Fernández Sánchez et al., 2023; Kumar et al., 2020; Olagunju et al., 2022). The experienced farmers, on the other hand, saved cost by cutting down on feed cost. Feed often constitutes more than 70% of the cost of catfish production; therefore, any measure to keep the cost of feed per unit harvest low would drive down the entire operational cost. Highly experienced farmers achieved this by incorporating cheaper locally compounded feed in their production which affected their seeming technical performance as their FCR is mostly high and technical efficiency sometimes lower than average, but this is considered a trade-off for financial prudency.

Attaining profitability through the inclusion of compounded feed depends on knowledge and experience, not only on the amount and quality of the compounded feed but also at which stage of the production cycle it is used. The highly experienced farmers included more locally compounded feed in their production and were still profitable (Figure 5). As with the ranked profit where the markedly profitable experience level began from 11 years and above, a higher proportion of use of locally compounded feed was also seen among farmers having experience of 11 years and above. This increasing use of local feed is a characteristic distinctly associated with experience as it is not observed with scale (Figure 5).

Most inexperienced managers lack adequate technical knowledge of the use of local feeds and would rather opt for the available commercial feeds which ends up driving up their cost of production. Similarly, while it may be difficult for the low-scale to save cost by increasing capacity, this knowledge of feed management by experienced farmers can be communicated to the low-scale and the less experienced through continuous training and extension services to save cost. A comparative study of small-scale carp farmers who were given long-term training and extension service in Bangladesh showed that farmers exposed to such capacity-enhancing support had increased profitability and efficiency over the years compared to those who did not have access to such support (Murshed-E-Jahan et al., 2008). These demonstrate that long-term training and extension can increase the profitability and efficiency of small-scale farmers. This could allow them to scale up their operations and increase their contribution and impact in the industry.

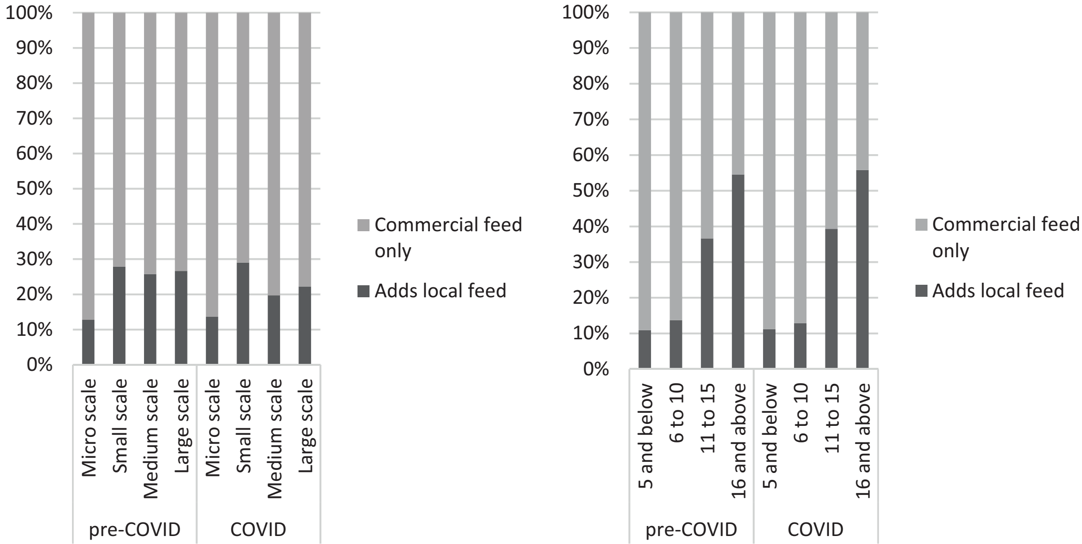

FIGURE 5 Feed-type usage by years of experience categorized by scale (left) and experience (right).

4.3 | Price and selective market strategy for the profitability of the cost-disadvantaged

There is limited price variation across most of the factors as most could only obtain just about the relative average. This is often observed when there is perfect competition in the market as is the case with catfish in Nigeria.[3] The farmers are, therefore, mostly price-takers and not price-makers. This relatively stable product price despite increasing input prices has also been reported for the most dominating fish species in Bangladesh aquaculture (Saha et al., 2022). Notwithstanding, the profitability strategy of certain farms is their higher price. This was the case for those who targeted individuals and restaurants or eateries during both periods. Though most of the hotels were shut down during the pandemic, selling to restaurants and eateries was possible as they mostly offered takeaways and no sit-ins. The government also allowed free movement of food and agricultural products. Since many farmers stopped operating during this period, the ones who were operating were able to key into these markets usually selling in smaller quantities and often excluding middlemen. This type of marketing fetches the highest price both during the difficult economic period and the shock period. Producers in this category are also characterized by moderately high production costs, but this did not hinder their profitability. The high cost is mostly driven by the cost of feed, which is a quality feed as indicated by their high technical performance. The use of quality feed has a very strong positive influence on technical efficiency, but it also comes with higher costs (Olagunju et al., 2023). The contingency table (Tables A3 and A4) indicates that the majority of those in this group are lower in production scale and experience. The implication is that, while the smaller-scale and the less experienced farmers may be limited by the high cost of operation, if they maintain good technical performance and use quality inputs, they can achieve profitability by being selective of their target market. Their level of production could easily fit this kind of market. However, it may be practically impossible for high-output producers like medium and large-scale farmers to rely more on this type of market which is why reliance on bulk buyers increases with scale of operation and years of experience (Figure 6).

Maintaining a diverse market is central to profitability, especially during a shock period. The large-scale farmers had a relatively lower profit during the COVID period as they only had to depend on bulk buyers during the period. The experienced farmers, however, target diverse kinds of markets so the order and rank of profitability were not

[3]In a perfectly competitive market, there are large number of firms producing identical goods or services with many buyers and sellers in the market. In this situation, buyers and sellers have complete information about prices in the market and the producers are price-takers and cannot change the price of a product by modifying the quantity of output because any increase in price can make the buyer consider another seller (Greenlaw & Shapiro, 2018).

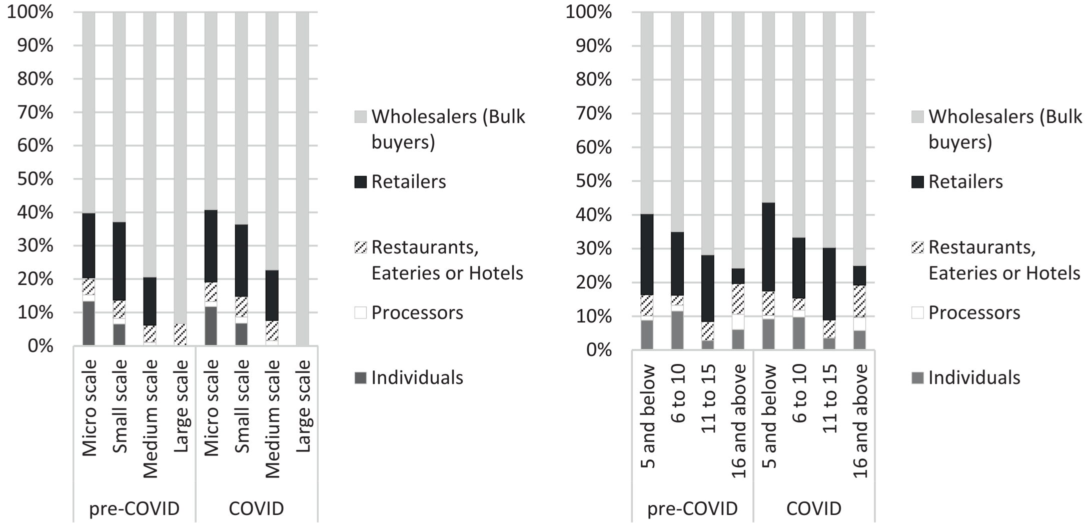

FIGURE 6 Major markets accessed by the farmers categorized by scale (left) and experience (right).

affected during the shock period. It may, therefore, be advisable that larger producers create channels of reaching diverse markets as this would sustain and guarantee profit, especially in situations like the shock period. Another factor that achieved high profit through price was having other agricultural ventures as the main occupation. This factor was only prominent during the COVID period. Though they have relatively high production costs, as is common to low-scale and low-experience producers yet were highly profitable. Two things could have favored these farmers: (i) the complementarity of farm products may have sustained or increased market access for the fish despite the lockdown, which means those who came to purchase other agricultural items, purchased fish as well; (ii) they were also able to secure a relatively higher price for their products.

Increasing the product price was also the major reason the farmers remained profitable during the pandemic. Despite the decreasing value of the Naira and inflation which have affected production costs, the farm gate price of catfish has remained relatively unchanged in recent years (Table 1). However, during the pandemic, the Catfish Farmers Association of Nigeria (CAFAN), pressured by the need to sustain their businesses, had to, for the first time, take control of product prices due to the surge in production costs. They announced and enforced a new price regime for their products, which was circulated to all state levels and coordinated accordingly. This action was also followed by other related associations within the industry. This price adjustment was also favored by product scarcity during the period as many farmers, especially the larger ones, stopped operating at the time and production per farmer was reduced, which created a market that was no longer perfectly competitive. This seemed to be very effective in the case of a developing economy like Nigeria. The lesson here is the role of formidable farmers' associations in intervening to adjust or control prices in response to economic situations. However, price increases cannot be sustained endlessly, especially in situations where the inflation rate continues to soar as this would eventually affect the demand for the product because the purchasing power of consumers will reduce, and consumers may opt for alternative products. Hence, price adjustment should be considered together with other measures of profitability like cost saving and efficient resource management. Also, government intervention such as a price guarantee scheme would be valuable in such a situation to save the sector from collapsing due to rising production costs. On the other hand, Hasan et al. (2021) reported reduced farm gate prices of pangasius and catfish in Bangladesh during COVID which resulted in reduced profit margins for the farmers. Though the middlemen and the consumer-end sales prices were increased during this time, the farmers, however, could not realize the benefit. To achieve profit maximization, it is, therefore, expedient for farmers to develop platforms such as cooperatives or market fora that can minimize the role of middlemen by reaching consumers directly. Examples of such platforms include the online fish market platform "Fiskmarkaðurinn" in Iceland and "Poiscaille" in France.

4.4 | Summary of the technical and financial management dynamics associated with the profitability factors

All the highly profitable factors (Group A) are rated technically GOOD (Figure 7). The position of High Experience in the chart (slightly GOOD) is so because the seeming average technical performance is borne out of a deliberate trade-off for cost reduction by the farmers. A strategy they have mastered well. The farmers in this group can also be said to be financially astute. In the chart, the factors that characterize AVERAGE financial performers are those who utilized the advantage of just either cost or price. GOOD financial performers were those farmers who had a price advantage plus a little cost advantage. The farms identified under the least profitable factors are POOR both technically and economically.

Based on the classification above, it appears implausible to be good technically and poor business-wise and vice versa. A combination of both types of knowledge and skills is necessary for a successful catfish farming operation as the success of an aquaculture enterprise does not only depend on its technical management but also on economic viability (Tisdell, 2019). This underscores the crucial role of managerial knowledge in the success of catfish farming. Farmers characterized by poor performance are typically ineffective managers, incurring high costs due to mismanagement of input and poor business decisions. The experience and knowledge of farm managers are, therefore, highly pivotal to the profitability of farms.

5 | CONCLUSION

In the face of numerous challenges posed by both an economic crisis and COVID, the lessons gleaned from Nigeria's catfish farming industry provide invaluable insights into the profitability strategies that have proven effective. The experiences and strategies of catfish farmers in this study underscore the need for adaptability and the ability to

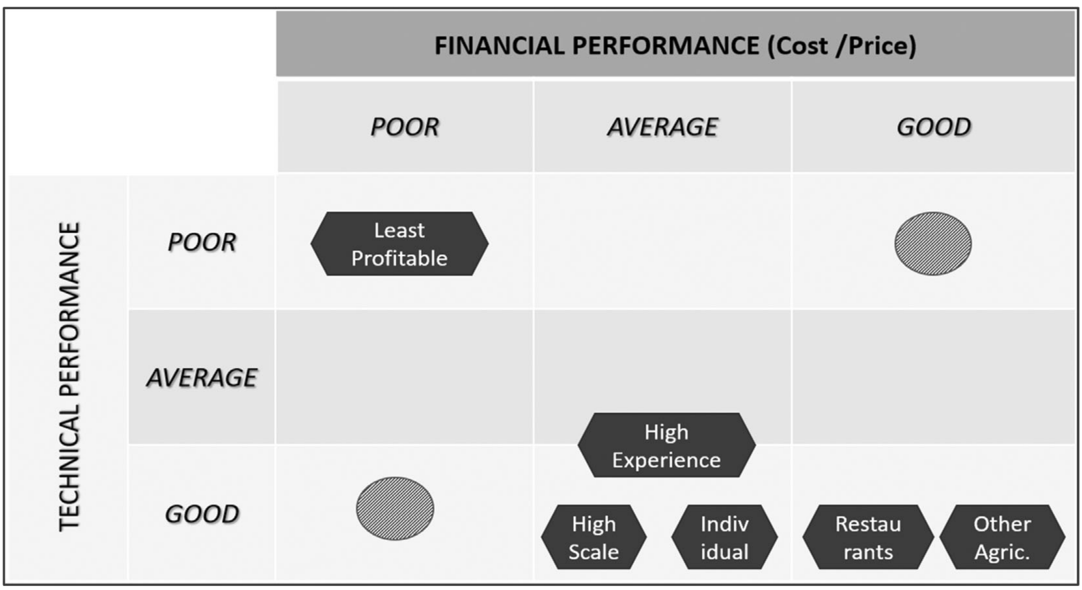

FIGURE 7 Schematic description of the technical and financial performance associated with the most profitable and the least profitable factors. The circles represent the contrastive extremes that seem implausible in catfish farming.

navigate turbulent economic waters. The findings of our study provide insights that can assist decision-makers, policymakers, and entrepreneurs in the aquaculture sector who aim to succeed amidst challenging circumstances.

The potential for profitability in catfish farming is not limited by the scale of operation or the level of experience of the manager, if they employ strategies that are optimal for their particular enterprise. Highly profitable factors usually are those that bear a strong influence on cost or price, but not necessarily on both at the same time. Under the generally difficult economic conditions (pre-COVID), scale, experience and market played major roles in contributing to profitability. Profitability increased with an increase in both scale and experience. The profitability of higher-scale producers was mostly driven by the cost advantage they earned by their scale of operation while the experienced farmers saved cost by mastering the incorporation of cheaper local feed to achieve profit, a decision that impacted their technical performance negatively but is considered a trade-off for financial prudency. The study also shows that the micro-scale producers and the low-experience farmers who are cost-disadvantaged could also achieve profitability if they make the right market decisions that will grant them price advantage such as targeting individuals and restaurants, which favors high product prices. If a farmer is cost-disadvantaged and is unable to achieve high product prices, such is bound to continually make losses until the business is no longer sustainable. However, the knowledge of the experienced farmers could be communicated to these farmers through training and extension services to build their capacity.

In addition to these expressed dynamics in profitability strategies, certain factors played a more prominent role in profitability when the pandemic struck: (i) Price flexibility: Relative profit was sustained during the pandemic despite the surge in production cost as the catfish farmers, through their association, were able to increase the product price; (ii) Market flexibility: The largest-scale producers who relied solely on bulk-buyers during the COVID period had relatively reduced profit while farmers who had diverse market option were able to maintain profitability in spite of the economic pressure and the shock. Experienced farmers maintained diverse target markets during the pandemic which helped them to sustain their profitability; (iii) Product complementarity and diversification: Having other agricultural enterprises was significantly profitable during the shock period which can be attributed to the complementarity in the sale of the farm products as the sale of other agricultural products could enhance the market for fish products.

In conclusion, the study establishes the need for skillful management, adaptability, a deep understanding of market dynamics, and the importance of leveraging both technical and business knowledge to ensure the profitability and sustainability of catfish farming businesses, especially in times of economic crisis and uncertainty.

ACKNOWLEDGMENTS

This work was supported by the UNESCO GRO-Fisheries Training Programme, Iceland, and the Doctoral Grants of The University of Iceland's Research Fund. We are grateful to the catfish farmers, fish feed suppliers, farmers associations, and government officers who provided farmers' lists and valuable information through questionnaires and interviews. We would like to thank the enumerators for their painstaking efforts in the data collection. The authors are grateful to the three anonymous reviewers for their helpful comments and suggestions.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Harvard Dataverse at https://doi.org/10.7910/DVN/4JIRV9 and https://doi.org/10.7910/DVN/NOUCOG.

