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Aquaculture and Rural Communities: Farm Diversification Strategy through Integrated Agriculture-Aquaculture Systems and Nutrition-Sensitive Value Chains for Better Nutrition Outcomes

Fish Innovation Lab

Final Technical Report [October 2021 – September 2023]

Cooperative Agreement 7200AA18CA0030



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[August 2023]

Prepared by:

Lead PI: Matthias Halwart, PhD
Food and Agriculture Organization of the United Nations

Lead Co-PI: Xinhua Yuan, PhD
Food and Agriculture Organization of the United Nations

Nigeria PI: Emmanuel K. Ajani, PhD
University of Ibadan

Nigeria Co-PI: Bamidele O. Omitoyin, PhD
University of Ibadan

U.S. PI: Amrit Bart, PhD
University of Georgia

U.S. Co-PIs: Esendugue G. Fonsah, PhD
University of Georgia

Gary Burtle, PhD
University of Georgia

Project Coordinator: Oluwafemi Ajayi
Food and Agriculture Organization of the United Nations

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Partners/Institutions

The Food and Agriculture Organization of the United Nations (FAO)

Viale delle Terme di Caracalla

00153 Roma RM

Italy

University of Ibadan

Agbowo, Oyo Road, 200005, Ibadan, Oyo State

Nigeria

University of Georgia

Athens, GA 30602

United States of America

Abbreviations and Acronyms

BE	Break-even
FIES	Food Insecurity Experience Scale
FAO	Food and Agriculture Organization of the United Nations
GFSS	Global Food Security Strategy
GIS	Geographical Information System
GSAAP	Global Sustainable Aquaculture Advancement Partnership
H&MC	Harvesting and marketing costs
HDDS	Household Dietary Diversity Score
IAA	Integrated Agriculture-Aquaculture
IRF	Integrated rice and fish
KBTv	Kebbi State Television Service
P-VC	pre-variable costs
ROI	Return on Investment
R&D	Research and Development
TI	Test Ingredient
TC	Total Cost of Production
TFC	Total Fixed Cost
TVC	Total Variable Cost
UGA	University of Georgia
UI	University of Ibadan
USAID	United States Agency for International Development
WTP	Willingness to Pay

Glossary

Term	Meaning
Agripreneurship	Refers to entrepreneurship in agriculture
Aquatic biodiversity	Aquatic biodiversity is the rich and wonderful variety of plants and animals that live in watery habitats.
Entrepreneurship	Entrepreneurship refers to the process of creating a new enterprise and bearing any of its risks, with the view of making the profit.
Malnutrition	Malnutrition results from deficiencies, excesses or imbalances in the consumption of macro- and/or micronutrients.
pH	Potential of Hydrogen
Phytoplankton	Very small aquatic plants which are suspended in the water; plant component of the plankton
Plankton	The various very small organisms, either plants (phytoplankton) or animals (zooplankton), which live suspended in the water
Wetland	Wetlands have been defined as areas that have free water at or on the surface for at least the major part of the growing season

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Abstract

The farm diversification process through integrated agriculture-aquaculture introduced a combination of aquaculture-related technologies into transforming existing farm practices in rice growing communities of Kebbi and Ebonyi states. The technologies introduced include the co-culture of rice and fish, fish seed production, fish feed production and value-addition through smoking. A total of 727 farmers, graduate students, and extension workers were trained on the different farm diversification processes, among them were 232 female, 495 male and 54 youths (32 percent of project beneficiary are female, 7 percent youth). The implementation of these activities has led to the initiation of agri-food systems transformation of rice-growing communities for better production, better nutrition, better environment and better life, making farming activities more productive and resilient. Additionally, students and staff at the collaborating universities close to research sites were introduced to new rural development techniques (e.g., Participatory Mapping) and learned how to test and develop aquaculture technologies with farmers in a more participatory way. The major outcome of the project activities is the development of entry-level advice for rice farmers to successfully transform their rice fields into an integrated rice-fish farm. This is also applicable to new farmers who may be interested in rice-fish farming. As the first step in establishing the knowledge base for integrated aquaculture -agriculture system, the mapping of wetland areas suitable for aquaculture and integrated agriculture-aquaculture farming was conducted using geographical information system (GIS). Six (6) wetland maps (of two States) were drafted. This led to establishment of best management system for the selection of appropriate sites for the establishment of the on-farm pilot demonstration plots. The results of the on-farm rice-fish adaptation plots and lessons learned from two cycles of production (which the time limit of project life permits) were enough to develop recommendations and guidance on field modification, water management regime, rice transplanting and fish stocking schedules, feeding regimes, and general management considerations for rice-fish farming. The experimental study on evaluation of water quality and soil properties of integrated rice and fish farming system revealed that dissolved oxygen, ammonia, pH, soil organic carbon, nitrogen, phosphorus, and soil pH were within the acceptable range. Furthermore, it was observed that the integrated rice-fish plot had high plankton abundance with diverse number of planktons (cells/litters), and as the days of culture increases in integrated rice-fish system, the algae biomass and number of plankton cells increases thereby making available natural food for fish in the field. The farm diversification process though rice-fish farming knowledge development was complemented with equally important ancillary aquaculture technologies that are needed to support the needs of farmers for effective adoption of the rice-fish technology. Thus, fish seed production training was introduced as a farm diversification technology. The training conducted has resulted into four (4) farmers producing fish seed in their communities thereby serving fish seed needs of rice-fish farmers for stocking in their modified rice fields. Another complementary farm diversification technology activity was the identification and testing of locally available feed ingredients for application in integrated rice-fish system. The local feed ingredient tested include rice bran meal, fish offal meal, and the combination of the two. The results of the experimental studies of feeds formulated from these ingredients showed that they support the optimum growth and performance of fish (African Catfish; *Clarias gariepinus*) similar to conventional feeds. The experimental study on “apparent digestibility coefficients of by-products in integrated rice and fish farming (rice bran and fish offal meal) fed to the African catfish, *Clarias gariepinus* and *Oreochromis niloticus* juveniles” revealed that nutrient digestibility by *C. gariepinus* and *O. niloticus* was good for both Test Ingredients (rice bran feed and fish offal meal), while fish offal meal gave better results for the test fishes. The value-addition technology through smoking created additional market for harvested fish, including employment and earning potentials for fish smoking operators, prevention of food loss through fish spoilage and diversified market for farmers to either sell fresh or smoked fish.

The economic/financial feasibility studies of rice-fish farming system indicated profitability of the system compared to rice-monocropping. In conclusion, the hypothesis that the farm diversification process has triple win benefits for farmers by increasing total farm yield (productivity), improved nutrition (increased fish availability and consumption), and incomes (employment and profit from the sale of fresh or smoked fish) were confirmed by the success stories of farmers that adopted the technology.

1.0 Introduction

In a context where many rural households continue to face serious challenges to their food and nutrition security, farmers' desire for "practical solutions" are increasingly relevant. Thus, actions are required to help communities develop sustainable, safe and healthy methods of food production. Diversification of farming systems to produce more food through integrated agriculture-aquaculture (IAA) systems could play a vital role as an intervention strategy to make rural communities' food secure and open up additional economic opportunities with multiple benefits for communal food security outlook, including poverty alleviation and improved nutrition and livelihood diversification.

Nigeria ranks among the most food insecure nations in Africa, with poor rural communities being the most vulnerable to periods of hunger and malnutrition (Akinyele, 2009; FAO, 2017). The Federal Government of Nigeria has intensified efforts to increase local rice production for national self-sufficiency (FMARD, 2016). Pertinent to note is that communities in the Nigerian States listed in the USAID Global Food Security Strategy (GFSS) Zones of influence are active rice producers.

Rice-fish agroecosystem supplies energy and nutrient-rich foods (micronutrients, proteins, and essential fatty acids that are especially important in the diets of pregnant women and young children) (FAO, 2019). The interconnected activities within IAA system and associated activities bares simultaneous benefits for farming families, communities, and associated value chain actors in the forms of rural employment, opportunities for youth agripreneurship, conservation of biodiversity, climate change adaptation, and support for institutional and policy innovations (Halwart *et al.*, 2014). Piloting development-focused research to identify innovative approach to assist rural communities in these zones transition their rice field environments into a more productive, biologically diverse and efficient farming landscape to produce an additional crop of farmed fish in their existing rice fields (rice fish culture) will provide immediate boost to the nutrition security of these communities. Aquatic biodiversity in the rice-based ecosystem is an important source of human food. It has triple-win benefits for farming families by increasing yields, incomes, and levels of nutrition.

This research for development project aimed to kick-start a process of farm diversification and intensification, which can then be maintained by the communities themselves, with the support of local agricultural extension officers and other development partners. Knowledge gathered and lessons learned from the project will also be useful in mainstreaming aquaculture into other applicable agriculture/horticulture production systems within and beyond target communities.

The project goal is to secure supply and access to rice and fish, improve nutrition-sensitive diets, promote resource use efficiency, and generate employment and better livelihood options in the selected communities. The project demonstrated the importance of aquaculture technology innovations for enhancing and sustaining aquaculture production, economic opportunities for youths and women and resilience of rural communities to food and nutrition security challenges.

The lessons learned from the project could be scaled up and implemented in other parts of the country and other sub-Saharan African countries.