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How to cite this article: Olagunju, O. F., Kristofersson, D., Tómasson, T., & Kristjánsson, T. (2024). Farm strategies and characteristics influencing profitability in Nigerian catfish aquaculture: Lessons on resilience during economic crisis and COVID-type shock. *Journal of the World Aquaculture Society*, e13058. https://doi.org/10.1111/jwas.13058

APPENDIX 1: Full model estimates used in the stepwise regression and some comments

Stepwise regression using Stats package in R is an automated stepwise modeling that uses the Akaike Information Criterion (AIC) which addresses both the fit of the model and the number of predictors used. In the backward elimination method, all predictors are initially placed in the model. Predictors are removed from the model one at a time until a stopping rule is satisfied. Using AIC, the variable which optimizes a criterion is removed, i.e. leads to the smallest AIC (the highest R^2adj, the highest test statistic, or the smallest significance) among all possible choices. Forty-nine predictors from 14 categories were included in the full model. Majority of those significant by at most 5% were retained in the final model. Some were significant in the model but were not eventually included in the final model. These may have been removed because of other AIC criteria than the *p*-value. Also, due to the use of categorical variables, some coefficients were not defined in the full model because of singularities. However, the excluded variables in the main model were factored in the backward elimination.[4] Unlike the general use in predictive models, stepwise regression in this study was used to only identify the main categories of variables that have a predominant effect on profit which can be used for further analysis. Out of the 14 categories of variables, only five demonstrated strong effect before COVID and an additional 2 categories during COVID.

[4]The steps, codes, and detailed output of the stepwise regression are available on Harvard Dataverse: https://doi.org/10.7910/DVN/NOUCOG.

Full model estimates – pre-COVID period

Call:

lm(formula = Profit.kg ~., data = RegDatP).

Residuals:

Min	1Q	Median	3Q	Max
−1040.37	−97.32	6.34	102.63	657.21

Coefficients: (14 not defined because of singularities).

	Estimate	SE	*t* value	Pr(>|t|)
(Intercept)	80.504	56.572	1.423	0.155269
ProdScaleLarge	45.253	54.882	0.825	0.409967
ProdScaleMedium	43.338	25.829	1.678	0.093920
ProdScaleMicro.Small	−99.348	20.353	−4.881	1.37e-06***
ProdScaleSmall	NA	NA	NA	NA
Experience11.to.15	55.317	28.278	1.956	0.050928
Experience16.and.above	62.148	31.466	1.975	0.048739*
Experience5.and.below	−29.268	19.687	−1.487	0.137644
Experience6.to.10	NA	NA	NA	NA
FeedUsageAdds.local.feed	−4.359	24.331	−0.179	0.857892
FeedUsageCommercial.feed.only	NA	NA	NA	NA
RegionNorth	−33.989	20.337	−1.671	0.095209
RegionSouth	NA	NA	NA	NA
MainOccupCivil.Servant	31.429	28.469	1.104	0.270075
MainOccupEmployed.in.a.private.organization	−27.357	43.414	−0.630	0.528845
MainOccupFish.Farming	−1.103	22.846	−0.048	0.961518
MainOccupOther.Agric.Ventures	43.997	29.771	1.478	0.139993
MainOccupOther.enterprise	32.587	47.165	0.691	0.489904
MainOccupPersonal.Business	NA	NA	NA	NA
EducationArabic	−28.901	84.639	−0.341	0.732879
EducationDegree	24.950	24.482	1.019	0.308588
EducationMSC.Above.Grad.studies.	18.443	35.730	0.516	0.605930
EducationND.NCE	28.600	26.589	1.076	0.282552
EducationNone	51.659	201.178	0.257	0.797438
EducationPrimary	−23.128	59.860	−0.386	0.699369
EducationSecondary	NA	NA	NA	NA
LabourXticsHired	−12.172	18.576	−0.655	0.512593
LabourXticsHousehold	NA	NA	NA	NA
AgeRange31.40.Yrs	46.054	36.291	1.269	0.204951

(Continues)

	Estimate	SE	t value	Pr(>|t|)
AgeRange41.50.Yrs	27.111	37.825	0.717	0.473824
AgeRange51.60.Yrs	48.579	40.358	1.204	0.229195
AgeRangeAbove.60.Yrs	51.603	47.719	1.081	0.279980
AgeRangeLess.than.30.Yrs	NA	NA	NA	NA
OwnershipOwned	90.897	23.232	3.913	0.000102***
OwnershipRented.Leased	NA	NA	NA	NA
MarketTypeIndividuals	148.003	31.821	4.651	4.10e-06***
MarketTypeProcessors	−6.137	64.195	-0.096	0.923875
MarketTypeRestaurants.Eateries.or.Hotels	60.529	37.209	1.627	0.104348
MarketTypeRetailers	−126.642	21.962	-5.766	1.32e-08***
MarketTypeWholesalers.Bulk. buyers.	NA	NA	NA	NA
GenderFemale	−40.605	22.411	-1.812	0.070537
GenderMale	NA	NA	NA	NA
Pond.TypeConcrete.pond	−15.358	22.128	-0.694	0.487949
Pond.TypeEarthen.pond	39.302	26.113	1.505	0.132861
Pond.TypeMobile.pond	NA	NA	NA	NA
FarmTypeCluster	5.720	32.570	0.176	0.860647
FarmTypeFarm.Site	−23.139	21.596	-1.071	0.284419
FarmTypeHomestead	NA	NA	NA	NA
FingSourceOn.Farm	−59.731	21.183	-2.820	0.004973**
FingSourceOther.farms.or.hatcheries	NA	NA	NA	NA

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Residual standard error: 196.6 on 573 degrees of freedom.

Multiple *R*-squared: 0.2756, Adjusted *R*-squared: 0.2313.

F-statistic: 6.228 on 35 and 573 DF, *p*-value: < 2.2e-16.

Full model estimates – COVID period

Call:

lm(formula = Profit.kg ~., data = RegDatC).

Residuals:

Min	1Q	Median	3Q	Max.
−1043.36	−124.05	10.62	161.69	958.30

Coefficients: (14 not defined because of singularities).

	Estimate	SE	*t* value	Pr(>|t|)
(Intercept)	185.488	86.934	2.134	0.033385*
ProdScaleLarge	−64.943	96.462	−0.673	0.501115
ProdScaleMedium	41.920	41.348	1.014	0.311175
ProdScaleMicro.Small	−108.629	30.574	−3.553	0.000419***
ProdScaleSmall	NA	NA	NA	NA
Experience11.to.15	78.954	43.710	1.806	0.071505
Experience16.and.above	43.981	49.287	0.892	0.372666
Experience5.and.below	−7.294	29.843	−0.244	0.807012
Experience6.to.10	NA	NA	NA	NA
FeedUsageAdds.local.feed	−9.564	37.132	−0.258	0.796852
FeedUsageCommercial.feed.only	NA	NA	NA	NA
RegionNorth	7.584	30.898	0.245	0.806208
RegionSouth	NA	NA	NA	NA
MainOccupCivil.Servant	−13.214	43.734	−0.302	0.762673
MainOccupEmployed.in.a.private.organization	1.732	65.685	0.026	0.978978
MainOccupFish.Farming	−28.169	33.812	−0.833	0.405211
MainOccupOther.Agric.Ventures	150.108	47.093	3.187	0.001530**
MainOccupOther.enterprise	−66.054	74.427	−0.888	0.375259
MainOccupPersonal.Business	NA	NA	NA	NA
EducationArabic	50.969	127.534	0.400	0.689592
EducationDegree	60.638	36.944	1.641	0.101385
EducationMSC.Above.Grad.studies.	132.749	55.111	2.409	0.016389*
EducationND.NCE	29.701	39.309	0.756	0.450266
EducationNone	6.268	278.745	0.022	0.982071
EducationPrimary	11.533	86.404	0.133	0.893870
EducationSecondary	NA	NA	NA	NA
LabourXticsHired	−4.097	29.286	−0.140	0.888811
LabourXticsHousehold	NA	NA	NA	NA
AgeRange31.40.Yrs	−61.926	54.309	−1.140	0.254759
AgeRange41.50.Yrs	−95.242	56.618	−1.682	0.093194
AgeRange51.60.Yrs	−92.411	60.698	−1.522	0.128563
AgeRangeAbove.60.Yrs	−59.293	72.443	−0.818	0.413490
AgeRangeLess.than.30.Yrs	NA	NA	NA	NA
OwnershipOwned	122.850	35.423	3.468	0.000572***
OwnershipRented.Leased	NA	NA	NA	NA
MarketTypeIndividuals	123.933	48.112	2.576	0.010300*
MarketTypeProcessors	−57.844	99.458	−0.582	0.561116
MarketTypeRestaurants.Eateries.or.Hotels	124.993	53.459	2.338	0.019798*
MarketTypeRetailers	−168.398	32.916	−5.116	4.54e-07***

(Continues)

	Estimate	SE	*t* value	Pr(>|t|)
MarketTypeWholesalers.Bulk. buyers.	NA	NA	NA	NA
GenderFemale	−13.410	33.868	−0.396	0.692331
GenderMale	NA	NA	NA	NA
Pond.TypeConcrete.pond	−72.990	33.451	−2.182	0.029600*
Pond.TypeEarthen.pond	17.869	38.673	0.462	0.644247
Pond.TypeMobile.pond	NA	NA	NA	NA
FarmTypeCluster	−11.963	51.588	−0.232	0.816721
FarmTypeFarm.Site	−22.194	32.528	−0.682	0.495384
FarmTypeHomestead	NA	NA	NA	NA
FingSourceOn.Farm	−5.032	32.727	−0.154	0.877864
FingSourceOther.farms.or.hatcheries	NA	NA	NA	NA

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Residual standard error: 271.1 on 473 degrees of freedom.

Multiple *R*-squared: 0.2182, Adjusted *R*-squared: 0.1604.

F-statistic: 3.773 on 35 and 473 DF, *p*-value: 2.631e-11.

TABLE A1 Average estimates of the technical and financial indicators for the ranked categories (pre-COVID).

	Pre-COVID	Average values	Large scale	Individuals	16 and above (experience)	Medium scale	Restaurants or hotels	11 to 15 (experience)	Small scale	Bulk buyers (off-takers)	Owned	Processors	6 to 10 (experience)	Other farms fingerlings	On farm fingerlings	Micro scale	5 and below (experience)	Rented/ leased	Retailers
	Number	609	15	54	66	97	32	71	183	395	492	10	234	477	132	314	238	117	118
	Profit per kg	126.6	251	243	242	215	207	207	164	145	142	131	130	128	120	71	67	63	−10
Technical	Technical Efficiency	0.85	0.90	0.88	0.83	0.88	0.87	0.86	0.86	0.84	0.86	0.87	0.85	0.85	0.82	0.82	0.84	0.81	0.84
	FCR	1.25	1.15	1.14	1.27	1.16	1.22	1.23	1.20	1.25	1.23	1.13	1.22	1.23	1.29	1.31	1.27	1.31	1.30
	Fingerlings per kg	1.74	1.19	1.35	1.38	1.34	1.34	1.49	1.50	1.71	1.71	1.78	1.64	1.72	1.80	2.02	2.00	1.84	2.09
	Labor per kg	0.33	0.04	0.29	0.19	0.09	0.73	0.16	0.18	0.24	0.33	0.34	0.23	0.35	0.24	0.50	0.51	0.33	0.52
Financial	Feed cost/kg	495.9	459.9	470.7	446.2	468.3	477.2	474.1	469.0	471.6	489.1	450.8	482.1	500.8	478.0	521.8	529.7	524.6	597.7
	Fingerlings cost/kg	42.5	28.3	35.2	29.6	29.6	23.1	32.2	33.3	38.8	40.8	38.6	40.0	42.8	41.2	52.5	51.6	49.4	63.7
	Labor cost/kg	44.6	19.9	30.0	42.6	32.7	50.5	38.4	43.7	43.3	41.6	59.2	40.8	43.7	47.7	50.0	50.7	57.1	52.7
	Other costs/kg	44.9	28.0	90.2	26.1	26.6	42.2	26.9	33.0	34.6	47.8	21.6	48.8	44.9	44.6	58.2	51.6	32.6	61.2
	Variable cost/kg	627.8	536.1	626.0	544.4	557.1	593.0	571.6	579.0	588.2	619.3	570.2	611.6	632.3	611.4	682.5	683.6	663.8	775.4
	Fixed cost/kg	10.4	4.1	5.7	6.4	4.2	13.2	5.7	6.6	8.3	3.9	13.1	10.2	9.7	12.7	14.8	13.1	37.8	18.3
	Total cost/kg	638.2	540.2	631.7	550.8	561.4	606.2	577.3	585.6	596.6	623.1	583.3	621.8	642.1	624.1	697.3	696.7	701.5	793.7
	Price	764.8	790.8	875.2	792.6	776.2	813.1	784.1	750.0	741.5	764.9	714.7	752.1	770.4	744.4	768.6	763.8	764.1	783.2
	ROI	0.29	0.50	0.43	0.53	0.45	0.47	0.44	0.34	0.31	0.30	0.29	0.28	0.29	0.28	0.19	0.18	0.21	0.10
	OPM	14.8	30.3	26.4	28.3	26.7	23.9	25.5	20.1	17.7	16.9	18.4	15.7	15.1	13.9	7.4	7.1	6.2	−2.8

TABLE A2 Average estimates of the technical and financial indicators for the ranked categories (COVID).

	COVID		Restaurants or hotels	Agric ventures	Individuals	Medium scale	16 and above (experience)	11 to 15 (experience)	Large scale	Small scale	Owned	Bulk buyers (off-takers)	6 to 10 (experience)	Processors	Concrete pond	5 and below (experience)	Micro scale	Rented/ leased	Retailers
	Number	509	30	47	43	66	52	56	9	162	408	324	195	8	194	206	272	101	104
	Profit per kg	159	322	308	296	251	244	232	200	199	184	178	156	133	127	122	113	62	−0.23
Technical	Technical Efficiency	0.86	0.91	0.88	0.87	0.89	0.84	0.87	0.88	0.88	0.87	0.87	0.87	0.88	0.85	0.85	0.84	0.84	0.83
	FCR	1.22	1.11	1.18	1.21	1.15	1.27	1.19	1.12	1.17	1.21	1.21	1.19	1.15	1.24	1.25	1.27	1.25	1.31
	Fingerlings per kg	1.66	1.25	1.27	1.43	1.34	1.44	1.36	1.36	1.48	1.61	1.57	1.64	1.93	1.83	1.81	1.85	1.86	2.12
	Labor per kg	0.37	0.71	0.39	0.42	0.10	0.31	0.24	0.06	0.20	0.38	0.27	0.26	0.51	0.37	0.53	0.55	0.36	0.57
Financial	Feed cost/kg	620.3	620.3	603.0	600.5	620.5	573.4	569.6	571.7	564.9	599.2	611.5	597.9	604.9	562.9	639.0	660.9	646.1	655.8
	Fingerlings cost/kg	48.74	48.7	30.7	39.1	43.0	35.7	36.2	33.2	35.3	39.7	45.9	42.2	45.5	62.8	54.1	59.2	57.7	60.3
	Labor cost/kg	47.85	47.8	43.9	42.9	30.3	32.7	41.7	46.6	24.2	48.1	43.9	46.8	46.3	48.0	48.0	51.2	52.2	63.6
	Other costs/kg	48.36	48.4	46.7	45.0	85.6	31.9	32.1	31.5	49.6	31.6	51.2	35.2	49.3	22.5	57.4	56.1	62.3	36.9
	Variable cost/ kg	765.25	765.3	724.2	727.5	779.4	673.6	679.6	683.0	673.9	718.6	752.5	722.1	746.1	696.2	798.5	827.4	818.3	816.6
	Fixed cost/kg	12.90	12.9	14.1	9.1	9.0	4.5	9.9	7.1	6.4	9.5	4.6	9.0	13.8	26.7	14.7	14.4	17.1	46.3
	Total cost/kg	778.15	778.2	738.3	736.6	788.4	678.1	689.5	690.1	680.3	728.2	757.2	731.1	759.9	722.9	813.3	841.8	835.4	862.9
	Price	937.63	620.3	603.0	600.5	620.5	573.4	569.6	571.7	564.9	599.2	611.5	597.9	604.9	562.9	639.0	660.9	646.1	655.8
	ROI	0.28	0.45	0.46	0.47	0.42	0.40	0.39	0.32	0.33	0.31	0.29	0.28	0.30	0.25	0.22	0.22	0.17	0.14
	OPM	12.11	27.46	27.01	25.40	25.39	23.95	23.28	21.23	19.86	14.48	14.60	14.45	11.07	4.55	3.87	3.97	2.53	−5.50

TABLE A3 Contingency table displaying the proportion of producers from scale, experience and feed usage categories that are classified to belong to the profitability factors (pre-COVID). Highlighted cells indicate there is a high proportion of cost-disadvantaged categories that are also within this profitable class (for instance, out of the 54 farmers that are profitable by considering individuals as a major market, 78% of them are Micro-scale, 98% relied solely on commercial feeds).

		Large scale	Individuals	16 and above (experience)	Medium scale	Restaurants or hotels	11 to 15 (experience)	Small scale	Bulk buyers (off-takers)	Owned	Processors	6 to 10 (experience)	Other farms fingerlings	On farm fingerlings	Micro scale	5 and below (experience)	Rented/ leased	Retailers
	Count	15	54	66	97	32	71	183	395	492	10	234	477	132	314	238	117	118
Scale	Large Scale	1.00	0.00	0.05	0.00	0.03	0.08	0.00	0.04	0.03	0.00	0.01	0.02	0.05	0.00	0.01	0.02	0.00
Scale	Medium Scale	0.00	0.00	0.27	1.00	0.16	0.25	0.00	0.19	0.16	0.10	0.18	0.13	0.25	0.00	0.08	0.15	0.12
Scale	Small Scale	0.00	0.22	0.38	0.00	0.31	0.37	1.00	0.29	0.28	0.30	0.35	0.28	0.36	0.00	0.21	0.38	0.36
Scale	Micro Scale	0.00	0.78	0.30	0.00	0.50	0.30	0.00	0.48	0.53	0.60	0.46	0.56	0.34	1.00	0.69	0.45	0.52
Experience	16 and above	0.20	0.07	1.00	0.19	0.19	0.00	0.14	0.13	0.11	0.30	0.00	0.07	0.25	0.06	0.00	0.09	0.03
Experience	11 to 15	0.40	0.04	0.00	0.19	0.13	1.00	0.14	0.13	0.12	0.00	0.00	0.10	0.16	0.07	0.00	0.11	0.12
Experience	6 to 10	0.20	0.50	0.00	0.43	0.22	0.00	0.44	0.38	0.38	0.40	1.00	0.37	0.44	0.34	0.00	0.39	0.37
Experience	5 and below	0.20	0.39	0.00	0.20	0.47	0.00	0.28	0.36	0.39	0.30	0.00	0.46	0.15	0.53	1.00	0.40	0.48
Feed Usage	Adds local feed	0.27	0.02	0.55	0.26	0.31	0.37	0.28	0.25	0.16	0.30	0.14	0.18	0.25	0.13	0.11	0.35	0.06
Feed Usage	Commercial feed only	0.73	0.98	0.45	0.74	0.69	0.63	0.72	0.75	0.84	0.70	0.86	0.82	0.75	0.87	0.89	0.65	0.94

TABLE A4 Contingency table displaying the proportion of producers from scale, experience and feed usage categories that are classified to belong to the profitability factors (COVID). Highlighted cells indicate there is a high proportion of cost-disadvantaged categories that are also within this profitable class (for instance, out of the 30 farmers that targeted restaurants, 53% of them are Micro-scale, and 70% relied solely on commercial feeds).

		Restaurants or hotels	Agric ventures	Individuals	Medium scale	16 and above (experience)	11 to 15 (experience)	Large scale	Small scale	Owned	Bulk buyers (off-takers)	6 to 10 (experience)	Processors	Concrete pond	5 and below (experience)	Micro scale	Rented/ leased	Retailers
	Count	30	47	43	66	52	56	9	162	408	324	195	8	194	206	272	101	104
Scale	Large Scale	0.00	0.00	0.00	0.00	0.04	0.04	1.00	0.00	0.02	0.03	0.02	0.00	0.01	0.01	0.00	0.01	0.00
Scale	Medium Scale	0.13	0.09	0.00	1.00	0.17	0.20	0.00	0.00	0.13	0.16	0.15	0.13	0.12	0.08	0.00	0.11	0.10
Scale	Small Scale	0.33	0.28	0.26	0.00	0.38	0.45	0.00	1.00	0.30	0.32	0.37	0.38	0.27	0.21	0.00	0.41	0.34
Scale	Micro Scale	0.53	0.64	0.74	0.00	0.40	0.32	0.00	0.00	0.55	0.50	0.46	0.50	0.60	0.70	1.00	0.48	0.57
Experience	16 and above	0.17	0.21	0.07	0.14	1.00	0.00	0.22	0.12	0.11	0.12	0.00	0.25	0.07	0.00	0.08	0.09	0.03
Experience	11 to 15	0.10	0.13	0.05	0.17	0.00	1.00	0.22	0.15	0.12	0.12	0.00	0.00	0.11	0.00	0.07	0.09	0.12
Experience	6 to 10	0.23	0.36	0.44	0.45	0.00	0.00	0.33	0.45	0.38	0.40	1.00	0.50	0.38	0.00	0.33	0.39	0.34
Experience	5 and below	0.50	0.30	0.44	0.24	0.00	0.00	0.22	0.27	0.40	0.36	0.00	0.25	0.44	1.00	0.53	0.44	0.52
Feed Usage	Adds local feed	0.30	0.21	0.02	0.20	0.56	0.39	0.22	0.29	0.16	0.25	0.13	0.13	0.10	0.11	0.14	0.34	0.08
Feed Usage	Commercial feed only	0.70	0.79	0.98	0.80	0.44	0.61	0.78	0.71	0.84	0.75	0.87	0.88	0.90	0.89	0.86	0.66	0.92

Paper IV

TEACH ME TO FISH: POLICY OPTIONS FOR PROFITABLE AND SUSTAINABLE AQUACULTURE.

(SUBMITTED MANUSCRIPT)

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ABSTRACT

Aquaculture's global contribution to fish production and consumption has grown significantly. In Nigeria, private sector interests in catfish farming have driven its growth, boosting income, dietary diversification, women and youth empowerment, and overall economic growth. This necessitates the development of policies that support aquaculture profitability. We utilized economic, operational, and socioeconomic data obtained from catfish farms in Nigeria to identify potential policy options that would promote the profitability of aquaculture. Key policy options were categorized into knowledge/learning-based, tactical decision-based, and infrastructure-based policy options. We used analysis of covariance (ANCOVA) to measure the effect size and regression to assess the significance and direction of the effect of the policy-related factors on profit. Their effect on profit is measured through the effect they have on performance (economic) variables that directly impact profit. Among the key performance variables, product price, feed conversion ratio, feed price, and other costs exert the strongest effects on profit in the sector. Policy-related factors associated with knowledge and learning, such as experience, training, and access to knowledge sources, have the strongest overall effect on profitability and were significant. These factors notably impact the key performance variables, collectively resulting in profitability. Additionally, participation in training significantly contributes to sustainable resource management through efficient input usage. It is concluded that policies promoting the capacity enhancement of farmers have a greater tendency to not only enhance profitability but also promote sustainability and are thus critical to aquaculture development. Other policy issues were also considered.

KEYWORDS: Aquaculture management, Policy, Effect size, Training, Profitability, Sustainability, Social media access

1 INTRODUCTION

The global contribution of aquaculture to total fish production and consumption has continued to increase both in absolute and relative terms, not least in many aquaculture nations (FAO, 2022a). This has been more pronounced in populous developing nations where increasing populations have mostly fuelled production and consumption (Garlock et al., 2020). Aquaculture has therefore been considered a significant contributor to food and nutrition security and capable of addressing many SDG targets, including Poverty Eradication, Zero Hunger, Decent Work and Economic Growth, and Reduced Inequalities (Asche et al., 2022; Belton et al., 2018; Filipski and Belton, 2018; Garlock et al., 2022; Gephart et al., 2020). All these gains in aquaculture development have been driven by increased interest in the sector, largely due to its profitability, which has led many entrepreneurs and business-oriented individuals to go into fish farming. It is therefore important that aquaculture's profitability is maintained to sustain all these associated benefits. Hence, policies promoting aquaculture profitability are germane to its sustenance and continual role in steering nations towards attaining key SDGs.

Similarly, the contribution of aquaculture to national fish production in Nigeria has increased over the years, mostly instrumented by the increase in catfish production (Dauda et al., 2018; Marin et al., 2024). As the second largest producer in Africa, aquaculture is making a significant contribution to increasing income, dietary diversification, empowering women and youth, and general economic growth (Subasinghe et al., 2021). This potential is particularly evident in catfish farming, underscoring its economic viability through job creation and revenue generation. It has been estimated that the catfish sector could create approximately 30,000 jobs and generate an annual revenue of around $160 million (Chiekezie et al., 2023). The profitability of catfish farming has been a focal point of numerous studies, indicating that farmers can achieve substantial returns on investment. For instance, research conducted in various regions, including Enugu and Kaduna states, has demonstrated that catfish farming can be both economically viable and sustainable, with many farmers reporting positive profit margins (Issa et al., 2014; Umaru et al., 2021). Furthermore, catfish contributes significantly to the animal protein intake of Nigerians, accounting for about 40% of the animal protein consumed in the country (Olabode and Olaniyi, 2023). The cultivation of catfish not only meets local protein demands but also offers a pathway for economic empowerment.

Despite these benefits, the aquaculture sector in Nigeria faces numerous challenges affecting profitability. Production has declined in recent years, from 316,727 metric tons in 2015 to 296,191 metric tons in 2017, with further decreases observed subsequently (FAO, 2022b). Major issues often reported include the high cost of production, largely influenced by the high cost of commercial fish feeds, the poor quality of fingerlings, which sometimes leads to mass mortality, and the poor quality of feeds, resulting in inadequate production performance (Anetekhai, 2013; Digun-Aweto and Oladele, 2017; Edema-Sillo et al., 2017; Olagunju et al., 2022). Moreover, the previous research in this series showed that Nigeria's aquaculture sector is highly sensitive to macroeconomic conditions. Challenging economic climate, exacerbated by a devaluation of the Naira, has made it increasingly difficult for farmers to maintain profitability, requiring farmers to adopt dynamic strategies to achieve profitability (Olagunju et al., 2024a). These challenges highlight the need for supportive policy measures to sustain the sector's profitability and growth. To guard the gains of aquaculture in Nigeria and sustain its numerous benefits, it is important that policies that will promote the profitability of aquaculture be put in place and encouraged.

While the earlier study focused on examining strategies that farmers themselves could employ to achieve profitability, the present study, however, shifts the focus toward identifying government interventions and policies crucial to supporting sustainable profitability in the aquaculture sector. Since profitability remains vulnerable to various external factors, it is essential to consider both farmer-led strategies and policy support to ensure sustained growth. To determine effective policy directions for profitable catfish aquaculture, this study examined some current characteristics and practices of farmers and assessed their impact on farmers' profitability. This would allow the government to make evidence-based policy decisions that will positively impact the aquaculture sector, supporting its growth and sustainability.

We used analysis of covariance (ANCOVA) to measure the effect size of the policy-relevant factors on profit and the linear regression component to show the direction of the effect. Studies have, however, indicated that the scale of operation could highly influence how these factors impact profit (Olagunju et al., 2024a, 2022). Hence, the scale of operation was included as a covariate in the estimation of the effect size. Although not common in aquaculture studies, the use of effect size measures could be a very useful analytical instrument to support results and test the strength of relationships between variables. By integrating effect size measures into aquaculture research, the field can achieve a deeper and comprehensive understanding of the factors influencing industry outcomes, ultimately contributing to its advancement and sustainability. In the next section, we describe the data followed by the methods used in the analysis of the data, while in sections four and five, we present the results of the study and provide a robust discussion on the implications of the results, respectively. Lastly, in section six, we proffer some policy recommendations and give concluding remarks.

2 SAMPLING AND DATA

2.1 Sampling and data collection

A multi-stage sampling technique was employed in the data collection (Bluman, 2019). Firstly, ten states were purposively selected from all the country's geopolitical zones, considering their production capacity, agroecological characteristics, and the need for national coverage (Figure 1). Five states were sampled from the northern region (Adamawa, Benue, Federal Capital Territory, Kaduna, and Sokoto) and five from the southern region (Delta, Imo, Lagos, Oyo, and Rivers). Purposive selection was then used to select the main production areas within each state. Lastly, farmers were randomly selected from lists of catfish farmers obtained from governmental and private sources, capturing both registered and unregistered farmers to minimize survivor bias. Pre-trained enumerators conducted data collection from May 2021 to February 2022 through an electronic questionnaire, Open Data Kit (ODK), which allowed for efficient data collection and validation.

The data collected include cost and returns, socioeconomic and other farm operational characteristics. All surveyed farms practised intensive farming, with their products primarily intended for the market. The data encompassed the COVID period (2020-2021) and the Pre-COVID period (before 2020) to capture the operations characteristics across these two periods. A total of 609 catfish farms were surveyed consisting of 1,118 production cycles. Having such large datasets with broad coverage minimizes the influence of outliers and allows for more representativeness of the sample. An additional benefit of the broad data scope in this study is the reduction of bias in effect size measurement.

The combination of data from both periods was undertaken to leverage the advantage of a larger dataset and not to assess the impact of the COVID period. Previous studies using the same dataset have addressed the period's technical and financial impacts (Olagunju et al., 2024a, 2023). This study focuses instead on broader government-driven policies aimed at enhancing profitability, irrespective of economic shocks like COVID. A side analysis confirmed that including data from the COVID period did not introduce bias or alter result interpretations, aligning with earlier findings (Olagunju et al., 2023) that farmers' technical performance remained consistent across the two periods. Other information about the data collection process has been documented in earlier studies (Olagunju et al., 2024b, 2023) and the data is available publicly[1] (Olagunju, 2024).

[1] This also includes the SAS code used for the analysis in this study.

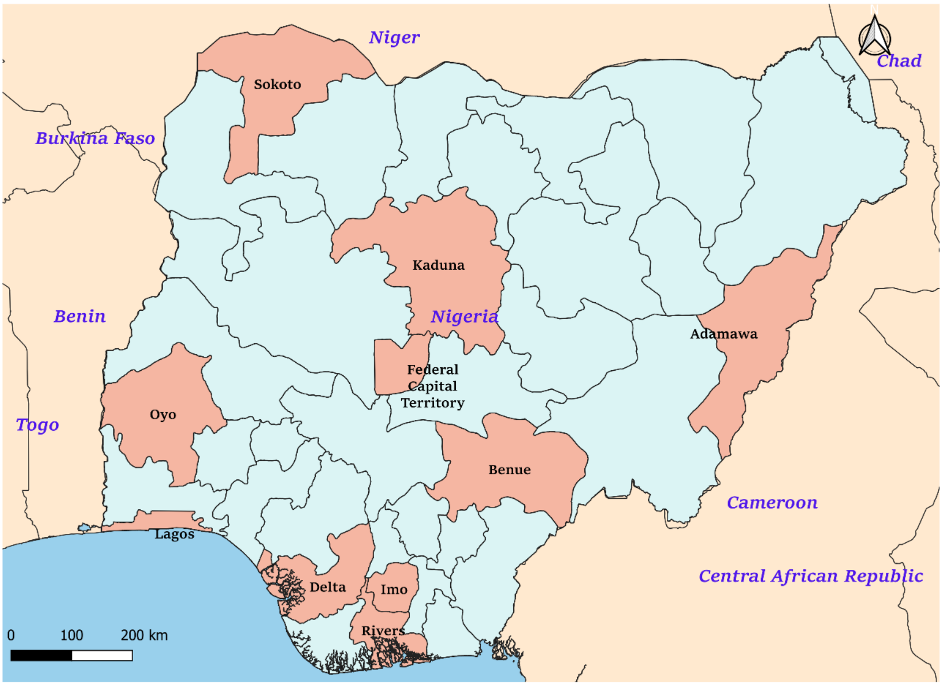


Figure 1. Geographical distribution of the ten states sampled in the study.