2.0 Research Methods

2.1 Research approach to achieving Outcome 1: Development of suitable integrated rice-fish system through participatory research

- Exploratory community appraisal (rural assessment) and stakeholder meetings involving farmers, community leaders, extension workers and other stakeholders to identify needs and gaps needed for farm diversification was conducted. Information was gathered using Participatory Rural Appraisal methods (including Participatory Mapping techniques) on the prevailing farming systems, and youth and gender roles (Please see [Annex 1](#) for more information on community appraisal and situational analysis).
- Mapping of wetland areas/rice farms suitable for integrated rice-fish farming in the participating states using Geographical Information System (GIS).
- The assessment of locally available feedstuffs as suitable supplemental feed ingredient for selected species in integrated rice-fish system (please see Annexes [2](#), [3](#) and [4](#) for details of the research proposals on fish feed studies).
 - Experimental study on “apparent digestibility coefficients of by-products in integrated rice and fish farming (rice bran and fish offal meal) fed to the African catfish, *Clarias gariepinus* and *Oreochromis niloticus* juveniles”
 - The experimental study on “chemical evaluations of agricultural wastes from Integrated Fish and Rice Farming and their potential as a fish feed ingredient
- Initiation of on-farm adaptive rice-fish trial plots to compare the parameters of appropriate integrated rice-fish farming system that meets local conditions requirements, which are culturally acceptable, and to be farmer-managed through farmer participatory process (please check [Annex 5](#) for details of the research proposal for this study).

The diversification process involved rice field modification- digging fish main circulation (trench) area of 1 m wide, and 1 m deep in a 15m X 22m rice production area in Ebonyi state and 40m X 50m in Kebbi state. Rice variety (FARO-44-National code: NGOS-91-44)) was transplanted at 20 X 25 cm spacing, and 1, 500 juveniles of Catfish (*Clarias gariepinus*) of 8-10 g (recommended average size) were stocked and fed two times a day with fish feed developed by the project.

- The key experimental research topics include: Biological and technical efficiency of integrated fish and rice farming for food enhancement in Ebonyi and Kebbi states, Nigeria
- Aquatic biodiversity under integrated rice and fish culture system and their food provision contribution in Kebbi and Ebonyi states
- Performance evaluation of integrated rice-fish farming in Kebbi and Ebonyi states, Nigeria.
 - Assessment of water use efficiency, water quality and soil chemistry of rice and fish field under these different ecological systems in Ebonyi and Kebbi
 - Evaluation of the production efficiency of combining rice and fish culture in these two different ecological systems in relation to fish and crop growth performance
- Growth performance, Immunological responses, and antioxidant status of *Clarias gariepinus* and *Oreochromis niloticus* fed varying inclusion level of agro-industrial waste product (fish offal meal and rice bran) from integrated fish and rice culture system
- The process of setting up the on-farm adaptation:
 - Community coordination and stakeholders’ workshop was conducted, before site selection.

- One stakeholder meeting was organized in each of the participating states during which all concerned stakeholders such as farmers, extension workers, community representatives were involved in developing working modalities for the pilot demonstration. Identification and the process for selecting project beneficiary farmers was initiated during this meeting.
- Baseline survey of the possible rice paddy areas for integrated agriculture-aquaculture in each of the participating states was conducted, thus detailed information on the rice paddy areas suitable for integrated rice-fish farming were documented.
- The type of modification to be made on the rice farm to start the rice-fish demonstration was decided by the farmers. Farmers decide to dig trenches around the rice field which covered about 10 percent of the total rice field area.

2.2 Research approach to achieving Outcome 2: Understanding convenient market access approach and nutrition contributions of rice-fish farming products.

- The Evaluation of various end-market opportunities for the farm output with risk factors identification (please see [Annex 6](#) for more information)
- Survey and assessment of economics, financial and marketing consideration, to determine rice-fish grower's profitability margins or return on investment (ROI), grower's acceptability and consumer purchasing behavior and willingness to Pay (WTP) for local integrated agriculture-aquaculture products (please see Annex 6 for more information)
- Surveys on fish consumption, household dietary diversity score (HDDS) and food insecurity experience scale ((FIES)
- Preliminary investigation of observed changes in aquatic biodiversity/aquatic resources in rice fields converted to integrated rice-fish farms.

2.3 Research approach to achieving Outcome 3: Capacity development and enhancement of co-learning among all stakeholders (farmers, extension workers and other development partners)

- Surveys conducted to explore opportunities for full utilization of the products from the integration through a demand-driven research and development (R&D) process for product development (see Annexes [17](#) and [18](#) for the survey questionnaires).
- Source locally available, preferred and economically valuable species across the two selected regions, to evaluate their performance, including impact of stocking density, feeding, limited feeding and non-feeding regimes.
- Train farmers on entrepreneurship/business management skills in rice and fish production

3.0 Research Results

The descriptions below are combination of research and development results of the project activities.

3.1 Research results of Outcome 1: Development of suitable integrated rice-fish production technology through participatory research actions

The following were the results of the implementation activities:

- 1) The results of the Participatory Rural Appraisal methods (including Participatory Mapping techniques) during the community situational analysis, and prevailing farming practices include:
 - Historical background as presented by long term residents
 - Map of the community
 - Seasonal farming calendar
 - The activity profiles of women and men
 - The appraisal indicated the existence of rice farming as the major farming operations. There was no practice (non-existence) of integrated rice-fish farming at the time of the appraisal.
 - The predominant farming operation is rice production. Two rice farming systems were identified in both states (Kebbi - lowland rice production and Ebonyi - rainfed/upland rice production)
 - The other agricultural commodities farmed include:
 - Ebonyi: yam, cassava, maize and vegetable production
 - Kebbi: capture fisheries, millet, guinea corn livestock production
 - There are 3 planting seasons in Kebbi. These include: rainy season, dry season and flood period production.
 - The farming calendar in Kebbi indicated two main seasonal productions of rice in a year (Kimba has 3). Consequently, there could be rice-fish production at same times of the year.
 - Dan Galadima – 2 cycles of production (February – June; August – November).
 - Taka Kume/Tungar Tsamiyar- 2 cycles of production (March – July; August – October)
 - Kimba – 3 cycles of production: (February/March – May; June – August; September (after flooding) – December)
 - The farming calendar in Ebonyi indicated one production cycle for rice production in a year. Consequently, one seasonal rice-fish cycle would be possible.
- Please see [Annex 1](#) for the report of the community appraisal, situational analysis and prevailing farming practices in the communities.
- 2) Knowledge base on agroecological of wetlands suitable for aquaculture and integrated rice-fish farming in Kebbi and Ebonyi States was developed (Please check [Annex 7](#) on wetland maps results for more details).
 - 3) The assessment of local feedstuff suitable as alternative fish feed led to the experimentation to substitute rice bran and fish offal for fish meal in feed formulation. The project has developed a feed formular based on the research outcome.
 - The experimental study on “apparent digestibility coefficients of by-products in integrated rice and fish farming (rice bran and fish offal meal) fed to the African catfish, *Clarias gariepinus* and *Oreochromis niloticus* juveniles” revealed that nutrient digestibility by *C. gariepinus* and *O. niloticus* was good for both Test Ingredients (rice bran feed and fish offal meal), while fish offal meal gave better results for the test fishes (please see [Annex 8](#), abstract describing the study for more details).

- The experimental study on “chemical evaluations of agricultural wastes from Integrated Fish and Rice Farming and their potential as fish feed ingredient” revealed that the proximate composition of the rice bran and fish meal when substituted for fish meal in fish diet formulation, compared favourably with the conventional feed diet requirement for fish growth (Please see [Annex 9](#) for more information).
- 4) On-farm pilot demonstration sites were established in the project sites. Simultaneously, institutional experimental demonstration trials were established in the fish farm of University of Ibadan, and Usman Dan Fodio University.
- a. A total of eight (8) on-farm adaptive research sites were established (3 each in Kebbi and Ebonyi states, and 1 each in the University of Ibadan, and Usman Dan Fodio University Sokoto) and operationalized to demonstrate the process of converting rice field into a rice-fish farm. The sites were stocked with fish (*Clarias gariepinus*) and transplanting with rice seedlings FARO 44. The first cycle of production in project sites was successful with rice and fish harvested. Recommendations to address the challenges and gaps were made, and recorded as lessons learned. The recommendations were implemented in the second cycle of production. The lessons learned were further revised based on the outcome of the second cycle of production. The lessons learned include:
 - Water retention in rice field trenches: This refers to the water seepage and rapid evaporation observed during the dry season. In the absence of a working irrigation structure, additional cost of pumping water for replenishment may not be sustainable for farmers with limited financial resources. The initial adaptation measure employed was to lay plastic bags inside the trenches to hold water for longer period. However, for environmental sustainability consideration, the plastic lining was discouraged, and thus rice-fish farming is encouraged during the wet/rainy season.
 - If there is a delay in rainfall that leads to a delay in rice transplanting or in cases of unreliable rainfall patterns that may affect proper rice cultivation for maximizing yield, the introduction of fish into such rice system would serve as insurance for crop failure and increase the profitability margin for the farmer.
 - Fish seed availability: Limited access to fish seed was reported by the farmers. The solution was to train farmers on low-cost fish breeding techniques, thus improving availability within their locality. Four successful examples of farmers doing fish breeding have been recorded in Kebbi and Ebonyi.
 - Predation from birds: Loss of fish due to predation from birds was recorded. The use of net covering and stocking of fish of bigger size were recommended to prevent actions of the predatory birds.
 - Fish size at harvest: The fish were harvested at 250-350 g after 3 months of co-culture with rice. Although the size was not competitive for the desired size in Nigeria fresh fish market, value-addition through smoking was introduced to boost the economic value of the fish, noting that smoked fish commands high market value irrespective size.
 - Expensive commercial feed: The cost of commercial fish feed was challenging to the farmers. The project therefore introduced alternative feeds, using locally sourced feed ingredients (rice bran, fish offal) for feed formulation. Also, there is an ongoing process to develop a training protocol for farmers on using black soldier fly larva as alternative fish feed.
 - Knowledge sharing among project beneficiaries: Farm diversification processes slightly differ from plot to plot. Therefore, farmer-farmer

knowledge exchange and experience sharing are considered an important aspect of knowledge transfer and information dissemination among practitioners.

- The on-farm adaptive research and the lessons learned were used to generate an entry-level advice that will enable a rice farmer with no or little knowledge of aquaculture to transform her/his rice field into an integrated rice-fish farm (please see [Annex 19](#) on instructional care for rice-fish farming for more information). While it is expected that the farmers will continue to adapt to local situation and master the technology, the status and level of implementation so far indicates that the knowledge generated from the first and second cycle of production is enough as entry-level advice for farmers with little or no knowledge of aquaculture to transition from rice monocropping into integrated rice-fish farming.
 - Over 700 farmers participated in the diverse farm diversification trainings (rice-fish co-culture management, fish seed production, water management, fish feeding regimes, farm record keeping, fish smoking) , and 8 graduate students were involved in the research.
- b. The experimental study on evaluation of water quality and soil properties of integrated rice and fish farming system in Oyo and Ebonyi states, Nigeria revealed that dissolved oxygen, ammonia, pH, soil organic carbon, nitrogen, phosphorus, and soil pH were within the acceptable range, while nitrate and nitrite were undetectable. It was revealed that integrated rice-fish system practices in these zones do not lead to any negative impact on water quality and soil properties (please see [Annex 10](#) for more information).
- c. The integrated rice-fish plot had high plankton abundance with diverse number of planktons (cells/liters). This is attributed to the use of organic manure which promotes their growth. The dominant phytoplankton were Ulothrix, Euglena and Rotifera spp. This agrees with Halwart and Gupta (2004) that the application of fertilizers promote phytoplankton growth and enhance the natural food web that supports fish (please see [Annex 11](#) for detailed information).
- d. Based on the experimental study on “Nutrients, Water Primary Productivity, Plankton and Macro-invertebrates Diversity of Integrated Rice and Fish (IRF) Farming in Nigeria”, it was observed that as the days of culture increases in IRF, the algae biomass and number of plankton cells increases thereby making available natural nutrient for the fish cultured in the system (please see [Annex 12](#) for detailed information)
- Plankton abundance in the studied fields ranged from only 70 up to 110 organisms per liter, while macroinvertebrates abundance ranged from 2 to 23. For macroinvertebrates the diversity ranged from 0.17 to 0.33 across the sampling days except for week 2 that shows no diversity of macro-invertebrates as the macro invertebrates were evenly distributed.
 - Chlorophyll A shows the algal growth across the days of culture and it indicates the phytoplankton biomass in the water
 - The macroinvertebrates in IRF productivity enhances the productivity. This agrees with Covich et al (1999) that stated that cycling nutrients outflows from the ecosystem are done by transforming organic detritus from sedimentary storage into dissolved nutrients that can be mixed into overlying water and used by rooted plants and algae to enhance productivity.
 - Fish eat macroinvertebrates (pests and insects) in rice fields, the rate of planthoppers reduction by fish is 26 (Xie *et al.*, 2011) which is a strategy for integrated pest

management thereby increasing IRFs productivity which agrees with Horstkotte Wessler (1999) and Berg and Tam (2018)

- The consumption of aquatic plants by fish in rice fields reduces weed biomass by 59 richness by 62 and abundance by 68 percent (Wan *et al.*, 2019)
- This study shows the various biological productivity of the IRFs which also agree with the study done by Ahmed and Sing (1989) that the biological productivity of any aquatic body is generally judged through the qualitative and quantitative estimation of plankton, which form the natural food of fish.

e. The study on “rice and fish yield optimization under integrated aquaculture and agriculture system” revealed that IRF system could help in the optimization of rice and fish production, thus serving as an economically sound veritable means of enhancing food and nutrition security (please see [Annex 13](#) for detailed information).

- The average number of tiller 23.76 and length of tiller 100.22cm obtained under IRF are higher than the performance under rice monoculture with average number of tiller 16 and tiller height of 93cm as reported by Fedrick et al (2016).
 - The lowest and highest number of grain/panicles was recorded as 47 and 180, respectively. This shows that the rice got the adequate nutrient to produce good yield. According to Espinor and Greer (2014), most rice plants produce 70 – 100 grain per panicle.
 - The system (294 m²) produced a higher yield of rice (127 kg) when compared to the conventional rice monoculture system which produce 73.5kg at 294 m². This result agreed with Ahmed and Garnett (2011) that observed that the existence of fish in rice field provide many advantages that increase rice yield.
 - In all, the yield of both rice (3.98ton/ha) and fish (4.93ton/ha) is above the national conventional for rice (2ton/ha) and fish (2.5ton/ha)
- f. The graduate students gathered data, analyzed and developed the analyzed data into four manuscripts for publication in reputable journal outlets.

3.1.1 Summary of key findings of Outcome 1:

- Diversification of rice-based systems with fish is a viable strategy providing higher returns than rice mono-cropping alone.
- Participatory needs assessment is an essential step leading to better understanding, ownership and buy-in from all stakeholders.
- On-farm pilot rice-fish farming enhances engagement and generates knowledge with little risk

3.2 Research results of Outcome 2: Understanding convenient market access approach and nutrition contributions of rice-fish farming products

1. The surveys on fish consumption, household dietary diversity score (HDDS) and food insecurity experience scale ((FIES) were conducted (please see Annexes [14](#), [15](#) and [16](#)) for detailed information).
 - Fish consumption is common in Kebbi and Ebonyi (according to the 24-hour fish consumption recall) (please see Annexes [14](#) and [15](#)).
 - a. The preliminary fish consumption survey conducted in the two states provided information on the most desired fish for consumption (African Catfish). This informed the fish species that was integrated in rice fields for the on-farm demonstration trials (please see [Annex 14](#)).

- b. The first three reasons (main reasons) given by survey respondents of the fish consumption survey for choosing the type of fish to consume include: “inexpensive, affordable and fits budget”, “fresh and good quality” and “taste” (please see Annexes [14](#) and [15](#))
 - c. Majority of the respondents interviewed (62 percent of 385) are aware of the importance of fish consumption on a child’s cognitive development (please see [Annex 15](#)).
 - d. There is no taboo against fish consumption by pregnant and lactating mothers in the communities (Please see Annex 14).
 - e. Ninety (90) percent of integrated rice-fish farmers practice either home consumption or selling of fish harvested from their plots, while other 10 percent prefer to sell the fish (please see [Annex 15](#)).
 - f. The FIES indicated severe food insecurity situations in the communities surveyed (please see [Annex 14](#)).
 - g. The results of the preliminary investigation of observed changes in aquatic biodiversity/aquatic resources in rice fields converted to integrated rice-fish farms as reported by rice-fish farmers; some noticed an increase in the number of snake, snail, crabs, frog, rats, insects, frog, toad, and crabs, while a few reported new sighting of some of the aforementioned aquatic animals after they converted their rice fields to rice-fish farm (please see [Annex 15](#)).
2. (i) The Evaluation of various end-market opportunities for the farm output with risk factors identification.
 - (ii) Survey and assessment of economics, financial and marketing consideration, to determine rice-fish grower’s profitability margins or return on investment (ROI), grower’s acceptability and consumer purchasing behavior and willingness to Pay (WTP) for local integrated agriculture-aquaculture products.

To determine profitability margins for the newly introduced integrated rice operation in a rice-fish production system in Nigeria, it was absolutely important to identify all the cost components such as pre-variable costs (P-VC), harvesting and marketing costs (H&MC), total variable cost (TVC), total fixed costs (TFC) and total cost of production (TC) for all the six location sites in the study areas, i.e. Ebonyi and Kebbi States respectively.

- The P-VC for Onicha in Ebonyi State was N51,072 while the TC of production was N62,569 on a 330 m² size research plot. On the other hand, The P-VC for Wawu-Jaji in Kebbi State was N103,850 while the TC of production was N118,598 on a 2,000m² size research plot.
- The P-VC for Ikwo in Ebonyi State was N92,815 while the TC of production was N109,555 on a 330 m² size research plot. On the other hand, The P-VC for Kimba in Kebbi State was N228,410 while the TC of production was N324,562 on a 2,000 m² size research plot.

The economic investigation of introducing an integrated rice-fish production system in Ebonyi and Kebbi States of Nigeria, respectively, included a break-even (BE) analysis which is very important in analysing the financial viability of a project. BE analysis tells the farmer or investor the minimum output, whereby they are not losing money. BE point (BE-P) refers to when total cost (TC) and total revenue (TR) are equal. In other words, it means there is no loss or gain for the enterprise or business, i.e., when the farmer has reached the production level at which the production costs equal the revenues for a product. BE-P is calculated by dividing the total fixed costs (TFC) associated with production by the total revenue (TR) per individual unit minus the total variable costs (TVC) per unit (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018).