2.2 Variables included in the model

We utilized economic, operational, and socioeconomic data from the survey to identify potential policy options that would promote the profitability of the catfish farmers. Farmers' characteristics and practices exert their effect on profit through other performance variables that directly affect profit. Some of these variables are technical input management indices such as the feed conversion ratio (FCR), fingerlings-to-harvest ratio or seed-to-harvest ratio (SR) and labour-to-harvest ratio (LR), while some are financial indices relating to the price of products and costs of inputs (Table 1). The extent to which farmers can optimize these technical and economic indices as influenced by the policy-related factors will significantly impact their level of profitability.

Table 1. Descriptive statistics of profit and performance variables.

Variables	Description	Number	Mean	Std. Deviation	Min.	Max.
Profit (Profit/kg)	Profit/Total harvest	1118	141.57	259.70	-1221.78	933.71
Feed Conversion Ratio (FCR)	Feed (kg)/Total harvest	1118	1.24	0.31	0.59	3.57
Seed-to-Harvest Ratio (SR)	No. of fingerlings stocked/ Total harvest	1118	1.70	1.07	0.28	11.54
Labour to Harvest Ratio (LR)	Labour (man-days)/ Total harvest	1118	0.35	0.56	0.01	6.14

Price of 1kg feed (P_f)	Feed cost/ Feed quantity (kg)	1118	452.33	101.20	199.62	879.05
Seed price (Unit price of fingerlings) (P_s)	Fingerlings cost/ No. of fingerlings	1118	26.01	11.79	8.00	120.00
Price of labour (man-day) (P_l)	Labour cost/ No. of Labour (man-day)	1118	330.29	404.19	1.52	4838.71
Other costs per kg fish (O_c)	Other costs/ Total harvest	1118	57.98	69.81	0.13	591.15
Product price (Price per kg of fish) (P_y)	Revenue/ Total harvest	1118	843.47	189.78	84.99	1941.56

Prices and costs are in Naira (pre-COVID, $1 = ₦306; COVID $1 = ₦393 average exchange rates for the periods reported (Central Bank of Nigeria, 2023)).

The policy-related factors were categorized into three major groups viz: (1) the learning based which includes experience and other knowledge sources: Education, Training, Extension, social media and other farmers; (2) tactical decisions, which includes the inclusion of local feed and the decision to produce own fingerlings; and (3) infrastructure-related factors which include farm type/location and pond type. The study primarily considers three types of farms: backyard (in-house) farms, farms located outside the residence (farm site farms), and farms that are part of a farm cluster. The pond types considered are earthen, concrete, and mobile ponds, with the mobile category including various forms such as glass-reinforced plastic, framed collapsible tarpaulins, and pallet tanks. Studies have, however, indicated that the scale of operation can significantly influence how these factors impact profit (Olagunju et al., 2024a, 2022). Therefore, production scale was included as a covariate to account for variation due to the scale of operation, reducing potential biases and isolating the effect of the variables of interest in the model. The farms' annual production capacity was used as the measure of their scale. All these factors and their sub-classes are described in Table 2.

Table 2. Descriptive statistics of policy-related factors

Variables/Factors	**Sub-class/Levels**	**Number**	**Mean**	**Std. Deviation**	**Min.**	**Max.**
Experience	5 years and below	444	0.40	0.49	0	1
	6 to 10 years	429	0.38	0.49	0	1
	11 to 15 years	127	0.11	0.32	0	1
	16 years and above	118	0.11	0.31	0	1
Education	Higher Education	777	0.70	0.46	0	1
	Secondary	192	0.17	0.38	0	1
	Primary equiv.	36	0.03	0.18	0	1
	No Education	2	0.00	0.04	0	1
Knowledge source*	Extension Agent	347	0.31	0.46	0	1
	Other Farmers	876	0.78	0.41	0	1
	Social media	276	0.25	0.43	0	1
	Training Courses	518	0.46	0.50	0	1
Fingerlings source	Fingerling on farm	239	0.21	0.41	0	1
	External source fingerlings	879	0.79	0.41	0	1
Feed usage	Local feed added	219	0.20	0.40	0	1

	Only commercial	899	0.80	0.40	0	1
Farm location	Cluster Farm	148	0.13	0.34	0	1
	Site Farm	522	0.47	0.50	0	1
	Backyard Farm	448	0.40	0.49	0	1
Pond type	Concrete Pond	427	0.38	0.49	0	1
	Earthen Pond	417	0.37	0.48	0	1
	Mobile Pond	274	0.25	0.43	0	1
Scale**	Scale	1118	6.85	8.34	0.072	60

*Variables describing various knowledge sources are not mutually exclusive, so are treated independently in the model. **Production of farmers in tonnes.

3 METHODS

3.1 Structural overview

Analysis of covariance ANCOVA is a statistical method that integrates multiple linear regression (MLR) and ANOVA to examine the impact of categorical variables on the dependent variable after accounting for the effects of covariates (continuous variables) (Holman et al., 2005). Using PROC GLM in the SAS statistical package, ANCOVA process returns Type 3 sums of squares, as well as measures of effect sizes. In this study, we used ANCOVA to measure the effect size of the policy-related factors on profit, using scale as the covariate, and the linear regression component, in a separate model, to show the direction and significance of the effect. The strength of a policy-related factor on a performance variable or profit was measured by its effect size and further clarified by its level of significance and direction of effect. The complementary use of both effect size measures and significance tests in quantitative research has been encouraged to improve the interpretation of results and provide better insights into research findings (Iacobucci et al., 2023; Kroes and Finley, 2023; Lecroy and Krysik, 2007; Levine and Hullett, 2002; Olejnik and Algina, 2003). To identify potential policy options that would promote the profitability of the catfish farmers, three models were employed (Figure 2), which addressed the following questions:

i. Model 1: How much effect do the performance variables have directly on profit?
ii. Model 2: How much effect do the policy-related factors have, through the performance variables, on profit?
iii. Model 3: What is the significance and direction of the effect of the policy-related factors on the performance variables and profit?

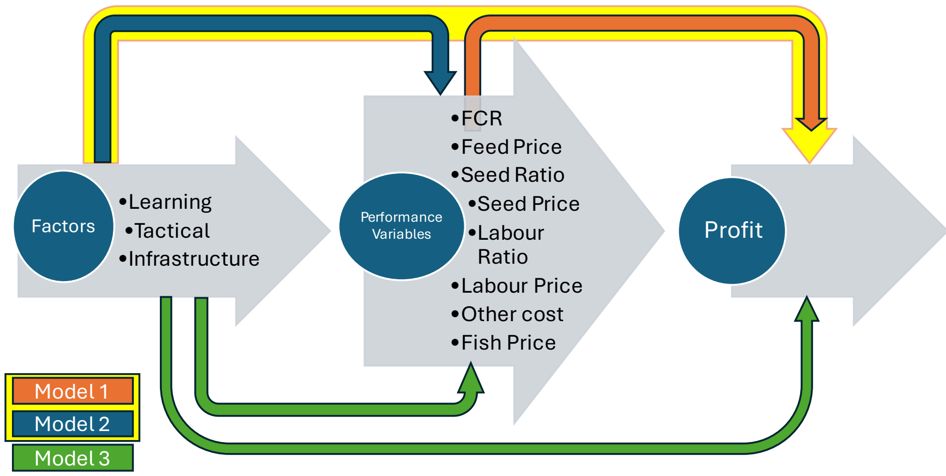


Figure 2. Schematic diagram of the analytical methods used for effect size measurement and linear regression. Model 1 is the direct effect of performance variables on profit. Model 2 is the effect of policy-related factors on the performance variable. The effect of policy-related factors on profit through the performance variables is depicted in the yellow arrow. Model 3 assesses the significance and direction of the effect of the factors on profit and the performance variables.

3.2 Measures of Effect Size

Eta-squared (η^2), omega-squared (ω^2) and epsilon squared (ε^2) are the major effect size measures. Of these three, eta-squared is the most used partly due to its simplicity (Iacobucci et al., 2023). It is measured the same way as the commonly used R-squared - ratio of the Sum of Squares of a factor and the Total Sum of Squares SS_T. This measure indicates the proportion of total variance (or SST) that is explained by each predictor (independent variable), showing how much of the variation in the outcome can be attributed to specific factors. However, it has a reputation for being positively biased and overestimates the true population effect size (Mordkoff, 2019). Omega-squared and epsilon-squared are considered to be less biased estimators of variance in the population. However, biased corrected estimators can return a negative value, especially when the effect size is small (Kroes and Finley, 2023), which is not expected as the lower and upper bounds of effect size should be 0 and 1, respectively. Moreover, this does not indicate a negative effect, and it may not be appropriate to treat it as an absence of effect (zero) either, as it could result in substantial overestimation (Okada, 2017). However, effect sizes become less biased in eta squared as sample size increases. Iacobucci et al 2021 demonstrated that the differences in effect sizes using omega, epsilon and eta-squared disappear when sample sizes reach 1000 or more. Eta-squared was therefore chosen because it is straightforward to interpret and widely used, like the commonly understood R-squared measure. Unlike other effect size measures, eta-squared does not yield negative estimates, which makes it more interpretable—especially when effect sizes are small. While eta-squared can slightly overestimate the true effect size, this bias diminishes with increased sample size. Given our large sample, we expect our results to be comparable to those obtained with bias-corrected measures, making eta-squared a practical and reliable choice.

Mathematically, eta-squared can be expressed as:

$$\eta^2 = \frac{SS_{factor}}{SS_{total}}$$

where:

SS_{factor} is the Sum of Squares associated with a specific performance variable (predictor) and

SS_{total} is the Total Sum of Squares for the model.

This calculation gives the proportion of the total variance in the outcome that can be attributed to each performance variable, allowing us to quantify the individual impact of each predictor on the dependent variable.

In addition, where there are multiple predictors or factors, researchers often consider whether to use a partial or semi-partial eta-squared measure. Semi-partial eta squared quantifies a predictor's unique contribution to the dependent variable's variance, excluding shared variance between that predictor and other predictors. This measure helps determine how much variance in the dependent variable is uniquely attributable to a particular predictor, ignoring overlap with other predictors. Partial eta squared, however, measures a predictor's contribution to the dependent variable's variance while controlling for other predictors in the model. It indicates how much of the outcome variance can be uniquely explained by a specific predictor, considering the shared variance with other predictors. Given our multi-factor model and potentially shared variance among predictors, partial eta squared is considered more appropriate, allowing for an accurate assessment of the impact of specific factors while controlling for others. This measure is valuable when factors could have overlapping influences, providing a clearer understanding of their unique contributions.

3.3 Model specification

The profit measure used in this study is the Net Farm Income which is the overall profit of the farm after considering both the variable and the fixed costs. In this study, eta-squared and partial eta-squared measures were adopted to determine effect size.

3.3.1 Model 1-Effect size of performance variables on profit

For Model 1, we used eta-squared for its simplicity and ease of measurement. In a model with multiple predictors, using simple eta-squared might not provide a complete picture because it does not account for the shared variance among predictors, but because the profit per kg is a calculated value[2] and thus more deterministic, we can adjust and modify each variable to assess the unique contribution of each performance variable. The profit per kg is expressed thus:

$$\frac{\pi}{y} = P_y - P_f(FCR) - P_s(SR) - P_l(LR) - \frac{O_{cost}}{y} \quad ....(1)$$

Where $\frac{\pi}{y}$ is the profit per kg and $\frac{O_{cost}}{y}$ is other costs per kg harvest, while other performance variables are defined in Table 1.

[2] Because profit is calculated from revenue and cost, we can use the formula to establish where the ratios and indices fit. Profit = Revenue – Cost, where Revenue = Output x Price and Cost = ∑(input quantity x price). The Other costs include the fixed cost and farm operational costs. If the two sides of profit calculation are divided by output in kg, then equation 1 results, that is, profit per kg.

The performance variables account for profit per kg in the order found in the equation above. We redefined the performance variables based on their relative contribution to the equation to single out how each individually contributes to profit per kg. This was done by including deviation from mean of the variable in the equation, and this replaces the direct contribution the variable has on profit per kg with the overall mean of the performance variable. This accounts for the effect that comes solely from that variable to profit.

For instance, to replace P_y with mean value in Equation 1, its deviation from the mean is subtracted from both sides of the equation, while for P_f and FCR, being negative, their deviation from the mean is added to both sides. According to Equation 1, profit-rated P_y and P_f will, respectively, be as follows:

$$\frac{\pi}{y} - (P_y - \overline{P}_y) = \overline{P}_y - P_f(FCR) - P_s(SR) - P_l(LR) - \frac{O_{cost}}{y} \ldots.(2)$$

and

$$\frac{\pi}{y} + \left(P_f - \overline{P_f}\right)FCR = P_y - \overline{P}_f(FCR) - P_s(SR) - P_l(LR) - \frac{O_{cost}}{y} \ldots.(3)$$

Thus, we created profit-rated performance variables used in Model 1 as predictors, a general model with detailed description is provided in the Appendix 1. By including this profit-rated performance variables in Model 1, eta-squared can account for the variance in the dependent variable from a predictor that is not already accounted for by the other predictors in the model. If there is no shared variance among the predictors and the model is deterministic, the sum of all the effects should be 1. The equation for model 1 is defined as follows:

$$Y_\pi = X_{py} + X_{pf} + X_{fcr} + X_{ps} + X_{sr} + X_{pl} + X_{lr} + X_{oc} \quad \ldots..(4)$$

where Y_π represents the profit per kg, and each X term corresponds to a performance variable as defined in Table 1 but now profit-rated.

3.3.2 Model 2-Effect size of policy-related factors on profit through performance variables

On the other hand, in the second model (Model 2), partial eta-squared was used to estimate the effect size of policy-related factors on each performance variable. Model 2 will yield the effect size of each factor variable on a particular performance variable (using the profit-rated variable that already captures the total effect on profit).

$$Y_{py\ldots oc} = X_{exp} + X_{ed} + X_{tr} + X_{ext} + X_{soc} + X_{of} + X_{fu} + X_{fs} + X_{ft} + X_{pt} + X_{ps} \ldots.(5)$$

where $Y_{py\text{-}oc}$ is each of the predictors in model 1 and *X* is for factors representing experience *(exp),* education *(ed),* training *(tr),* extension *(ext),* social media *(soc),* other farmers *(of),* feed usage *(fu),* fingerlings source *(fs),* farm type *(ft),* pond type *(pt)* and production scale *(ps).*

To determine the effect of the factors on profit, we applied the additive and multiplicative rule in regression which is used in estimating total effect from direct and indirect effects (Heij et al., 2004). For the indirect effect, the effect of a factor through the performance variable on profit was calculated as a product of the effect size of the factor and the relative effect size of the performance variable on profit. Also, since the effects of the performance variables on profit are independent of one another, they are therefore additive (Howell, 2013). The sum of this proportionate effect for the different performance variables is the total effect of that factor on profit (Heij et al., 2004) (Figure 3).

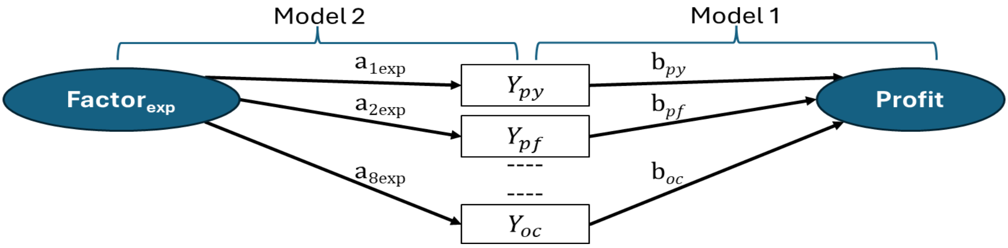


Figure 3. A description of how the total effect size of each factor on profit is calculated using Experience as an example. The performance variables are in the middle boxes as independent variables for Model 1 and dependent variables for Model 2. Here, a and b are the effect sizes from the predictors in Models 2 and 1, respectively, where $a_{1\text{exp}}$ is the effect size of experience on product price Y_{py} and b_{py} is the effect size of product price Y_{py} on profit. The total effect of Experience on Profit is therefore captured as $a_{1\text{exp}}\,b_{py} + a_{2\text{exp}}\,b_{pf} + \cdots + a_{8\text{exp}}\,b_{oc}$. Similarly, the total effect of training on profit will be $a_{1tr}b_{py} + a_{2tr}b_{pf} + \cdots + a_{8tr}b_{oc}$, and likewise for other factors.