The project successfully summarized the BE point for fish in a rice-fish production system for selected critical economic parameters such as the pre-variable cost (P-VC), harvesting and marketing

cost (H&MC), total fixed cost (TFC), total cost (TC) and yields. A comparison of these selected parameters was conducted for the different integrated fish-rice research sites, i.e., Ikwo, Onicha, Kimba, Wawu, the University of Ibadan (UI) and Usmanu Danfodiyo University of Sokoto (UDUS), respectively. For instance, the P-VC of the Ikwo site in Ebonyi State was N749 compared to N281 for the Wawu site in Kebbi State. A similar break-even (BE) analysis was conducted for rice in a rice-fish production system in both Ebonyi and Kebbi states. For instance, the BE total cost (BE-TC) for Onicha, Ebonyi State, Southeast Nigeria, was N894 compared to N1,284 for Wawu, Northwest Nigeria. It is worth noting here that the plot sizes were different. The plots in Ebonyi state were 330 m², while the ones in Kebbi state were 2,000m². The two controlled research sites, i.e., the University of Ibadan (UI) and the Usmanu Danfodiyo University of Sokoto (UDUS), were also 330m², respectively.

A survey was conducted during the introduction of the integrated fish-rice production system to determine consumers' willingness to pay (WTP) and gauge consumers' behaviours vis-à-vis consuming rice raised simultaneously with fish in the same field. Our findings revealed that Nigerian consumers preferred the local rice to the foreign counterpart. Most (65.45 percent) respondents opined that they eat locally-produced rice three times a week and 19.72 percent of the respondents say they would buy or consume locally-produced rice if readily available in the market. The amount the consumers are willing to pay for 1kg of local rice was less than N2, 000.00, and they are willing to pay NGN 1000–1500 for one MUDU or rubber of local rice. The most locally preferred variety was FARO-44, followed by FARO-52 and FARO-61. Consumers preferred local rice for taste/flavour, availability, sweetness, and cooking. Other reasons adduced by the consumers were finger size, colour and cosmetic appearance.

The survey further revealed that the most preferred fish consumed by the respondents was local, compared to imported fish. Consumers' most preferred local fish was catfish, followed by tilapia, carp, and other locally available fish species. Most consumers (82.39 percent) are willing to buy local fish if it is readily available in the market rather than imported fish. The amount the consumers are willing to pay for 1 kg of preferred local fish was between N500 and N1000, as opined by the majority (59.86 percent) of the consumers, while the reasons given for preferring local fish were taste/flavour, sweetness, availability, cosmetic appearance, fish size, fish length and colour.

Please check Annexes [20](#) and [21](#) for more information on outcomes of research activities on end-market evaluation, the RO1, WTP and other socio-economics analyses.

3.2.1 Summary of key findings for Outcome 2:

- Fish available locally from rice-fish systems increases household dietary diversity and/or generates income used for the food budget, addressing the high prevalence of food insecurity
- Market preference for bigger-sized fresh fish can be compensated by value addition through smoking of the smaller-sized fish available at rice harvest
- Less use of chemicals in integrated rice-fish systems leads to better ecosystem health and increased biodiversity utilized by households

3.3 Research results of Outcome 3: Capacity development and enhancement of co-learning among all stakeholders (farmers, extension workers and other development partners)

Outcome 3 has development results only.

- Farmers were trained on different management techniques in integration of fish and rice farming such as rice field modification and design, key element of integration (field preparation, water management, rice transplanting and fish stocking timing), nutrient cycle and utilization, feeding practices, disease control.

- Fish breeding training for farmers and hatchery operators opened a channel to address unavailability of fish seed in the communities.
- Value addition training to process fresh fish into smoked fish, enabling preservation and preventing food loss.
- Study of locally available feedstuffs as suitable supplemental feeding for *selected species*. Identification and evaluation of best performing and preferred fish species suitable for sustainable production led to the testing of rice bran and fish offal as ingredients for fish feed formulation.
- Workshops and seminars on the adoption and benefits of IAA as a livelihood option for rice-fish farmers and market stakeholders, with more attention on women and youths
- Capacity development (training and workshops of farmers, extension workers, university students, academics and other relevant stakeholders) on market access for rice-fish products
- Successful implementation of a national workshop on rice-fish farming where farmers exchange their experiences on transforming their rice fields into a rice-fish farm, and discussed options for upscaling.

3.3.1 Summary of key findings of Outcome 3:

- Availability and/or cost of fish feed can be a barrier to adoption; good results achieved with feed production from locally available feed ingredients
- Co-learning and capacity development should go hand-in-hand and reinforce each other; the exchange of experiences by farmers, extension agents and researchers enhances knowledge, builds trust and confidence
- Partnerships generated among multiple institutions; inherent value with comparative advantages

4.0 Outputs and Conclusions

Please see [Annex 22 for the summary of actual accomplishments of the outputs](#) based on the Monitoring, Evaluation and Learning indicators of the project.

4.1 Outputs

Output 1.1 Action research is conducted to develop a knowledge base on agroecological wetlands suitable for integrated fish and rice farming

This Output was delivered and the project exceeded the delivery targets set in the Monitoring, Evaluation and Learning Framework. [A Knowledge Base on agroecology of wetlands in Kebbi and Ebonyi States was established in 2021](#) as part of project activities to map local wetlands and undertake a participatory situation analysis in the target communities of project beneficiaries.

With support from FAO, the University of Ibadan (UI) mobilized its network of local education institutions (Usmanu Dan Fodio University Sokoto, Michael Okpara University Umudike) to organize a series of meetings and consultations with over 300 farming families in six communities. As well as faculty and students, participants in these consultations also included representatives from the States' Ministry of Budget and Economic Planning, Ministry of Information, Ministry of Agriculture and Fisheries, and agricultural extension workers. Local journalists from TV, radio and print media also participated.

The meetings and consultations (3 meetings/State organized over two weeks during 2021), used Participatory Rural Appraisal methods (including Participatory Mapping techniques) to generate a wealth of information about the agroecology of the target areas and a situation analysis of the target communities. The Knowledge Base generated from this information included 6 wetland maps (of two States) and identified key features of production activities of local households in the target communities (see [Annex 1](#) for summary reports of these meetings and consultation).

In addition to generating the project's Knowledge Base, the 2021 meetings and consultations also showcased participatory data collection techniques. They demonstrated new tools and methods to local stakeholders, that could be used for more effective rural development research and planning. Local representatives from training and development agencies in Kebbi State were particularly interested in these techniques and the information generated. The State has a large rice growing area but is also susceptible to severe flooding. Participatory rural appraisal techniques facilitated a more informal dialogue with rural communities which could more easily explore the complexities of this State's agroecology. Stakeholder meetings in this State highlighted opportunities for the promotion of more extensive systems of rice-fish culture (including management of the wild fishery), that may be more suitable for areas at risk from severe flooding.

Output 1.2: Farming Systems are analyzed to characterize the prevailing rice-fish farming practices and gather evidence on how to introduce innovative and high performing farming system through appropriate management options

The Participatory Rural Appraisal with farmers, community leaders and other stakeholders informed of two distinct rice farming systems in the study areas; 1.) lowland rice production in Kebbi; 2.) rainfed/upland rice production upland rice farming in Ebonyi. From the meetings and consultations with farmers, it was reported there have not been any integrated rice-fish farming activities in the area but the farmers are eager to learn about it. The information gathered on the farming practices, especially the seasonal calendar for rice farming elucidated the entry points for introducing aquaculture into rice farming in the communities. For example, in Kebbi, there is a possibility of integrating rice-fish two times a year (February – July; and August – November); whereas in Ebonyi, there is mainly one seasonal calendar for rice farming, thus integrated rice-fish farming could be done through the rice seasonal farming. An instructional care for rice-fish farming ([Annex 19](#)) was designed based on activities observed during the farmer trainings and exchange at the on-farm rice-fish demonstration plots, and the needs of farmers for integrating aquaculture with rice farming. This instructional guide was useful in

advising 727 farmers and extension workers (232 female, 495 male, 54 youth) for appropriate rice-fish management options in the six (6) rice-fish demonstration plots. The farmer advisory and training sections followed patterns similar to farmer field school sessions and took place in all the six (6) project communities, making up a total of six (6) farmer training groups.

Output 1.3: Evidence-based and locally adaptable cost-effective integrated rice-fish system, including market access development are piloted in the target communities

Eight on-farm adaptive research sites were established to obtain information on resource-use in rice-fish farming, and the influence on rice and fish yield, and fish performance.

The combined results of the: i.) evaluation of water quality and soil properties of integrated rice and fish farming IRF system under different agro-ecological zone in Nigeria; ii) water utilization, nutrient assessment and water quality performance under integrated rice-fish system; iii) water primary productivity and macro-invertebrates diversity of integrated rice-fish system; and iv) rice and fish yield optimization under integrated aquaculture and agriculture, conducted in the on-farm adaptive sites provided evidence of adaptability of rice field to include aquaculture. These experimental results informed on the biological interactions in rice-fish systems that supports the growth of rice and fish. The economic/financial profitability analysis of rice fields converted into an integrated rice-fish farm provided evidence of cost-effectiveness of the new farming system and superior profitability it has to rice-monocropping of similar plot size (as indicated in the economic/financial profitability result (please see Annexes [20](#) and [21](#) on business manual and social economics study results for more information).