3.3.3 Model 3 -Direction of effect of policy-related factors on profit and performance variables

Effect size indices are intended to gauge the magnitude of the effect of a variable regardless of its significance. Notwithstanding, the significance and direction of the effect of an independent variable can be obtained in the linear regression model estimate. However, because Equations 2 and 3 resulted in profit-rated variables, the interpretation of coefficients of the independent variables in a linear regression model will be in terms of profit value irrespective of whether the dependent variable is a technical or financial index (that is, the change in the dependent variable for each one-unit increase in the independent variable is in Naira value and does not indicate the actual direction of effect on the performance variable). Hence, to determine the direction of the effect of various factors on performance variables, non-profit-rated performance variables were used as the dependent variables in Model 3. In this model, both non-profit-rated performance variables and profit per kg were included as dependent variables to determine the direction of the effect of policy-related factors on them, using Ordinary Least Squares (OLS) regression. This estimation method was chosen for its efficiency and straightforward interpretability in assessing the relationships between the predictors and the outcomes. The multiple linear regression specified in Equation 6 represents the third model.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon \ldots . (6)$$

where Y represents the non-profit-rated performance variables and profit per kg, and X_1, X_2,…, X_n represent the different factor variables used in Model 2 as the predictors, while β_1, β_2,…, β_n are their respective coefficients, and ϵ represents the error term, accounting for variability in the data not explained by the linear relationship.

4 RESULTS

Product price, feed price, feed conversion ratio (FCR), and other costs exert the strongest effects on profit in the sector with eta-squared values at 0.35, 0.21, 0.18 and 0.14 respectively. Labour price (0.004) and labour ratio (0.000015) influence profit the least (Table 3).

Table 3. Effect of performance variables on profit

Performance variable	**Eta-squared effect size**
Product price	0.3520
Feed price	0.2091
FCR	0.1845
Other costs	0.1437
Seed price	0.0681
Seed ratio	0.0385
Labour price	0.0041
Labour ratio	1.54E-05
Sum	**1.00**

The scale of operation, which was used as the covariate in the model with the policy-related factors, bore the strongest effect (0.023) on profit demonstrating the strong influence of scale directly on profit outside the effect of other policy-related factors (Figure 4). Having excluded the variance explained by the covariate (scale), learning-based policy-related factors of experience (effect size = 0.012) and training courses participation (effect size = 0.008) rank next in influence on profit. This was followed by infrastructure-related variables of pond types (effect size = 0.007) and farm types (effect size = 0.006). The lease effect is demonstrated by having formal education and learning through other farmers (effect size = 0.001 for both). The tactical decisions of farmers on fingerlings source (effect size = 0.005) or local feed usage (feed usage, effect size = 0.002) had a comparatively moderate effect on profit, just like learning-based factors of knowledge through extension agents and social media.

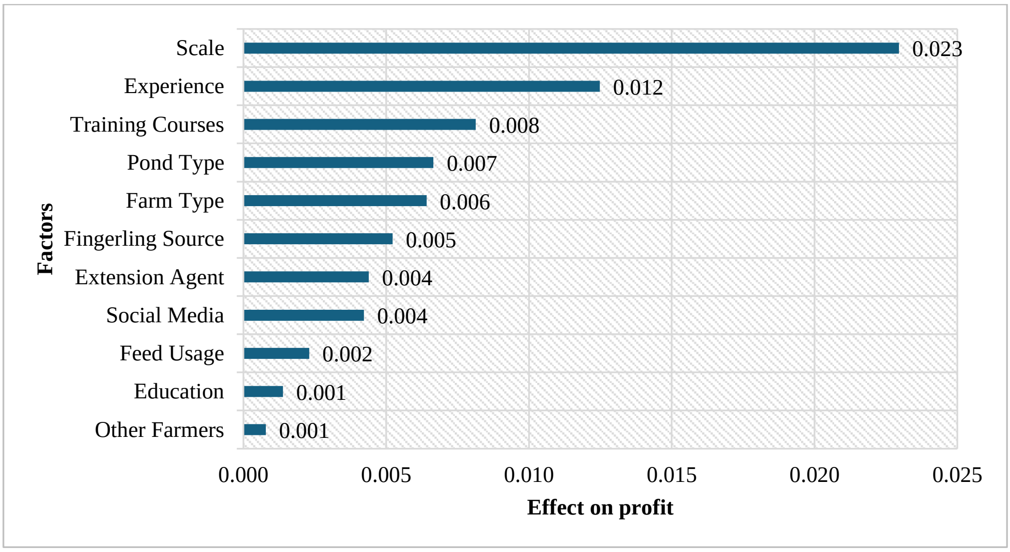
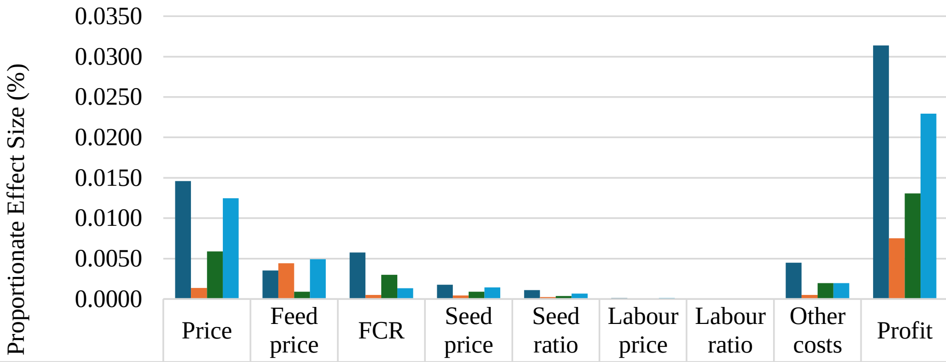


Figure 4. The effect size of policy-related factors on profit measured as the effect they have through the performance variables on profit.

Overall, the learning-based policy-related factors had the highest effect on profit (0.0314). This significant impact is due to their high effect on key profit influencers such as product price, FCR, other costs, and feed price. Following this, the infrastructure-based policy-related factors had a notable effect on profit (0.0131), primarily through their influence on product price, other costs, and FCR (Figure 5). The policy-related category relating to the farmers' tactical decisions had the least influence on profit (0.0075). The effect of scale on profit was also very prominent (0.023), highlighting its significant role even as a covariate.



	Price	Feed price	FCR	Seed price	Seed ratio	Labour price	Labour ratio	Other costs	Profit
Learning	0.0146	0.0035	0.0058	0.0018	0.0011	0.0002	0.0000	0.0045	0.0314
Tactical	0.0014	0.0044	0.0005	0.0004	0.0002	0.0000	0.0000	0.0005	0.0075
Infrastructure	0.0059	0.0009	0.0030	0.0009	0.0004	0.0000	0.0000	0.0020	0.0131
Scale	0.0125	0.0049	0.0013	0.0014	0.0007	0.0002	0.0000	0.0020	0.0230

Figure 5. Effect size of policy-related factor category on profit and the effect they have through the respective performance variables.

The results so far demonstrate the size of the effect these variables have on profit through the performance variables. However, it does not indicate the direction of their effects. To understand how these factors relate to each of the performance variables and profit, the multiple linear regression of the policy-related factors on profit and the performance variables was carried out. Where there is a main variable class, the different sub-classes of the variable class were used to assess the direction and significance of their influence on the dependent variable (Table 4).

Table 4. Linear regression of the factor variables against profit and the performance variables indicating the direction and significance of the effect

Variables	Profit	Product price	Feed price	FCR	Other costs	Seed price	Seed ratio	Labour price	Labour ratio
Intercept	*67.13* (32.2)*	*878.4*** (24.14)*	*476.56*** (12.54)*	*1.26*** (0.04)*	*76.8*** (8.49)*	*31.42*** (1.43)*	*2.27*** (0.13)*	*142.96** (46.26)*	*0.62*** (0.07)*
EXP6 to 10	36.21* (18.38)	-13.46 (13.79)	-10.98 (7.16)	-0.05* (0.02)	-1.3 (4.85)	-1.82* (0.82)	-0.15* (0.07)	-8.77 (26.42)	-0.19*** (0.04)
EXP11 to 15	85.7** (28.62)	29.64 (21.46)	-12.34 (11.15)	-0.03 (0.03)	-14.65 (7.55)	-2.78* (1.27)	-0.17 (0.12)	-31.73 (41.13)	-0.13* (0.06)
EXP16 and above	112.9*** (30.63)	45.24* (22.97)	-29.75* (11.93)	0.01 (0.04)	-12.6 (8.08)	-2.96* (1.36)	-0.23 (0.12)	-120.25** (44.01)	-0.09 (0.06)
Training Courses	50.16** (17.5)	-13.01 (13.12)	-11.88 (6.82)	-0.05* (0.02)	-4.97 (4.62)	-1.49 (0.78)	-0.2** (0.07)	-22.3 (25.14)	-0.12** (0.04)
Extension Agent	3.67 (16.86)	-49.64*** (12.64)	-17.74** (6.57)	0 (0.02)	-15.2*** (4.45)	-4.23*** (0.75)	-0.02 (0.07)	-71.69** (24.22)	-0.03 (0.04)
Social media	45.51* (18.49)	28.73* (13.86)	3.97 (7.2)	-0.01 (0.02)	0.94 (4.88)	-3.77*** (0.82)	-0.21** (0.07)	-89.16*** (26.56)	-0.06 (0.04)
Other farmers	-11.91 (20.42)	7.81 (15.31)	-3.15 (7.95)	0.07** (0.02)	4.96 (5.39)	-0.06 (0.91)	-0.22** (0.08)	45.43 (29.34)	0 (0.04)
Primary education	17.44 (49.09)	-11.04 (36.81)	-12.72 (19.13)	-0.08 (0.06)	26.32* (12.95)	-0.86 (2.18)	0.16 (0.2)	129.03 (70.54)	0.05 (0.1)
Secondary education	-17.46 (31.1)	-36.22 (23.32)	-4.91 (12.12)	0 (0.04)	8.39 (8.2)	-4.69*** (1.38)	0.02 (0.13)	-4.66 (44.68)	-0.03 (0.07)
Higher education	-12.8 (25.38)	-5.61 (19.03)	0.1 (9.89)	0.01 (0.03)	5.66 (6.69)	-1.27 (1.13)	0.14 (0.1)	20.9 (36.46)	0.06 (0.05)
On farm seed/ fingerlings (ExS)	-49.25* (19.68)	-24.42 (14.76)	-26.95*** (7.67)	0.07** (0.02)	17.29*** (5.19)	-0.16 (0.87)	0.18* (0.08)	57.48* (28.28)	0.02 (0.04)
Local feed (CF)	-8.68 (22.13)	-37.3* (16.6)	-38.97*** (8.62)	0.07** (0.03)	-7.58 (5.84)	0.82 (0.98)	-0.17 (0.09)	222.84*** (31.8)	-0.04 (0.05)
Cluster farm (Bf)	-33.72 (27.03)	24.1 (20.26)	24.94* (10.53)	0.02 (0.03)	-5.51 (7.13)	5.01*** (1.2)	0.18 (0.11)	254.73*** (38.83)	-0.13* (0.06)
Site farm (Bf)	-44.77* (18.13)	-9.9 (13.59)	20.35** (7.06)	-0.02 (0.02)	-4.1 (4.78)	-1.24 (0.81)	0.21** (0.07)	73.6** (26.05)	-0.12** (0.04)
Earthen pond (CCp)	50.33* (20.52)	-10.1 (15.39)	-12.22 (7.99)	-0.02 (0.02)	-24.06*** (5.41)	1.49 (0.91)	-0.31*** (0.08)	-72.43* (29.48)	0.03 (0.04)
Mobile pond (CCp)	37.85 (19.56)	10.82 (14.67)	0.36 (7.62)	-0.05* (0.02)	3.35 (5.16)	-0.72 (0.87)	-0.34*** (0.08)	34.13 (28.11)	0.1* (0.04)
Scale	4.89*** (0.98)	-0.6 (0.74)	0.48 (0.38)	-0.01*** (0)	-1.47*** (0.26)	0 (0.04)	-0.03*** (0)	14.99*** (1.41)	-0.01*** (0)

Note: *Standard errors in brackets. *, **, and *** denote statistical significance at the 5%, 1%, and 0.1% levels, respectively. Reference categories (Rc) used: Experience- EXP 0_to_5; Education- No Education; Other Rc are ExS= External source, CF= Commercial feed only, Bf = Backyard farming, and CCp = Concrete Pond*

In addition to the strong effect expressed on profit, the result of the linear regression in Table 4 further shows that the major learning-based factors (experience and training) have a positive and significant impact on profit. Particularly, profit increases with years of experience. The impact of experience is seen through their diverse input and cost minimization through the different performance variables with most of them bearing negative signs. Notably, only farmers with over 16 years of experience demonstrate a statistically significant positive effect on product price. Similarly, participation in training courses also significantly increases profit (coefficient=50.16). However, this is most significantly through technical management as shown by the significant negative coefficients of FCR, SR and LR. Although knowledge through extension agents and social media had equal comparatively moderate effect size, only knowledge through social media increases profit significantly (45.51) through securing high product prices and minimizing labour price, seed price and seed ratio. Conversely, the significantly negative product price gained by those accessing knowledge through an extension agent negates the potential benefits gained through their significant input and cost reductions. Education levels (Primary, Secondary, Higher) do not show significant impacts on profit or major costs, suggesting other factors might be more influential.

Tactical decisions of farmers such as the use of on-farm fingerlings and local feed generally show negative impacts on profit. Although the inclusion of local feed significantly reduces feed price (-38.97) and slightly increases FCR (0.07) while production of on-farm fingerlings also reduces seed price but is not significant (-0.16), these decisions did not result in profit. Similarly, the infrastructure-based policy-related factors represented by cluster farms and site farms have negative impacts on profit, with site farms showing a significant negative impact on profit. Specifically, cluster farms and site farms show substantial increases in feed price and labour prices, indicating higher costs associated with these areas. These elevated costs suggest that both types of farms face higher operational expenses, particularly in terms of labour and inputs such as feeds. Although the impact on profit is slightly better for cluster farms compared to site farms, it is not significant. With backyard farms being the reference category to this group, this indicates that backyard farming does better than these two. Only earthen ponds have a significant positive impact on profit (50.33) among the pond types. The impact of using mobile ponds is positive but not significant, while concrete pond use, being the reference category, has the least impact on profit. Lastly, the scale has a significant positive impact on profit (4.89).

5 DISCUSSION

5.1 Learning-based policy-related factors

Product price, feed price, FCR and other costs bear the strongest effect on profit. This implies that any factor that could influence these key performance variables will largely influence profit. Learning-based policy-related factors are able to strongly influence profit through these key variables and were therefore prominent. Price as a performance variable is often determined by the type of market targeted (Engle, 2010; Olagunju et al., 2024a). Knowledge of different markets and the decision on which type to access is often a determinant of the product price a farmer can obtain. Product price increases with years of experience. Farmers with experience are knowledgeable enough to demonstrate dynamic responses to different markets and thereby secure good product prices (Olagunju et al., 2024a). Using social media to access information enables farmers to secure a higher price. Price information often influences and guides market decisions (Engle, 2010), a gap which access to social media must have filled as access to market information would help the farmers know the prevailing price and market options that would favour higher prices. Conversely, access to extension services, while effective in minimizing most input and cost variables, could not aid farmers in securing higher prices. This suggests that the contribution from the extension agents was more on farm management than marketing. While this may also indicate that disadvantaged farmers receive more extension support, extension agents could enhance their impact by offering guidance on market planning and decisions to help farmers secure better product prices for increased profitability.

Similarly, the profitability gained through participation in training is primarily due to improved technical management, that is, minimizing input usage. This highlights the direction and focus of most of the trainings the farmers attended. As observed on the field, while many farmers could be confident in their technical knowledge of farm operation, only a few know how to track the economic indices. This is further corroborated by the high technical efficiency of the farmers as reported by Olagunju et al. (2023). While this connotes impact of training on sustainable resource management, the impact of training on profitability could be further boosted if the training offered were to incorporate more financial and economic management indices that could help the farmers monitor and efficiently manage their costs and pricing. In this study, the contribution of formal education as a knowledge source is insignificant and unclear which further emphasizes that specialised sector-specific knowledge is more critical to a farmer's profitability than general education alone.

Many studies have reported the varied role of knowledge on the profitability of fish farm operations. The profitability of farmers has been shown to increase with years of experience (Gbigbi and Achoja, 2020). A comparative study in Bangladesh comparing trained and untrained farmers' profitability showed that the trained farmers were more productive and profitable than the untrained ones (Murshed-E-Jahan et al., 2008). The impact of formal education on production efficiency and profitability has been reported in studies and often in a positive way (Akinbode et al., 2011; Anozie et al., 2006; Begum et al., 2016; Gbigbi and Achoja, 2020; Khan et al., 2021; Ngoc et al., 2018; Ogundari and Akinbogun, 2010; Sivaraman et al., 2015). While it is possible that the level of education of farmers may enhance their openness to knowledge, it is more evident from our study that specialised training offers more benefit to the farmers as it provides relevant and applicable understanding and skills for their operation. Extension services in the country have been reported to be inadequate (Issa et al., 2014; Olaoye et al., 2016). The low number of extension agents and thus their limited services may have influenced the moderate effect size and insignificant contribution to profit. Given the positive impact extension service has on farm management, it is recommended that policies that would favour an increase in the number of extension agents should be promoted. Moreover, the extension agents should be provided with updated training that will enable them to render appropriate marketing advice. In the interim, this may not require new recruitment but redefining roles of already engaged officers with related professional qualifications in the sector who would also be adequately equipped with the necessary skill set and logistic support to reach out to the farmers.

5.2 Infrastructure-based policy-related factors

Infrastructure-based policy-related factors demonstrate a moderate effect on profit, but the regression results presented varied impacts, with some factors negatively impacting profit while others did not. Although the specific channels through which backyard farming impacts profit could not be ascertained, the practice could favour cost reduction through various means, including the utilization of facilities and services available at the residence (Gbigbi and Achoja, 2020). However, the interpretation of the result from the cluster farms has to be handled with caution considering that the number of sampled farms from the clusters was purposively restricted to avoid the possibility of overrepresentation of cluster farmers (Olagunju et al., 2024b). This calls for further investigation as farming in clusters has often been reported to grant farmers many profitable advantages (Achoja and Enwa, 2019; Enwa et al., 2024).

When considering pond types, only the use of an earthen pond significantly impacts profit. This agrees with other studies that have reported on the profitability and economic viability of farming in earthen ponds (Olaoye et al., 2016; Oluwatayo and Adedeji, 2019; Omobepade et al., 2014). The use of mobile ponds also contributes positively to profit but is not significant (Table 4). Backyard farming has been aided in more recent decades by the availability of mobile ponds. Policies that will promote technologies that will favour backyard farming should be encouraged. Though backyard farming is often a small-scale venture, it can offer great food security, economic and livelihood value. To take advantage of the benefits associated with the use of earthen ponds, policies that will favour farmland ownership should be encouraged such as the designation of land for the purpose of fish farming. Promotion of fish farming estate development however could combine the advantages of both backyard farming and earthen pond farming. The use of earthen ponds is also common in cluster farms, however, there needs to be a more comprehensive study on farm clusters assessing the potential factors that may affect their profitability.

5.3 Tactical decision-based policy-related factors

The low effect size and negative impact of tactical decisions on profitability is unexpected given the anticipated cost reducing effect from using local feed and producing own fingerlings. The inclusion of local feed in production reduced the feed price as expected while the production of own fingerlings reduced seed price too, though not significantly. However, that these impacts did not eventually result in profit indicates that it is not just enough to be able to deploy these tactics to reduce specific input costs, but it is also important to consider other aspects of management.

The poor outcome of these tactical decisions on profit may be attributed to the poor quality of the inputs involved. In their efforts to reduce costs, farmers may end up with lower-quality inputs, as evidenced by the increased Feed Conversion Ratio (FCR) and Seed Conversion Ratio (SCR). Poor broodstock management practices have been reported among fingerling producers in the country, particularly those who use on-farm produced broodstock, which can lead to poor-quality fingerlings (Ibiwoye and Thorarensen, 2018). Local feeds are known for having lower crude protein content than commercial feeds, resulting in higher FCR and poor growth performance (Mustapha et al., 2014). Therefore, the availability of high-quality feed and seed from specialized suppliers has been critical in driving aquaculture development in many countries, including Nigeria (Miller and Atanda, 2011; Ragasa et al., 2018).

We investigated further for potential heterogeneity in the relationship of the tactical policy options with profit by interacting them with key knowledge variables (Table A1, Appendix 2). While the use of local feed alone negatively impacts profit, its interaction with experience shows that farmers with 6 years and above experience were able to derive profit by incorporating local feeds in their production. This suggests that knowledge acquired through experience enables farmers to better leverage the benefits of using local feed. This aligns with our earlier findings, which indicate that the use of local feed increases with years of experience, and profit also increases with experience (Olagunju et al., 2024a). The interaction between local feed and training does not lead to increased profitability, even though training generally contributes to profitability. This may indicate that the training provided is not sufficiently specialized. Focused training on well-balanced economic decision on feed choice and management could be more beneficial.

In feed selection and management, it is essential to consider not only the Feed Conversion Ratio (FCR) but also the economic benefit of feed to the farm, referred to as the Economic Conversion Ratio (ECR) (Piedecausa et al., 2007). Studies conducted in Nigeria by Mogaji and Olafur (2020) on catfish have demonstrated that, although commercial feeds often exhibit lower FCR and better growth performance, the combined use of local feeds and commercial options can yield economically favourable results with a lower ECR. Similarly, other studies in Malaysia and Uganda evaluating the effects of local feed ingredients on African catfish performance reported a better ECR for local feed compared to the commercial diet, even though it had a lower FCR (Farahiyah et al., 2016; Limbu, 2015). Through experience, farmers recognize that a feed's value transcends its FCR, emphasizing the importance of its economic impact on the operation. Nevertheless, the effectiveness of this approach hinges on the quality and composition of the local feed used. This intricate balance requires knowledge that is typically acquired through training and experience. While local feeds may offer economic benefits, the selection of high-quality inputs is essential for long-term sustainable development in aquaculture.

However, the profitability of producing on-farm fingerlings is not significantly improved by either experience or training. The significant negative relationship between low experience (5 years and below) and on-farm fingerling production suggests that low experience can worsen the profitability of on-farm fingerling production. The result of using on-farm fingerlings generally speaks to the poor quality and performance of the domesticated strain of catfish in Nigeria (Iwalewa et al., 2017; Olaleye, 2005). To secure high quality fingerlings, many fingerlings' producers have resorted to importing broodstocks (Dutch strains) from the Netherlands, which are not widely available (Iwalewa et al., 2017). However, the significant positive relationship between the use of on-farm fingerlings and social media use indicates that knowledge acquired through social media can significantly help to maximize profitability from on-farm fingerling production. This may be due to access to information provided through social media and the performance may not be unconnected with use of imported broodstock. These findings underscore the need to improve seed quality in the country by providing immediate training for farmers in effective broodstock management practices and, as a long-term strategy, developing a comprehensive breed improvement program for catfish.

In essence, tactical decision-based factors require additional knowledge for them to result in profit. The knowledge that years of experience offer could be communicated through training and extension services. Although the use of local feed tends to reduce feed costs, it is essential that farmers receive training that enables them to make balanced economic decisions regarding feed choice and management, while also prioritizing high-quality inputs, which are necessary for the long-term sustainable development of aquaculture. This study also highlights a very important role that social media could play in enhancing farmers' profitability by bridging the information gap. Though being among the most prolific internet users in Africa with 103 million internet users and 36.75 million active social media users, the internet penetration rate in Nigeria is still low compared to other African countries, standing at 45.5% and ranking 23rd in Africa (Kemp, 2024; Statista, 2024). To capitalize on the benefits observed in this study, it is recommended that policies be developed to improve internet infrastructure and access across the country. Increasing internet penetration and encouraging the use of social media among farmers can significantly boost their access to market information, enabling them to make informed decisions that enhance profitability.

The effect of scale on profit is prominent and significant. Though not included as the main policy-related variable in the present study, this however indicates that if through these other policy-related factors farmers can increase their profitability, it will create an opportunity for them to increase their scale thus further enhancing their profit.

6 CONCLUSION AND RECOMMENDATIONS

Globally and particularly in Africa, aquaculture continues to make significant contribution to increasing income, dietary diversification, empowering women and youth, and general economic growth. Being a profit-driven sector and to sustain these benefits, it is pertinent to provide policies that will promote aquaculture profitability. This study highlights the critical role that learning-based factors play in influencing aquaculture profitability and suggests ways to maximize the benefits of infrastructure-based factors. Our findings demonstrate that experience, training, and access to market information through social media significantly enhance farmers' ability to secure higher product prices and manage costs more effectively. Additionally, the study underscores the role of knowledge and the importance of specialized training programs that incorporate financial and economic management to further boost profitability. Training fosters sustainable resource management through efficient input utilization, thus emphasizing the potential of learning in not only promoting profitability but also sustainability. The positive impact of backyard farming and earthen pond usage on profitability also points to the need for policies that support these practices through technological advancements and land designation for fish farming. Addressing these key areas through strategic policy interventions can lead to substantial improvements in the efficiency and profitability of the fish farming sector.

Specifically, the following policy recommendations are provided:

i. Training Content: Financial and economic management should be incorporated into training programs to help farmers track economic indices and manage costs and pricing effectively.
ii. Training Focus: The focus should be on sector-specific training rather than general education, as specialized knowledge has a greater impact on profitability. Likewise, educational institutions offering requisite programmes should be adequately supported.
iii. Improve internet infrastructure and access across the country. This will increase internet penetration and encourage social media use among farmers to significantly boost their access to market information, enabling them to make informed decisions that enhance profitability.
iv. Promote policies to increase the number of extension agents and provide updated training for extension agents to include marketing advice to help farmers achieve better product prices, alongside their current focus on farm management.
v. Encourage policies that promote technologies favouring backyard farming due to its cost-reducing benefits recognizing that backyard farming is a valuable small-scale venture contributing to food security, economic, and livelihood benefits.
vi. Implement policies to facilitate farmland ownership for fish farming, promoting the use of earthen ponds.
vii. Develop fish farming estates which combine the advantages of backyard and earthen pond farming to enhance profitability.
viii. To improve catfish seed quality, provide immediate training for farmers in effective broodstock management practices and, as a long-term strategy, implement a comprehensive breed improvement program for catfish.

Overall, this study reveals the fundamental importance of sector-specific knowledge in contributing to the profitability of farmers and shows that policies that promote this kind of knowledge will largely benefit the farmers. This study contributes to the larger body of literature on the role of knowledge as well as other policy options in driving profitability, underscoring the importance of prioritizing the economic viability of a sector in policy discourse. Furthermore, this study demonstrates that such knowledge will not only enhance profitability but also promote sustainability through efficient resource management.

7 ACKNOWLEDGEMENTS

We extend our gratitude to the catfish farmers, fish feed suppliers, farmers' associations, and government officers for providing valuable information and farmers' lists through questionnaires and interviews. We also thank the enumerators for their diligent efforts in data collection.

8 AUTHOR CONTRIBUTIONS: CREDIT

Olanrewaju Femi Olagunju: Conceptualization, Methodology, Writing- Original draft, Formal Analysis, Data curation, Writing- Reviewing and Editing; **Dadi Kristofersson**: Conceptualization, Methodology, Writing- Reviewing and Editing, Supervision; **Theódór Kristjánsson**: Formal Analysis, Writing- Reviewing and Editing, Supervision; **Tumi Tómasson**: Writing- Reviewing and Editing, Supervision

9 STATEMENTS AND DECLARATIONS

Funding: This work was supported by the UNESCO GRO-Fisheries Training Programme in Iceland; and Doctoral Grants of the University of Iceland's Research Fund [grant number: 10301033314].

Conflict of interest: The authors have no relevant financial or non-financial interests to disclose.

Consent for Publication: All authors made contributions to the study, reviewed and approved the final version to be published, and accepted responsibility for the accuracy of the study.

Data availability: The supporting data and the SAS code used in this study are accessible in the Harvard Dataverse at: https://doi.org/10.7910/DVN/VXWBPE.

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11 APPENDIX

11.1 Appendix 1.

Profit-Rated Performance Variable Calculation – General Model

Assume you want to analyse an expression for U, defined by the linear combination:

$$U \equiv \sum_j P_j V_j$$

where *P* and *V* are two variables. Assume another variable *Z* that affects U through its effect on P and *V*. The direct effects of P and *V* on U can be eliminated by replacing each variable with its average and analysing the effects of Z on the modified sum.

$$U^{(-P_k)} = \sum_{\forall j, j \neq k}^{-k} P_j V_j + \overline{P}_k V_k$$

where $\overline{P_k}$ is the average value of P_k. $U^{(-P_k)}$ now represents a modified sum, excluding the contribution of the variable P_k.

The same can be done for any V variable. To isolate the effect of a specific V_k, we replace V_k with its average $\overline{V}_k$, resulting in the following modified sum:

$$U^{(-V_k)} = \sum_{\forall j, j \neq k}^{-k} P_j V_j + P_k \overline{V}_k$$

where $\overline{V}_k$ is the average value of V_k. The expression $U^{(-V_k)}$ represents the value of U, after excluding the contribution of the variable V_k.

Incorporating the Effect of Z.

We can now define a second model where the effect of variable Z on *U* is captured through the effect it has on each of $U^{(-P_k)}$ and $U^{(-V_k)}$.

$$U^{(-P_k)} = P(Z)$$
$$U^{(-V_k)} = V(Z)$$

Thus, the derivatives $\frac{dP(Z)}{dZ}$ and $\frac{dV(Z)}{dZ}$ capture the effects of *Z* on *U* through *P* and *V*.

Empirical Model Using the Profit per kg Equation.

The general model can be expressed empirically with our profit equation:

$$\frac{\pi}{y} = P_y - P_f(FCR) - P_s(SR) - P_l(LR) - \frac{O_{cost}}{y}$$

where we define the components as follows:

V = $\left\{1, -\text{FCR}, -\text{SR}, -\text{LR}, -\frac{O_{cost}}{y}\right\}$

P = $\left\{P_y, P_f, P_s, P_l, \text{and } 1\right\}$, and

U = $\frac{\pi}{y}$ (Profit per kg)

This formulation allows us to evaluate how each variable within *P* and *V* individually contributes to profit per kg, by isolating and analysing the impact of each component. Additionally, the effect of a third variable *Z*, which may influence *U* through its interaction with *P* and *V*, can be assessed via the modified forms $U^{(-P_k)}$ and $U^{(-V_k)}$.

The left side of the profit per kg equation (modified forms, expanded in Equations 2 and 3) was structured as an Excel formula to derive values for specific profit-rated variables. This configuration enabled us to isolate and track the unique contributions of the performance variables.

11.2 Appendix 2.

Table A.1. Model showing the effect of interaction between Tactical decision policy-related factors and major knowledge variables on profit.

Parameter	Estimate	Standard Error
Intercept	133.62***	9.38
EXP5nBelow *Local feed	-28.42	40.73
Local feed*EXP6 to 10	78.54(*)	45.89
Local feed*EXP11 to 15	127.47*	59.13
Local feed*EXP16 and above	102.47(*)	56.24
Local feed*Training	-42.13	42.44
Local feed*Extension	24.97	43.41
Local feed*Social Media	-14.20	47.21
EXP5nBelow*Fingerling	-161.38***	48.97
EXP6 to 10*Fingerling	-15.70	37.89
EXP11 to 15*Fingerling	42.00	52.43
EXP16nAbove*Fingerling	-9.99	58.79
Training*Fingerling	-14.82	39.98
Extension*Fingerling	-28.20	35.34
Social Media*Fingerling	125.38***	38.81

Note: *(*), *, **, and *** in the Estimate column denote statistical significance at the 10%, 5%, 1%, and 0.1% levels, respectively.*

Paper V

Data in Brief 52 (2024) 109917

Contents lists available at ScienceDirect

Data in Brief

journal homepage: www.elsevier.com/locate/dib

Data Article

A national survey data for the technical and economic assessment of African catfish production in Nigeria before and during the COVID-19 period

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ARTICLE INFO

Article history:
Received 15 October 2023
Revised 25 November 2023
Accepted 30 November 2023
Available online 6 December 2023

Dataset link: Technical and Economic Assessment of Catfish Farming in Nigeria (pre- and post-COVID data) (Original data)

Keywords:
Aquaculture
Production management
Production scale
Experience
Markets
Feed types
Profitability
Production constraints

ABSTRACT

This data article presents a dataset obtained from a national survey of African catfish production in Nigeria. The African catfish is an important aquaculture species in various regions in the world and it is, after Tilapia, the most commonly cultured fish in Africa. Nigeria's share in the global production of African catfish exceeds 67 %. The dataset encompasses data collected from ten major catfish-producing states in Nigeria, with a focus on two distinct periods: before and during the COVID-19 pandemic. A total of 609 operations were captured for the pre-COVID and 509 for the COVID period. The dataset includes a wide array of variables, covering the cost and quantities of inputs and outputs, socioeconomic factors, market dynamics, feed types, challenges faced by farmers, scale of production, and farmers' level of experience. It offers valuable insights and opportunities for various stakeholders. Researchers can utilize it to explore production performance, resilience, and adaptation strategies. Industry players, including catfish farmers and suppliers, can make data-driven decisions to enhance their operations. Policymak-

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https://doi.org/10.1016/j.dib.2023.109917

ers can formulate evidence-based policies to support sustainable growth in the catfish farming sector. Other developing countries can draw lessons from Nigeria's experiences to bolster their aquaculture sectors.