Rice-fish farming clusters have emerged in Wawu and Argungu communities (Kebbi state), and in Abakaliki local government area in Ebonyi state, with more farmers willing to start rice-fish farming in these areas, and in other areas. So much is the acceptance of rice-fish farming in the community that their children start to mimic the field modification made by their parents with a little rice-fish field beside their parents' own.

Output 1.4: The promotion and adoption of cost-effective, sustainable and innovative approaches and practices to support agroecologically sound aquaculture operations in rice farms of target communities are evaluated

The integrated rice-fish farming was promoted during the community sensitization event at the project inception, and through the on-farm adaptive plots to showcase and demonstrate that integrating fish farming with rice farming is possible. In all, about 108 farmers have applied the trainings received from the project to initiate rice-fish farming practice. Among them are also farmers who decided to adopt the practice after seeing the rice-fish farm of their friends. The total area of rice farming converted into rice-fish farming based on trainings received from the project is about 10 hectares. Given the project spent two (2) years developing the evidence for converting rice field to integrated rice and fish based on locally prevailing conditions (two cycles of production), it is expected that more farmers will begin to see the benefits of the system and will be willing to adopt the new system by the next rice farming season. Although, the project will administratively end in September 2023, the local stakeholders (especially the government of Kebbi state, Nigeria) has secured buy-in, and are willing to continue to promote and adopt the rice-fish system as an empowerment package for interested smallholder farmers.

The major challenge limiting adoption is the cost of modifying rice field for rice-fish farming (even though, once this cost is borne once, the modified field could be in use for another 12-15 years without any need to spend on field modification). Another challenge is fish seed. Even though the project has facilitated some fish seed production training, there is a need to follow-up with in-depth fish seed production such as rice field nursery production that will directly serve the needs of the individual rice-fish farmer.

While it is expected that the farmers will continue to adapt to local situation and master the technology, the status and level of implementation so far by the farmers that has adopted the technology indicate that the knowledge generated from the first and second cycle of production is enough as entry-level advice for any farmer with little or no knowledge of aquaculture to transition from rice monocropping into integrated rice-fish farming.

Furthermore, the training and involvement of local students, extension workers and partner collaborating institutions close to Kebbi and Ebonyi states, will continue to support current and new farmers with advice and recommendations to promote rice-fish farming.

In terms of percentage increase in rice and fish yield under the best condition of integrated rice-fish farming, the economic analysis conducted indicated more than a 5 percent increase in yield, and also more than 10 percent increase in monetary value, compared to rice monocropping (please see Annexes [20](#) and [21](#) for more information).

Output 1.5: Production technological packages for sustainable integration of rice-fish farming in the participating states through adaptive research are developed

The following technological packages were developed for the sustainable integration of rice-fish farming:

- **Water management technological package:** Water management was one of the challenges identified during the adaptation process (the reported water seepage and challenges of accessing water during dry season). For this reason, a water management technological package was developed to inform farmers, extension workers and other practitioners of the adaptation strategies to water management issues in Kebbi and Ebonyi states, and most importantly how water management regimes and application of organic manure into the water influences primary production of phytoplankton and the control of pests and diseases (please see [Annex 18](#) for more information).
- **Instructional care for rice-fish farming technological package:** An easy-to-follow and step-by-step process for converting rice field into a rice-fish system was developed. This will be particularly useful for farmers to consult or follow during the adoption process (please see [Annex 19](#) for more information)
- **Business manual/Economic feasibility of rice-fish system:** This was produced from the economic feasibility/financial study of the adaptation sites. Taking all costs (fixed and variable) into consideration, this manual indicates the profitability margins of rice-fish system for farmers (please see [Annex 20](#) for detailed information).

Output 1.6: A functional Innovation Platform on IAA system is established

The project successfully conveyed meetings in the six geopolitical zones of Kebbi and Ebonyi states for the potential establishment of innovation platforms during the explorative community appraisal to identify and select communities to site the on-farm demonstration plots. At the end of the explorative appraisal, two (2) innovation platforms on integrated agriculture-aquaculture were established and operationalized; one each in Kebbi and Ebonyi states. The innovation platform serves as a forum to facilitate linkages, discussions and information sharing amongst farmers, community leaders, civil societies, government extension workers, journalists, hatchery operators and other aquaculture stakeholders on best management practices for rice-fish farming, and discussion on challenges encountered and proffering solutions for adaptation. Each innovation platform consists of a minimum of 20 members.

Output 1.7: Capacity building of local stakeholders (training programs for farmers, training of trainers) and mainstreaming gender roles in rice-fish farming systems based on research and/or survey data of stakeholder needs in rice-fish farming are conducted

- The participatory learning outcomes at the project sites enabled over 700 farmers to learn the operational and management procedures of converting rice production to integrated rice-fish production, including farm record keeping, value addition, and marketing considerations. Series of trainings were conducted for 232 female, 495 male and 54 youths. Training/communication materials developed for these trainings, some of the materials include:
 - Fish seed training procedure
 - Case study of farm diversification using Kimba as an example
 - Stakeholder workshop presentation describing project objectives and implementation arrangement
 - Site selection criteria presentation
 - Conference presentation and Posters (over 12)
 - Feeding fish in rice-fish systems
 - Revolutionizing agriculture in Africa
 - Instructional care for rice-fish farming
 - Water management technological package
- Six (6) graduate students have been successfully trained on integrated rice-fish production and fish feed experimentation, while two (2) PhD graduate students are at the advanced stage of their research, nearing completion.
- The involvement of experts from collaborating institutions (Usman Dan Fodio University, Sokoto, and Michael Okpara University, Umudike) on project implementation activities and series of training programmes, make the needed scientific and technical support close to the farmers in Kebbi, and Ebonyi states, respectively.
- Through this project, the University of Ibadan joined the FAO Global Sustainable Aquaculture Advancement Partnership (GSAAP). The GSAAP function as a collaborative platform to discuss key issues and challenges, innovations and findings in the development of aquaculture. The GSAAP also facilitate the transfer and implementation of aquaculture innovations and advancements in science and technology, assisting in the formulation of sound and comprehensive solutions to effectively address problems hindering sustainable aquaculture development.

Outputs 2.1: Situational analyses of markets before, during and after intervention process are conducted and analyzed

Evaluating end-market opportunities for farm output involves assessing potential markets where agricultural products can be sold or utilized. Identifying risk factors is crucial for making informed decisions and developing risk management strategies. Diversifying end-market opportunities can help spread risk and reduce vulnerability to fluctuations in any single market. The following end-market opportunities are ideal for the integrated rice-fish production technology. These analyses led to the development of a business manual for rice farmers and other producers who may be interested to diversify their rice production to include fish farming.

Two market access surveys were conducted. The analyzed result of the surveys indicated that rice-fish farming is more profitable than rice-monocropping. Please check Annexes [20](#) and [21](#) for more information.

Output 2.2 Situational analyses of nutrition status, gender and youth involvement before, during and after intervention process

The community appraisal conducted at the project inception informed on adjusting the proposed food security and nutrition surveys to be limited to fish consumption, household dietary diversity score (HDDS) and Food Insecurity Experience Scale (FIES) surveys only. Two food security and nutrition (HDDS, FIES) and fish consumption surveys were conducted.

The survey questionnaires for these food security and nutrition indicator measurements were designed and administered to respondents in the communities. The result of the surveys informed the project team about the level of food security and nutrition challenges in the communities, and the importance of the intervention to boost local food production, and enhance better production, better nutrition with increased fish availability, and better environment due to reduced chemical fertilizer use. At the end of the project, selected farmers (6) were interviewed in Ebonyi and Kebbi state. They reported increase in food availability, more money to buy other types of food, and improvement in their dietary diversity, as a result of engaging in the farm diversification project. They expressed willingness to continue the practice and volunteered to teach other farmers in their communities.

Output 2.3: Enhanced entrepreneurship or business skill of farmers, especially youths and women and end market opportunities from the farm outputs identified and supported through the project are evaluated.

Questionnaires on socioeconomics (production, consumer preference and marketability) of integrated rice-fish farm products were designed and administered to understand the market situation of rice and fish in the communities, the respondents' predisposition towards the purchase and consumption of products that come out of the integrated rice-fish system, and if rice farmers would be inclined to transition towards rice-fish farming. The adoption of the rice-fish system has created about 50 rice-fish entrepreneurs (the number is expected to increase by the end of the project in September 2023, and among 312 farmers involved in the entrepreneurship training, about 31 of them reported they will become rice-fish entrepreneurs who would prefer to sell the fish obtained from their field for profit only, while about 282 the rest informed, they will both sell and consume the fish at home, depending on their personal needs.

The value addition training of fish smoking created entrepreneurship opportunities for women and youths. The fish consumption survey result indicated a very high consumer demand for smoked fish, among other fish products. This in turn is expected to provide a profitable business venture with significant economic benefit for the women and youth involved.

The business manual developed for rice-fish farming can be found in [Annex 20](#).