Specifications Table

Subject	Agricultural Sciences/ Aquaculture
Specific subject area	Economic assessment, production management and profitability dynamics
Data format	Cleaned raw data, partly analysed data, questionnaire template.
Type of data	xlsx file (data set with numbers and strings).xlsx file (questionnaire template for the Open Data Kit - ODK).pdf file (PDF format of the survey form)
Data collection	The survey was carried out from May 2021 to February 2022 through interviews by pre-trained enumerators using an electronic questionnaire – open-data-kit (ODK). A multi-stage sampling technique was used. The 10 states were purposively selected while the farmers within each state were randomly selected from lists provided in the states. The elicited information consisted of the production cost and quantity, socioeconomic information, pond types, major feed used, market, constraints, sources of technical support variety of and other variables. The production data collected is based on a cycle and therefore the fixed cost was prorated to a cycle and the production scale to a year (details in the data description section).
Data source location	Country: Nigeria City/Town/Region: Adamawa, Benue, Delta, FCT, Imo, Kaduna, Lagos, Oyo, Rivers, and Sokoto States.
Data accessibility	Repository name: Harvard Dataverse Data identification number: https://doi.org/10.7910/DVN/4JIRV9 Direct URL to data: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/4JIRV9
Related research article	[1] O. F. Olagunju, D. Kristófersson, T. Kristjánsson, and T. Tómasson, "Technical efficiency of African catfish production in Nigeria: An analysis involving input quality and COVID-19 effects," *Aquaculture Economics & Management*, pp. 1–27, Jun. 2023, doi: 10.1080/13657305.2023.2222687

1. Value of the Data

- The aquaculture sector can benefit from the dataset by gaining insights into the resilience and adaptability of catfish farming during challenging times like the COVID-19 pandemic. It can provide a foundation for theoretical considerations of the mechanisms that contribute to the sector's ability to navigate challenges, serving as a valuable case study for enhancing overall resilience and sustainability in aquaculture.
- Researchers can use this data to conduct in-depth studies on African catfish production trends, efficiency, and challenges. They can analyse the impact of the COVID-19 pandemic on the industry, identify best practices, and develop strategies for sustainable catfish farming.
- Industry stakeholders, including catfish farmers, input suppliers (e.g., feed and equipment), and processors, can gain insights from the data to optimise their operations. It can help them make informed decisions on resource allocation, production techniques, and market positioning.
- Economic theories related to market dynamics and pricing mechanisms can be applied to understand how changes in demand and supply influenced catfish prices before and

during the pandemic. This could also include an examination of how market structures may have shifted during this period.
- Policymakers can use these data to formulate evidence-based policies and regulations that support the growth and sustainability of the catfish industry. It can inform decisions related to subsidies, environmental management, and market access.
- Developing countries with growing aquaculture sectors can learn from Nigeria's experience. They can adopt successful practices and avoid common challenges by studying the data. This knowledge exchange can enhance the development of the aquaculture sectors in other countries.

2. Data Description

Data from 609 catfish farms were validated and accepted for inclusion in the dataset [2]. The most recent available data were obtained from the farms. All the farms were able to provide their pre-COVID operation data, while only 509 of them reported on operations for the COVID period mostly because they had discontinued operations during that period. The detailed record of removed data could not be adequately tracked as there was active monitoring during the data collection. Farm data with discrepancies, uncertainties, or misreported key production data after clarifications and consultations were removed and data collection continued. In total, about 50 datasets were removed.

2.1. The cleaned raw data

Structurally, the questionnaire was classified into one background and four main sections addressing Pre-COVID Production, COVID Production, Management, and Socioeconomic data. The background section elicited information useful for identification and site location. This was followed by the production evaluation data for the two periods as well as the management and socioeconomic data of the farms. In the data spreadsheet (Survey data on catfish farming in Nigeria before and during COVID.xlsx), the data were first arranged based on the different periods with the pre-COVID data arranged in the first 609 rows followed by the COVID period data, making a total of 1118 rows of data. The first series of columns focused on the production data (F to BD) and their derived estimates (Q-T, AZ, BE-BQ). This was followed by the management and the socioeconomic data. While the production data were obtained separately for the two periods, the management and socioeconomic data of the respective individual farms were the same. This should be considered when analysing and interpreting the management and socioeconomic data for the different periods. The production data was collected for a complete production cycle for each period which lasts usually for three to six months, although during COVID, it could extend beyond six months. The production evaluation data includes the stocking and harvest dates; fingerlings quantity, price and source; cost, size and type of pond stocked with the specified fingerlings; details about the feed used including commercial feed and locally compounded feed; maintenance and other costs (Maint-Other cost) which include costs of fertilizers, water supply, electricity, treatment and maintenance of ponds; and lastly, harvest and revenue data.

Data relating to management (BY-CQ) includes the number and cost of labour engaged and the nature of their engagement (household or hired), farm type, number of cycles covered yearly, total annual production, product forms and market type. The labour characteristics are presented in two ways: (1) based on engagement, including household labour (Household), or (2) if only hired labourers were engaged. An additional column also provides information on whether the household labour was paid or unpaid, with hired labourers classified as paid under this column. The farm types considered are mainly three: backyard (in-house) farms, farm site (outside the residence) farms, and those who are part of a farm cluster (Fig. 1).

The last set of variables was the socioeconomic and other characteristics of the farm (CR-DX). These include data on the sex of the respondent (manager or owner of the farm), types

Fig. 1. Google Earth imagery of a fish farm cluster in Nigeria covering about 30 hectares with many small pond units (the smaller ones are about 70 m^2 each). Each farmer may have 1 to 5 ponds in the cluster. Measurements made using Google Earth measuring tool.

of ponds available on the farm (this includes all pond types on the farm), age range, education level, and major occupation of the farmer, farming experience, source of technical support, constraints, water source, ownership status, types of farm records and production technique based on water usage. Lastly, this section includes information on farmers known to have discontinued fish farming and the causes of their departure.

The question soliciting whether the farmer operated during the COVID period and the impact of COVID on the farmers' operations (BR-BX) comes immediately after the production data but should be treated like the management and socioeconomic data in that a single response was provided by each farmer for both the pre-COVID and COVID periods.

2.2. Calculated variables

The calculated variables include other costs (Maint-Other cost), labour cost, fixed cost and the production scale of the farms (Q-T, AZ, BE-BQ, CG, CJ). Maint-Other cost is the sum of the costs of fertilisers, water supply, electricity, treatment and maintenance of ponds. Nevertheless, each component of other costs can be used independently. The labour cost in the survey was provided as the monthly wage of hired workers. This was prorated based on the annual production of the farm to determine the labour cost for the cycle. In the case of the small-scale farmers who often rely on family labour, the labour cost was taken as an opportunity cost for the farmer as reported by Ali et al. [3]. In such instances, the next best value below the utility derived by other farms was used [4]. Labour measurements in man-days in aquaculture are typically calculated by considering the duration of the culture period and the intensity of the culture system (intensive, semi-intensive or extensive [5]. The length of the production cycle is provided in the dataset and all the catfish farms surveyed practiced intensive farming. Other related data included the number of labourers and the nature of their engagement.

The depreciated cost of the pond or the amount leased for the period was provided as the fixed cost for owned and leased farms, respectively. In cases where the farmers could not provide the cost of construction or purchase of pond, value of the nearest alternative was used based on the pond size and type provided. The annual production for each farm was directly obtained from the data but this was further reviewed in line with the production quantity reported per cycle and the duration of each cycle as reported by the farmer.

Table 1
Included validation variables and calculations used in the survey.

Variable	Meaning	Calculation
totseed.cost	Fingerlings cost	Number of fingerlings X unit cost of fingerlings
days.culture	Total days of culture	Stocking date minus harvest date
fishprice	Price of fish per kg	Revenue / harvest quantity
harvestplus	Harvest plus	Reported harvest plus the quantity reserved
revenueplus	New revenue with reserved fish considered	Harvestplus X Price
fcr	Feed Conversion Ratio	Feed quantity / quantity harvested
seed.harvest	Seed to Harvest Ratio	Seed quantity stocked / quantity harvested
feedc.kgfeed	Per kg cost of feed	
feedc.kgharv	Cost of feed used to achieve 1 kg fish	Feed cost / quantity harvested
seedwt	Fingerlings weight (g)	Fingerlings no. X Average unit weight
wtgain	Weight gain	Harvest weight minus Fingerlings weight
fcrplus1	Feed Conversion Ratio – Plus1	Feed Conversion Ratio calculated using Weight gain
fcrplus2 wt HvP*	Feed Conversion Ratio – Plus2	Feed Conversion Ratio calculated using Weight gain based on harvestplus

* Was not included in the initial survey calculation but later calculated in the Excel sheet.

2.3. Integrated calculation and validation checks

The data was validated through calculations of several variables which were added to the questionnaire (Table 1). In addition to being used as validation checks, they are relevant and useful values retained in the data. The questionnaire template (Nigeria Catfish Fish farm_states - ODK xlsform.xlsx) with the validation checks and the sample survey form (Survey of catfish farms in Nigeria-form.pdf) have been shared online at https://doi.org/10.7910/DVN/4JIRV9, Harvard Dataverse.

3. Experimental Design, Materials and Methods

3.1. Sampling design

The sampling design followed the approach of Subasinghe et al. [6], who employed a multi-stage sampling procedure that combined both probability (random) and non-probability (purposive) techniques [7] in sampling fish farms in Nigeria.

Stage I: Purposive selection of state with due consideration given to (i) geographical or regional representation, taking into account their production and agroecological characteristics relative to close non-selected states; (ii) availability of adequate number of catfish farms that allows for a reasonable random selection of a sample size; and (iii) security concerns.

Stage II: Purposive selection of main production areas within each state (Table 2). In collaboration with state supervisors and local experts, major production areas were identified for consideration. This ensured that the survey covers regions that are representative of the state's overall catfish production landscape. In addition, the survey can then concentrate efforts on areas that play a crucial role in the state's aquaculture output.

Stage III: Random sampling approach was employed to select individual farmers to participate in the survey from the selected areas. In each state, farmers were randomly drawn from collated lists obtained from government agricultural agencies, feed suppliers, and relevant associations.

To avoid overrepresentation of cluster farms and to ensure a more diverse and representative sample, purposive exclusion principle was adopted by limiting the number of farms that can be

Table 2
Data collection areas under the different states selected for the survey.

Region/Zone	State	Local Government Areas (LGAs)/Area Councils covered
North		
North-Central	Benue	*Gboko, Makurdi and Otukpo*
North-Central	FCT	*Abuja Municipal, Bwari, Gwagwalada and Kuje*
North-East	Adamawa	*Demsa, Girei, Numan, Mubi North, Mubi South, Yola North, and Yola South*
North-West	Kaduna	*Chikun, Igabi, Kaduna North, Sabon-gari and Zaria*
North-West	Sokoto	*Dange Shuni, Kware, Sokoto North and Sokoto South*
South		
South-East	Imo	*Ideato North, Ikeduru, Mbaitoli, Nwangele, Owerri Municipal, Owerri North and Owerri West*
South-South	Delta	*Ethiope West, Isoko North, Isoko, South, Sapele and Uvie*
South-South	Rivers	*Obio/Akpor, Port Harcourt*
South-West	Lagos	*Agege, Alimosho, Amuwo-Odofin, Apapa, Ajeromi, Badagry, Ifako-Ijaye and Oshodi-Isolo*
South-West	Oyo	*Akinyele, Egbeda, Ido, Ibadan North, Ogbomoso North, Oyo East and Oyo West*

Source: Field survey (2021/2022).

Table 3
Sample size estimation and the number of samples collected from the states surveyed in Nigeria.

Region/Zone	State	Farmers No.	Calculated minimum sample size	Pre-COVID	COVID
North		**2693**	**135**	**281**	**235**
North-Central	Benue	400	20	52	34
North-Central	FCT	497	25	62	59
North-East	Adamawa	508	25	64	52
North-West	Kaduna	1110	56	57	44
North-West	Sokoto	178	9	46	46
South		**4603**	**230**	**328**	**274**
South-East	Imo	201	10	46	44
South-South	Delta	621	31	72	60
South-South	Rivers	287	14	64	58
South-West	Lagos	3000	150	74	57
South-West	Oyo	494	25	72	55
Grand Total		**7296**	**365**	**609**	**509**

Source: Field survey (2021/2022). Adapted from Olagunju, et al. [1], with modifications.

sampled in a particular cluster. The number of farms in clusters is usually high, and if not regulated in data collection, the majority of the data collected might be dominated by cluster farms. A dedicated survey could be carried out focusing only on cluster farms and their performance.

A total of 7296 farmers were collated from the farmers lists (Table 3). For such a population size, the minimum sample size should be 365 at 95 % confidence interval and 5 % margin of error. We however increased our target sample size beyond this number to allow for more representativeness of the sample and improve the generalizability of study findings to the broader population. Larger datasets are less sensitive to the influence of outliers or extreme values, ensuring that the results are less likely to be distorted by individual observations. Overall, using the multistage approach, a total of 609 catfish farmers data were sampled covering 10 states from the 6 geo-political zones and 2 regions of the country (Fig. 2).

3.2. Survey design

The survey was carried out through a series of interviews conducted between May 2021 and February 2022. The pre-COVID data comprises the most recent information obtained from farms prior to 2020, whereas the COVID period data includes information from the years 2020 and

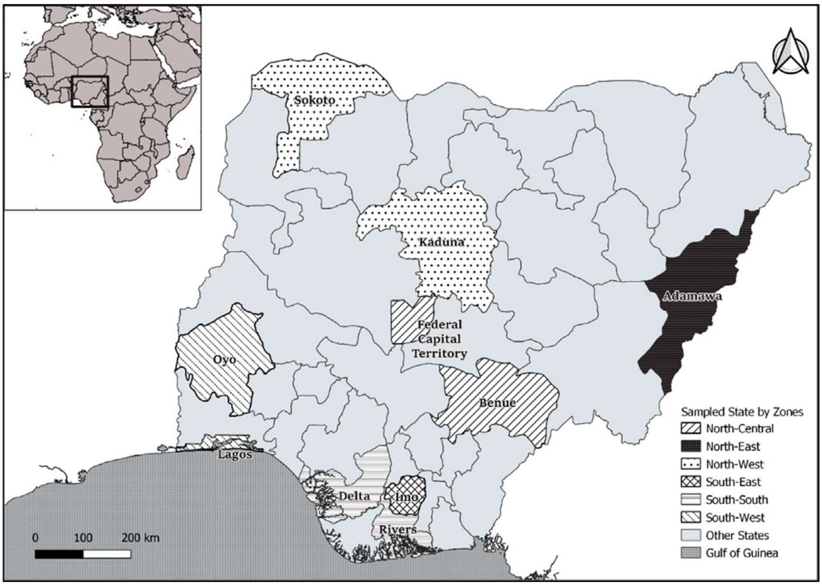

Fig. 2. A map of the Federal Republic of Nigeria indicating the zones and states where the survey was conducted. Adapted from Olagunju, et al. [1], with modifications.