Output 2.4 Partnership between scientists and the development community for improving food production-nutrition linkages to address undernutrition (malnutrition) are strengthened

Partnerships were developed with local research institutions, government bodies and civil organizations being a part of the innovation platform and training sessions for farmers. The major partnership established include:

- Rice Farmers of Association of Nigeria (Kebbi and Ebonyi chapters)
- Catfish Farmers Association of Nigeria (Kebbi and Ebonyi chapters)
- Usman Dan Fodiyo University, Sokoto (collaborating institution for activities in Kebbi state)
- Michael Okpara University of Agriculture, Umudike (collaborating institution for activities in Ebonyi state)
- State Ministry of Agriculture and Rural Development (Kebbi and Ebonyi states)
- FAO – Global Sustainable Aquaculture Advancement Partnership (GSAAP)

Output 3.1: Best performing and preferred species suitable for sustainable rice-fish production in the two states (Kebbi and Ebonyi) are identified and evaluated

The outcome of the fish consumption survey indicated Catfish as the most preferred fish to culture in rice fields of Kebbi and Ebonyi states. This is followed by Tilapia. The experience and reports of farmers indicated that Catfish performed well under integrated rice-fish system management.

Output 3.2: Locally available feedstuffs as suitable supplemental feeding for selected species are tested

Three locally available feedstuffs (rice bran meal, fish offal meal and the combination of the aforementioned two) were successfully tested for use in an integrated rice-fish system. This led to the development of three test feed ingredients, where in the end two were recommended (the one with fish offal meal and the one with the combination of fish offal meal and rice bran). The performance of the feed formulated using these ingredients on fish growth and development was comparable to that of conventional feed (please see Annexes [8](#) and [9](#) for more information).

Output 3.3: Manual for small-scale rural farmers that helps development of an investment and business plan is developed

A report detailing the risk-rated financial analysis, Break-Even Analysis, and sensitivity analysis of an integrated rice-fish system was formulated. The report indicated the economic/financial profitability of integrated rice-fish farm, higher profitability than rice-monocropping in similar plot area. The business manual can be found in [Annex 20](#) (please see [Annex 21](#) for additional information on socio-economic studies of rice-fish system).

Output 3.4: National conference on rice fish farming is organized

The national conference on rice-fish farming was held in December 2022. The conference had 45 attendees comprising of farmers, extension workers, researchers, students, journalists and government workers. Some of the key outcomes/recommendations of the discussion on strategies that could be initiated or implemented that will lead to more farmers adopting rice-fish farming include:

- Public policy, advocacy and awareness on processes and benefits integrated agriculture-aquaculture systems
- Awareness creation through extension services for better delivery of information and information on rice-fish technology
- Access to quality cheap feed
- Availability of seeds
- Entrepreneurship capacity building for youths on rice-fish farming
 - Policies that promotes entrepreneurship training as part of the curriculum in higher institutions, particularly for final year students
- Access to credit facilities
 - Provision of financial support (through credit facility, revolving fund)
- Accessibility to demonstration sites for hands-on learning – pilot studies (close to farm)
- Technical support to farmers to address challenges that may come up during the diversification process
- Development of a business plan manual to aid farmer production planning
- Input subsidization e.g machineries, power tillers, excavator, pumping machine, etc
- Organization of field days for rice-fish farmers to interact with one-another. That is farmers from same and different areas visit each other and interact so they could learn from one another.
- Further research to be done on non-fed rice-fish systems, to further assist resource-poor farmers to spend less on production (reduce production cost)
- Further research to compare rice yield between agroecological (non-chemical fertilizer) rice-fish systems and conventional rice production systems (with chemical fertilizer use) to convince famers of the agroecological approach to rice-fish farming.

Output 3.5: Policy brief as an informed guide to influence policies and practices for the inclusion, promotion, and implementation of IAA in future food policy designs and/or national agricultural programs, as a nutrition-sensitive approach are published

Four policy briefs to inform policymakers and promote the importance of integrated rice-fish farming were drafted (please see Annexes [23](#), [24](#), [25](#) and [26](#) for more information). The titles of the policy briefs are:

1. **Policy Brief 1:** [Changing the food production landscape in Nigeria through farm diversification process – modifying rice field for fish production](#)
2. **Policy Brief 2:** [Integrated rice-fish farming as a climate-smart land use strategy in Nigeria](#)
3. **Policy Brief 3:** [Leveraging integrated rice-fish farming for rural prosperity](#)
4. **Policy Brief 4:** [New Development Frontier: Unlicking the potential of rice field fisheries \(RFF\) in Nigeria](#)

[Please check Annex 22 for the Summary of Outputs \(Monitoring, Evaluation and Learning indicators of the project\)](#)

4.2 Conclusions and implications

1. Rice farming communities aware of benefits of rice diversification and interested to adopt this practice
2. Consumer preference study confirmed that locally farmed fish are more consumed and preferred by households due to taste and income levels
3. Farm diversification can address food insecurity while increasing income, reducing chemical use and enhancing biodiversity
4. Beneficiaries along the value chain include rice-fish farmers, fish hatchery operators, fish smoking operators
5. Rice-fish farming has strong potential for upscaling with high interest of participation by youth and women
6. Capacity exists for community-based extension with government and development agency backstopping

4.3 Sustainability measures

1. Integrated agriculture-aquaculture innovation platforms for stakeholders to continue the discussion and share experiences about rice-fish farming.
2. Local anchorage and institutionalization of the farm diversification process: Co-creation of the farm diversification knowledge with farmers, extension agents and local universities experts, ensuring the knowledge stays in the locality.
3. Adaptive research sites at situated in universities for demonstration and continuous research for present and future students.
4. Targeted trainings conducted to address barriers that could limit the farm diversification process. These trainings include fish seed production and fish smoking.
5. Government of buy-in: The state government of Kebbi has shown interest to promote the farm diversification (rice-fish) in the state.

6. FAO to initiate a bridging activity to support farmers beyond the project life till resources are mobilized for upscaling (Phase 2 activities).
7. There is fertile environment for consolidation of successes and lessons learned in the project to expand, upscale and replicate the farm diversification (rice-fish) activities in new communities in Nigeria, and other parts of Africa.

5.0 Technologies/Innovations developed, and what phase was achieved

Technology/Innovations Developed						
S/N	Technology	Phase 1 Under research	Phase 2 Under field testing	Phase 3 Made Available for transfer	Phase 4 Demonstrated Uptake	Activity Description
01	Rice-fish					Development of suitable integrated rice-fish production technology through participatory research actions.
02	Fish feed (using locally sourced feed ingredient)					Activity developing feeding model and formulation for sustainable fish production under integration
03	Fish seed					Development of farm-level fish seed production
04	Value addition (fish smoking)					Promotion of value-addition to fish through smoking
05	Black soldier fly as alternative fish feed					Development of suitable farm-level black soldier fly larvae production and processing for use as fish feed
06	Water management in rice-fish system					The management of water within rice field agroecosystem to support optimal growth of fish

6.0 Key Beneficiaries

The main beneficiaries are:

1. Farmers, especially rice farmers in Kebbi and Ebonyi states (more than 200 farmers trained)
2. Fish hatchery operators and farmers involved in fish seed training (more than 20 trained)
3. Fish processors involved in fish smoking in Kebbi and Ebonyi states (more than 8 trained)
4. The extension workers in Kebbi and Ebonyi states (4 workers involved in training)
5. The 8 graduate students from the University of Ibadan (6), Usamanu Dan Fodio University, Sokoto (1), and Michael Okpara University of Agriculture, Umudike (1)
6. Institutional sites (2) located in the experimental stations of University of Ibadan, and Usmanu Dan Fodio University, for continuous experimentation and demonstration for current and future students learning

7.0 How the scientific results were disseminated

1. Broadcasting in the media: Participation of representatives of Television stations in project inception activities (Kebbi State Television Service (KBTv), Radio Nigeria, Voice of Nigeria, News Agency of Nigeria)
2. Feature of project activities on prints (online news and blog prints)
 - a. Farmers access magazine:
<https://www.facebook.com/farmersaccessmagazine/photos/a.104963394646039/137758591366519/?type=3>
 - b. The Nation
<https://thenationonlineng.net/tackling-hunger-through-integrated-farming/>
 - c. TheFishSite:
<https://thefishsite.com/articles/nigerian-integrated-aquaculture-trial-increases-health-and-wealth>
 - d. Champion Newspaper:
[FAO trains rice farmers on diversity, resilience for profitability - Champion Newspapers LTD](#)
 - e. Sustainable Aquaculture Research Networks in Sub Saharan Africa
<https://www.facebook.com/193723127373/posts/nigeria-food-security-kebbi-farmers-get-training-on-combining-rice-with-fish-far/10157765560312374/>
 - f. Livestocktrend.com
<https://www.livestocktrend.com/2020/10/farmers-get-training-on-combining-rice.html>
 - g. Maritime first newspaper
<https://www.maritimefirstnewspaper.com/food-security-kebbi-farmers-get-training-on-combining-rice-with-fish-farming/>
 - h. The Herald
<https://www.herald.ng/usaid-fao-trains-fish-farming/>
 - i. Agrilinks:
 - Integrated rice-fish farming: Localization through farm diversification;
<https://agrilinks.org/post/integrated-rice-fish-farming-localization-through-farm-diversification>
 - <https://agrilinks.org/post/trainings-move-needle-toward-more-sustainable-farming-system-nigeria>
 - j. Feed the Future blog posts
 - Rice-fish farming increases yield, improves household nutrition and income for Nigerian families;
https://www.fishinnovationlab.msstate.edu/sites/www.fishinnovationlab.msstate.edu/files/inline-files/Rice-Fish%20Farming%20success-story-FY23%20story1_0.pdf
 - <https://www.feedthefuture.gov/article/integrated-rice-fish-farming-in-nigeria-a-resilient-approach-in-the-face-of-climate-change/>
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 - k. FAO Aquaculture Newsletter
[FAO Aquaculture News, June 2023 – No. 67](#)
 - l. UGA College of Agricultural and Environmental Sciences Newswire
<https://newswire.caes.uga.edu/story/8891/fish-and-rice.html>
 - m. WorldFish:

3. National workshop on integrated rice-fish farming. It includes farmer experience sharing, discussion on upscaling strategies, and policy advice to promote the integration system.
4. Sensitization of farmers on the benefits of rice-fish farming compared to rice monocropping
5. Produce instructional video (for farmers) on integrated rice-fish farming techniques (*the video was made courtesy Agrilinks*)
6. Raise awareness of rice farmers about the benefits of aquatic opportunities and identification/selection of farmers who will participate in the research project.
7. Range of training sessions for farmers on farm diversification implementation process and market access evaluations
 - a. Training of farmers on operational and management procedures on integrated fish farming - Benefits, Operational and Management (Biological and Economics) Procedures, conducted in Kebbi and Ebonyi
 - b. Training of farmers on on-farm data collection and recording
 - c. Train farmers on entrepreneurship/business management skills in rice and fish production
 - d. Feeding fish in rice-fish systems
 - e. Revolutionizing agriculture in Africa
8. Conference presentation and Posters (over 12)
9. Fish seed training procedure
10. Development of production technological packages for sustainable integration of rice-fish farming in the participating states through the adaptive research.
 - a. [Instructional care for rice-fish farming in Nigeria](#)
 - b. [Water management technological package](#)
 - c. [Business manual \(Economic/financial profitability analysis\)](#)
11. Discussions and information sharing at the integrated agriculture-aquaculture (IAA) innovation platform which serves as a forum to facilitate linkages, discussions and information sharing amongst farmers, community leaders, civil societies, government extension workers, journalists, hatchery operators and other aquaculture stakeholders
12. Field visits and demonstrations at institutional research sites at the University of Ibadan, and Usamnu Dan Fodio University, Sokoto.
13. The intended beneficiaries were involved and included in the project implementation phase, with the active participation of the fish farmers, farmer groups and organizations.

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9.0 Appendices

Annex 1: Situational analysis of the selected communities in Ebonyi and Kebbi states

This report provides an evaluation and situational analysis of current status and potential of small scale integrated rice and farming system in the selected rice producing communities in Ebonyi and Kebbi states under USAID sponsored projects on integrated fish and rice farming. Methods of analysis include both quantitative and qualitative data which were collected focusing on integrated farming activities. Primary data was collected using interviews, observation, and participatory rural appraisal (PRA). Various tools and techniques of PRA were used with the help of checklists and semi-structured questionnaires, such as Seasonal calendar, Venn Diagrams, Matrix Ranking, to identify some key features of production activities of local households in these communities. Results of data analysed shows that while most of these communities are agrarian with major cash crop in rice production other activities such as aquaculture are good option as alternative income sources. This option of farming has been found to be well suited in solving the problem analysis in the communities especially as regards environmental pollution. In addition, local farmers can raise more income from improving production effects and saving energy expenses. Also, removing observed gender barrier in these communities will ensure adequate representation of women and youths in the production sector and consequently improve economic well-being of the community. Therefore on-the-field model need to be conducted as a trial in regard to geography and household conditions to properly capture the production and economic dynamics of this system.

Introduction

The situational analysis will give a critical and detailed review of the context in which stakeholders operate before the project implementation. It will give template for measuring of the project outcomes and impacts. The approach developed was used in engaging the stakeholders' in the process of project site selection. This activity helped in achieving part of the activity under outcome 2 (Understanding convenient market access approach and nutrition contributions of rice-fish farming products) as addressed in outputs 2.1 and 2.2 in the project document.

Overall Objective

Strengthening and diversifying income opportunities through integrated rice and fish farming in rice farming communities in Kebbi and Ebonyi states.

Specific objective

- To investigate possibilities for development of the integrated farming system of aquaculture and rice in selected rice producing communities in Kebbi and Ebonyi states.

Methodology

Site selection

On arrival in Ebonyi and Kebbi states, the project team used the first three days, to move round the lowland and upland rice growing communities of the Kebbi and Ebonyi state, respectively.

This was mainly done to assess these communities on their suitability for establishment of the pilot adaptive research plots. During these exploratory survey, the team visited the three senatorial zones in each of the states. After which, three communities each representing each of each of the three senatorial zones in the two states were selected. Situational analysis of the selected communities was carried out for another two days, in each of the selected communities.

The information was collected using Rapid Appraisal techniques with focus on gender perspective. The data collection was grouped under two sub headings:

1. Development Content- with focus on
 - a. Historical background as presented by long term residents
 - b. Map of the community
2. Livelihood analysis
 - a. Seasonal calendar
 - b. Daily activity profiles of women and men
3. Swot analysis of the community

All the information was collected using participatory approach with the communities involved.

The team held a number of meetings with different members of the communities including women and men engaged in rice farming, fishing activities, non-fishing residents, long term residents and key informants (teachers, youth representatives, village council members and religious leaders). In addition, the team met with specific groups alone (such as women input owners) while, on other occasions, a cross section of the community was present. The team also explored the communities and walk across the locations. Information was gathered using several Rapid Appraisal techniques, Participatory Rural Appraisal and, where appropriate, was collected with a gender perspective. Through these activities, data on development content and livelihood analysis of the communities was collected.

The various wetland sites in the communities shall be assessed for their suitability for rice and fish farming using the procedures of Halwart and Gupta (2004).

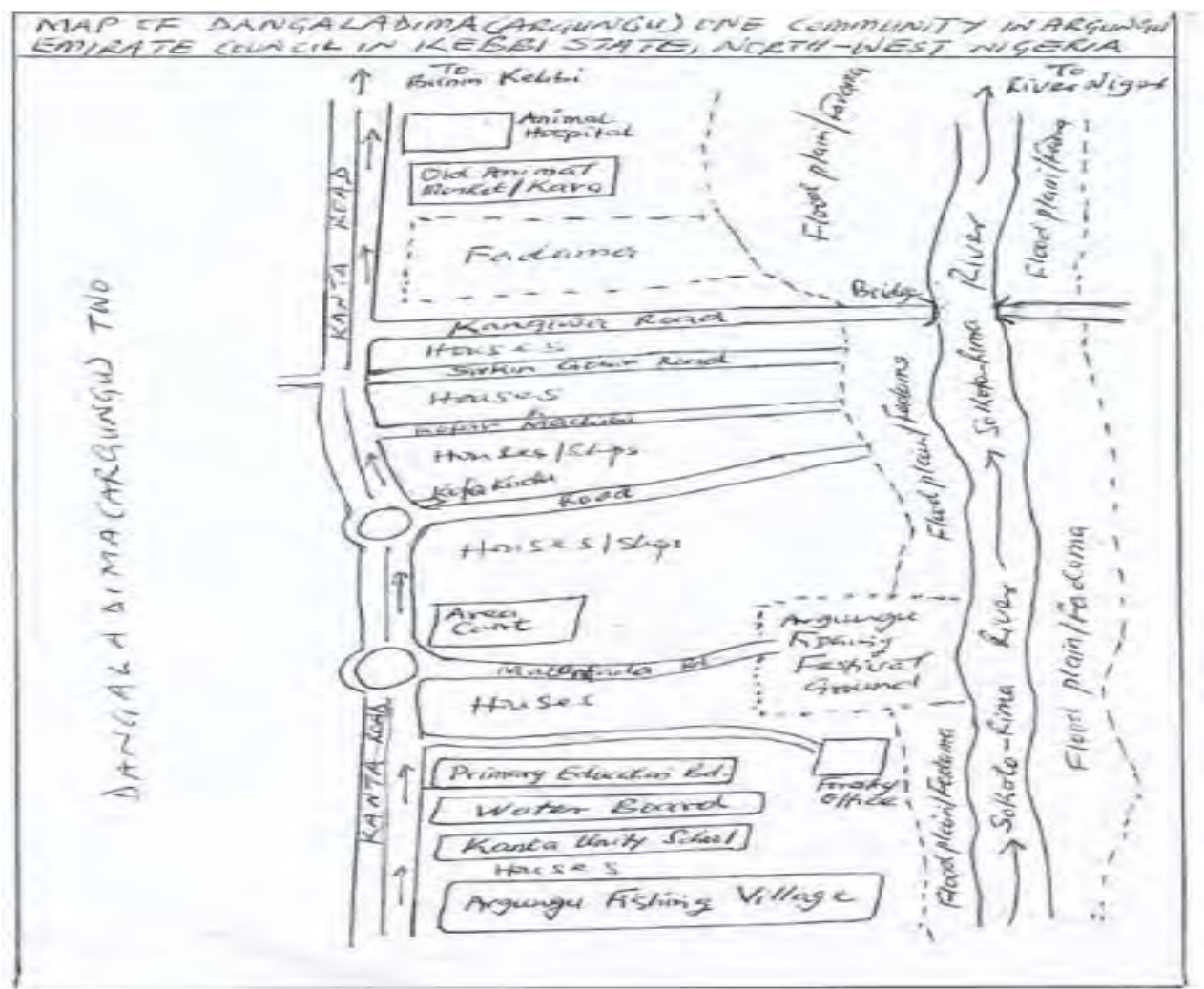
Data collection and analysis

All relevant information, both quantitative and qualitative data to the system were collected focusing on integrated farming activities. Primary data was collected using interviews, observation, and participatory rural appraisal (PRA). This provides synergy effect for data collection and evaluation efforts, and collection of a comprehensive amount of information about household's production systems in a relatively short time period. Various tools and techniques of PRA were used with the help of checklists and semi-structured questionnaires, such as Seasonal calendar, Venn Diagrams, Matrix Ranking, to identify some key features of production activities of local households.