2021. The survey was conducted using the Open Data Kit (ODK) platform. A comprehensive questionnaire was designed to capture a wide range of information related to African catfish farming in Nigeria. The questionnaire employed was an adaptation of the one utilised in the preliminary study conducted in the Federal Capital Territory [8]. It was structurally adjusted to comprehensively capture data for both the pre-COVID and COVID periods. The questionnaire included variables such as input and output quantities, socioeconomic factors, market dynamics, feed types, challenges faced by farmers, production scale, and farmers' experience levels. A team of trained enumerators was engaged to administer the surveys. They were equipped with the necessary skills to effectively conduct interviews with catfish farmers. Meetings and training sessions were conducted with enumerators in various states before the data-collection process to provide them with hands-on training. Additionally, follow-up meetings were held both midway and after data collection to oversee and evaluate the entire process. The data collection primarily took place on-site, with the acquisition of farm photos and geo-locations for the purposes of data verification and cleaning (not included in the dataset for privacy reasons). The enumerators received training on survey protocols and techniques for ensuring data accuracy.

3.3. Data quality management

The data collection process was monitored and facilitated by the corresponding author. It included continuous verification and clarification steps. The enumerators worked closely with the participating farmers to ensure that the information provided was accurate and complete. Doubtful or uncertain data were promptly identified and addressed. To enhance data quality, validation checks were integrated into the ODK survey forms. These checks helped in the real-time identification and correction of errors during data entry. The data validation also involved utilising sector-specific expertise and comparing it with related data from individual states. After the data collection, a thorough cleaning process was performed to identify and address any outstanding inconsistencies or inaccuracies. Data that were doubtful due to discrepancies or farmer uncertainty were discarded to maintain data integrity. Furthermore, the approach we adopted in the data collection was aimed at preventing or minimizing cases of missing or invalid data. The use of electronic questionnaire allowed us to make questions compulsory and incorporate calculations that would signal the occurrence of any anomaly. Nevertheless, there were instances of missing data points, such as pond costs (see section “Calculated variables” on how we addressed this). Moreover, some data points were empty, not because they were missing but they were not applicable to the farmer. Example of such is “Other costs” which some small producers did not report any data for, they were left empty. The choice of the methodology to use in addressing such missing data is left to the researcher (potential data user) based on the objective of their study and what they intend to use the data for.

Limitations

While the survey data and enumerators’ feedback suggest that a significant number of farmers withdrew from farming operations during the COVID-19 period, our data cannot directly provide the percentage of farmers who did or did not produce during the pandemic. Nevertheless, the data can be used to make meaningful comparisons between farm operations, performance, and characteristics before and during COVID. This is because, for 48 farms (DataID: PREC562-609), we could not ascertain whether some of them produced during COVID-19 period as they were only asked to provide data for operations before pandemic lockdown, and two farmers’ COVID period data (PREC513 and 517) were removed for incompleteness. However, a proportionate inference on percentage of producers during the periods can be drawn by excluding these 48 farms from the sample and correcting for the two that have incomplete data. We believe that future researchers could further enhance the dataset, specifically by focusing on farmers operating in clusters.

Ethics Statement

The authors confirm that we have read and followed the ethical requirements for publication in Data in Brief and confirm that the current work does not involve human subjects, animal experiments, or any data collected from social media platforms. Each participant was notified that their responses would be included in a research project and consented to this by completing the questionnaire. To safeguard the privacy of the participants, all collected data were anonymized. Identifying information, such as names and personal details, were replaced with unique codes to ensure confidentiality.

Data Availability

Technical and Economic Assessment of Catfish Farming in Nigeria (pre- and post-COVID data) (Original data) (Dataverse).

CRediT Author Statement

Olanrewaju Femi Olagunju: Conceptualization, Methodology, Writing – original draft, Formal analysis, Data curation, Writing – review & editing; **Dadi Kristofersson:** Conceptualization, Methodology, Supervision; **Tumi Tómasson:** Conceptualization, Writing – review & editing, Supervision; **Theódór Kristjánsson:** Writing – review & editing, Supervision.

Acknowledgements

The survey was sponsored by the UNESCO GRO-Fisheries Training Programme, Iceland. We are grateful to our team of 45 enumerators and supervisors across the 10 States. We are thankful to the government officers, fish feed suppliers and the catfish farmers who provided list of catfish farmers and participated in the survey. Special thanks to Bashir Amin (Retired Deputy Director of Fisheries/Aquaculturist and Consultant) and Gafar Wahab (Aquaculturist/Federal Livestock Officer, Lagos State) for insightful discussions on sectoral indicators, and Oluwaseun Osiyoye (FCT Fisheries Officer) who assisted with data verification.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

A1. Survey Questionnaire for Data Collection on Catfish Farms in Nigeria

Survey of Catfish Farms in Nigeria

Catfish farm data

The information provided in this survey will only be for research purpose. This survey aims to collect a mixture of your general information and details of your fish farm operations before COVID-19 and during COVID-19 pandemic. Provision of your personal or farm name is not compulsory but would be appreciated. Thank you.

Enumerator's Phone Number

Kindly provide your mobile contact for communication and clarification.

a. Farm ID

Use the state code assigned to you (e.g. OY.01)

b. Please collect GPS coordinate

Ensure the accuracy is one digit (i.e. 9 & below) or very close where impracticable.

latitude (x.y °)

longitude (x.y °)

altitude (m)

accuracy (m)

c. Contact person phone number

d. State

- ○ Oyo
- ○ Benue
- ○ Rivers
- ○ Lagos
- ○ Kaduna
- ○ FCT
- ○ Delta
- ○ Osun
- ○ Imo
- ○ Adamawa
- ○ Sokoto

e. Farm Name

____

f. Respondent name

____

SECTION 1. PROVIDE PRE-COVID PRODUCTION DATA HERE

1. Stocking Year

____

2. Date of stocking

yyyy-mm-dd

3. Date of Harvest

yyyy-mm-dd

4. Number of fingerlings stocked

(The term FINGERLING is generic here. It could mean FINGERLING or JUVENILE)

____

5. Average size of fingerling stocked (g)
Average size of a single fingerling in grams

____

6. Unit price of fingerlings (Naira)

____

7. Source of fingerlings

- ◯ On Farm
- ◯ Other farms or hatcheries

8. Number of ponds stocked
Only for the ponds stocked with the specified fingerlings

____

9. Type of pond stocked
The specific type of pond stocked with those fingerlings.

- ◯ Mobile pond (including plastic ponds and collapsible)
- ◯ Earthen pond
- ◯ Concrete pond
- ◯ Cage culture

10. Cost of pond (Naira)
(Provide rental value if leased, rented or cost not known)
Cost for the specific pond stocked with those fingerlings.

____

11. Mortalities (Number)

____

12. Pond dimension (Area in square meters)
Only for the ponds stocked with the specified fingerlings

____

13. Select at most 3 major feeds used

Please select all that apply . If it's not up to 3 just select applicable ones.

- [ ] Blue crown
- [ ] CHI
- [ ] Ecofloat
- [ ] Skretting
- [ ] Top Feed
- [ ] Vital Feed
- [ ] Aqualis
- [ ] Prime
- [ ] Aller Aqua
- [ ] Raanan
- [ ] Aquamax
- [ ] Acefeed
- [ ] Coppens
- [ ] Dickem
- [ ] Other commercial feeds
- [ ] Compounded/ Local Feed

14. If compounded feed or locally produced feed was selected, for how many days was it used in feeding?

Your answer should be provided in days. If the farmer provide months, you can convert it to days.

____

15. Total feed quantity (Bags)

This should include value of compounded feed if used.

____

16. Total feed quantity (Kg)

This should include value of compounded feed if used.

____

17. Total cost of feed (Naira)

This should include value of compounded feed if used.

____

18. Manure or fertilizer used (kg)

____

19. Price of manure or fertilizer (Naira)

____

20. Cost of water supply (Naira)
(This may be cost of pumping water or water purchase)

____

21. Cost of electricity (Naira)

____

22. Cost of generator fuel (Naira)

____

23. Cost of treatment (Naira)(antibiotics/ probiotics/ salts)

____

24. Cost of nutrient booster (Naira)

____

25. Maintenance and repairs (Naira)

____

26. Total harvest (kg)

____

27. Quantity reserved from harvest (kg)

____

28. Average weight of majority (kg)
(i.e. Average weight of one fish)

____

29. Total sale value (Naira)

Total amount of revenue from fish sale.

30. Have you produced since the COVID-19 period?

- Yes
- No

SECTION 2. PROVIDE COVID-19 PERIOD PRODUCTION DATA HERE

1. Stocking Year

2. Date of stocking

yyyy-mm-dd

3. Date of Harvest

yyyy-mm-dd

4. Number of fingerlings stocked

(The term FINGERLING is generic here. It could mean FINGERLING or JUVENILE)

5. Average size of fingerling stocked (g)

Average size of a single fingerling in grams

6. Unit price of fingerlings (Naira)

7. Source of fingerlings

- On Farm
- Other farms or hatcheries

8. Number of ponds stocked

Only for the ponds stocked with the specified fingerlings

____

9. Type of pond stocked

The specific type of pond stocked with those fingerlings.

- ◯ Mobile pond (including plastic ponds and collapsible)
- ◯ Earthen pond
- ◯ Concrete pond
- ◯ Cage culture

10. Cost of pond (Naira)
(Provide rental value if leased, rented or cost not known)

Cost for the specific pond stocked with those fingerlings.

____

11. Mortalities (Number)

____

12. Pond dimension (Area in square meters)

Only for the ponds stocked with the specified fingerlings

____

13. Select at most 3 major feeds used

Please select all that apply . If it's not up to 3 just select as it applies.

- ☐ Blue crown
- ☐ CHI
- ☐ Ecofloat
- ☐ Skretting
- ☐ Top Feed
- ☐ Vital Feed
- ☐ Aqualis
- ☐ Prime
- ☐ Aller Aqua
- ☐ Raanan
- ☐ Aquamax
- ☐ Acefeed
- ☐ Coppens
- ☐ Dickem
- ☐ Other commercial feeds
- ☐ Compounded/ Local Feed

14. If compounded feed or locally produced feed was selected, for how many days was it used in feeding?

Your answer should be provided in days. If the farmer provide months, you can convert it to days.

____

15. Total feed quantity (Bags)

This should include value of compounded feed if used.

____

16. Total feed quantity (Kg)

This should include value of compounded feed if used.

____

17. Total cost of feed (Naira)

This should include value of compounded feed if used.

____

18. Manure or fertilizer used (kg)

____

19. Price of manure or fertilizer (Naira)

____

20. Cost of water supply (Naira)
(This may be cost of pumping water or water purchase)

____

21. Cost of electricity (Naira)

____

22. Cost of generator fuel (Naira)

____

23. Cost of treatment (Naira)(antibiotics/ probiotics/ salts)

____

24. Cost of nutrient booster (Naira)

____

25. Maintenance and repairs (Naira)

____

26. Total harvest (kg)

____

27. Quantity reserved from harvest (kg)

____

28. Average weight of majority (kg)
(i.e. Average weight of one fish)

____

29. Total sale value (Naira)

Total amount of revenue from fish sale.

____

30. In what way did the COVID-19 affected your operation?

Please select all that apply.

- [ ] Reduced production quantity
- [ ] Reduced demand (reduced sales and market)
- [ ] Reduced profit margin
- [ ] No profit made (It resulted in loss)
- [ ] Not affected at all

SECTION 3. PROVIDE LABOUR AND MANAGEMENT DATA

1. Wages: Farm manager (Naira)

Provide a MONTHLY amount of the labour cost. Estimate the monthly cost if not provided directly.

2. Wages: Security (Naira)

Provide a MONTHLY amount of the labour cost. Estimate the monthly cost if not provided directly.

3. Wages: Attendants/Casuals (Naira)

Provide a MONTHLY amount of the labour cost. Estimate the monthly cost if not provided directly.

4. Wages: Other personnel (Naira)

Provide a MONTHLY amount of the labour cost. Estimate the monthly cost if not provided directly.

5. Total number of workers

6. Do the workers have other responsibilities aside from attending to the fish farming?

- ( ) Yes
- ( ) No

7. How best can we describe the nature of the labour?

- ◯ Household/family labour (Unpaid)
- ◯ Household/family labour (Paid)
- ◯ External individual/ labour (Paid)
- ◯ Combinations of the above

8. Select farm type

- ◯ Homestead
- ◯ Cluster
- ◯ Farm Site (farm outside owner's home but not cluster)

9. Average annual production from farm (Kilograms)

____

10. Select farm category based on total yearly (annual) production.

Note that if the farm mainly uses mobile tanks or collapsible ponds, you can categorize as Concrete.

- ◯ MicroSmall-Concrete-Owned (<5tons)
- ◯ MicroSmall-Earthen-Owned (<5tons)
- ◯ MicroSmall-Earthen-Leased (<5tons)
- ◯ Small-Concrete-Owned (5-10tons)
- ◯ Small-Earthen-Owned (5-10tons)
- ◯ Small-Earthen-Leased (5-10tons)
- ◯ Medium-Concrete-Owned (11-15tons)
- ◯ Medium-Earthen-Owned (11-15tons)
- ◯ Medium-Earthen-Leased (11-15tons)
- ◯ Large (15-50tons)

11. Cycles of production in a year.

- ◯ 1 Cycle
- ◯ 2 Cycles
- ◯ 3 Cycles
- ◯ 4 Cycles
- ◯ 5 Cycles and above

12. Select the MAIN product form in which you sell your fish

Please select one

- ◯ Live or Fresh
- ◯ Frozen
- ◯ Smoked
- ◯ Others product form

13. Select OTHER product forms in which you sell your fish

Please select all that apply.

- ☐ Live or Fresh
- ☐ Frozen
- ☐ Smoked
- ☐ Others product form

14. Select one major type of market for your product

- ◯ Retailers
- ◯ Wholesalers (Bulk buyers)
- ◯ Restaurants, Eateries or Hotels
- ◯ Individuals
- ◯ Processors

SECTION 4. SOCIOECONOMIC DATA

---

1. Gender

Just select the right option without asking the respondent.

- ◯ Male
- ◯ Female

2. Pond types used by the farmer.

You can select more than one if applicable.

- ☐ Mobile pond (including plastic ponds and collapsible)
- ☐ Earthen pond
- ☐ Concrete pond
- ☐ Cage culture

3. Age Range (Year)

- ◯ <=30
- ◯ 31-40
- ◯ 41-50
- ◯ 51-60
- ◯ >60

4. Education

- ◯ None
- ◯ Arabic
- ◯ Primary
- ◯ Secondary
- ◯ ND/NCE
- ◯ Degree
- ◯ MSC Above(Grad-studies)

5. Main Occupation

- ◯ Civil Servant
- ◯ Fish Farming
- ◯ Other Agric Ventures
- ◯ Employed in a private organization
- ◯ Personal Business
- ◯ Others

6. Household size

- ◯ <=5
- ◯ 6-10
- ◯ 11-15
- ◯ >16

7. Fish Farming Experience

- ◯ <=5
- ◯ 6-10
- ◯ 11-15
- ◯ >16

8. Source of Technical Support

Where the farmer gain knowledge and assistance from. Please select all that apply.

- ☐ Extension Agent
- ☐ Other Farmers
- ☐ Social Media
- ☐ Training Courses

9. Constraint

Please select all that apply

- ☐ Animal Interference
- ☐ Fish Feed Quality
- ☐ Inadequate Technical Knowledge
- ☐ Marketing
- ☐ Poor Fish Performance
- ☐ Fish Feed Cost

10. Water Supply Source

Please select all that apply

- ☐ Borehole
- ☐ Spring (Underground)
- ☐ Stream or River
- ☐ Well

11. Ownership status of pond

- ○ Owned
- ○ Rented/Leased

12. Record keeping of farm activities

- ○ All farm records (input quantities, finance, feed used etc.)
- ○ Only financials

13. Production technique

- ○ Stagnant water
- ○ Continuous flow through
- ○ Water change at intervals

14. How many fish farms have stopped operating (no longer farming) in your area in recent years that you know?

If none, type 0.

15. What were the reasons?

You can type out the reasons in few words. Separate by comma if the reasons are more.

Farm picture

Please provide a good shot of the farm with permission from the owner.

Click here to upload file. (< 5MB)

Enumerator's Comment

Kindly provide additional information about the data that can help in understanding the data better for analysis.

A2. Geographical Map Showing Within-State Spread of Sample Locations