1. NAME OF COMMUNITY: DAN GALADIMA

Dan Galadima is a community in Argungu town, the headquarters of the Argungu Emirate/Kabi kingdom. It was founded by Muhammed Kanta in the 16th century.

The major ethnic groups are the Lekawa, Kabawa and the Lailabawa. Lekawa are the descendants of Kanta of Kabi who are the Argungun royal families. The Lelabawa were also linked to the royal house by marriage during the reign of the 15th Emir, Kabi Samaila. The Kabawa are the Sarkawa (Fishermen). However, in modern times, the name Kabawa is used to describe all the bonafide indigenes of the Argungu Emirate



Seasonal calendar

Activities/Months	1	2	3	4	5	6	7	8	9	10	11	12
Farming												
Land preparation												
Nursery preparation												
Transplanting												
Fertilization												
Weeding												
Irrigation												
Harvesting												
Processing												
Fishing												

Daily activity profiles of men and women

Women

Wake up by 5:30am to pray. After prayers they prepare breakfast for this household for a 7:00am breakfast. After the breakfast the women wash the dishes. They then sweep and clean the house. The economic activities of the women involve cooking and production of small processed food items such as *kuli kuli* which are normally given to the children to hawk around the neighbourhood. In the afternoon the women cook lunch for the household and also cook dinner for the evening. The women observe the Islamic prayer times at home. They retired to bed around 8:00pm

Men

The men wake up by 5:30am to observe the Islamic prayers. Many go to nearby mosques to observe this prayer. By 7:00am they take their breakfast. After this they go about their daily activities. Some may go to Arabic schools before going to the farm. After farm, those that have shops/stalls go there to sell their goods. The practice in this community is for men to buy raw food stuffs and take home in the afternoon for their wives to cook. This is traditionally known as *chefane*. When the men return from work in the evening, they eat, pray and retire to bed by 8:00pm

Gender Analysis (activities)

Production of goods and services	Who does the work?		Frequency of activities
	women	Men	
Land preparation		Yes/hired labour	Regularly
Nursery preparation		Yes/hire labour	Regularly
Transplanting		Yes/hire labour	Regularly
Fertilization		Yes/hire labour	Regularly
Weeding		Yes/hired labour	Regularly
Irrigation		Yes/hired labour	Regularly
Harvesting		Yes/hired labour	Regularly
Processing		Yes/hired labour	Regularly
Fishing		Yes/hired labour	Regularly

Household tasks	Who does the work?		Frequency of activities
	women	Men	
Food provision		Yes	Daily
House construction		Yes	Occasionally
Cleaning the house	Yes		Daily
Child care	Yes		Daily
Washing clothes	Yes		Regularly
Health care for family	Yes	Yes	Regularly
Cooking/feeding the family	Yes		Regularly
Collecting firewood	Yes	Yes	Regularly

Community tasks	Who does the work?		Frequency of activities
	women	Men	
Attending village meetings		yes	Regularly
constructing religious buildings		yes	Occasionally
participating on local councils	Yes	yes	Regularly
Community security		Yes	Regularly

Gender analysis (Resources)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
family labour for other businesses	Yes	Yes	yes	Yes
family labour for farming	Yes	Yes	yes	Yes
family labour for household tasks	Yes	Yes	yes	Yes
Hired labour	Yes	Yes	Yes	Yes
Land	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Gender analysis (Benefits)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
income from fish sales		Yes		Yes
Fish for sale		Yes		Yes
food for household use	Yes	Yes	yes	Yes
water for household use	Yes	Yes	Yes	Yes
Income from rice	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Core problems analysis

Core problems	Causes of problems	Effects of the problems	Opportunities to overcome the problems	Assumptions
Flooding	➤ Overflow from dam, ➤ Climate change	➤ Crops are destroyed ➤ Temporary inability to use the land ➤ Many houses also destroyed	➤ Water recession farming whereby the farmer plants following receding water is receding	
Lack of capital	➤ Poverty ➤ Debt leads to loss of capital because proceeds are used to offset debt immediately after harvest	➤ Inability to prepare enough land for farming ➤ Poor nutrition	➤ Farmer cooperatives formed to lend money	
Quelea birds, rodents and insects		➤ Loss of crop ➤ Reduction in harvest	➤ Use of scare crows ➤ Use of pesticides	
Poaching, theft	➤ Insecurity	➤ Loss of crops and money	➤ Formation of vigilante groups ➤ Restriction of movement after 11:00pm ➤ Strange faces are challenged	
Poor extension linkages	➤ Inadequate number of extension agents	➤ Poor technical know-how among farmer	➤ Farmer interactions	
Government interventions don't get to real farmers but to political farmer	➤ Hijack by party members	➤ Poor yield	➤ Farmers always resort to self-help by borrowing ➤ Cooperatives	

COMMUNITY SWOT ANALYSIS

Strength

Vast abundant arable land
Wetland availability
Good irrigation facility
Experienced people in rice farming

Weakness

Lack of support from government
No power/electricity
Lack of good source of drinking water
Lack farm inputs such as chemicals, fertilizers

Opportunities

Good road network
Markets
Availability of labour

Threats

Excessive taxation
Banditry
Herders' conflicts



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Cross section of stakeholders in the selected project site – Dan-Galadima community, Argungu Emirate, Kebbi state during situational analysis

Historical profile

This community started about 25 years ago when some people who were displaced by flood waters were relocated to this current location. The settlers are Hausas, with subgroups being the Katsinawas, Zamfarawas, Bare-Bares, Magalawas.



Seasonal calendar

Activities/Months	1	2	3	4	5	6	7	8	9	10	11	12
Farming												
Land preparation												
Nursery preparation												
Transplanting												
Fertilization												
Weeding												
Irrigation												
Harvesting												
Processing												
Fishing												
Stocking												
Pond management												
Cropping												

Daily activity profiles of men and women

Women

Women wake up by 5:30am to pray. After prayers they prepare breakfast for this household for a 7:00am breakfast and do the house chores after that. Women are categorised as elderly or young. The first group are past child bearing and their children have grown up and do mainly rice farming as well as fish processing and marketing. The younger women stay at home to take care of the children and their husbands. They engage in petty trading from the small things like *kulikuli* they make at home. These women use their children to hawk their wares.

Men

The men wake up by 5:30am to observe the Islamic prayers. Many go to nearby mosques to observe this prayer. By 7:00am they take their breakfast. After this they go about their daily activities. Some may go to Arabic schools before going to the farm. After farm, those that have shops/stalls go there to sell their goods. The practice in this community is for men to buy raw food stuffs and take home in the afternoon for their wives to cook. This is traditionally known as *chefane*. When the men return from work in the evening, they eat, pray and retire to bed by 8:00pm

Gender Analysis (activities)

Production of goods and services	Who does the work?		Frequency of activities
	women	Men	
Land preparation		Yes/hired labour	Regularly
Nursery preparation		Yes/hire labour	Regularly
Transplanting		Yes/hire labour	Regularly
Fertilization		Yes/hire labour	Regularly
Weeding		Yes/hired labour	Regularly
Irrigation		Yes/hired labour	Regularly
Harvesting		Yes/hired labour	Regularly
Processing		Yes/hired labour	Regularly
Fishing		Yes/hired labour	Regularly

Household tasks	Who does the work?		Frequency of activities
	women	Men	
Food provision		yes	Daily
House construction		yes	Occasionally
Cleaning the house	Yes		Daily
Child care	Yes		Daily
Washing clothes	Yes		Regularly
Health care for family	Yes	Yes	Regularly
Cooking/feeding the family	Yes		Regularly

Firewood for family use	Yes	Yes	Regularly

Community tasks	Who does the work?		Frequency of activities
	women	Men	
Participating in local councils		yes	Regularly
constructing religious buildings		yes	Occasionally
participating on local councils	yes	yes	Regularly
Community security		Yes	Regularly

Gender analysis (Resources)

Resources	Who has access?		Who has control?	
	women	Men	women	Men
family labour for other businesses	yes	Yes	yes	Yes
family labour for farming	yes	Yes	yes	Yes
family labour for household tasks	yes	Yes	yes	Yes
Hired labour	Yes	Yes	Yes	Yes
Land	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Gender analysis (Benefits)

Resources	Who has access?		Who has control?	
	women	Men	women	Men
income from fish sales		Yes		Yes
Fish for sale		Yes		Yes
food for household use	Yes	Yes	yes	Yes
water for household use	Yes	Yes	Yes	Yes
Income from rice	Yes	Yes	Yes	Yes
Water resources	Yes	Yes		Yes

Core problems analysis

Core problems	Causes of problems	Effects of the problems	Opportunities to overcome the problems	Assumptions
Flooding	➤ Overflow from dam, ➤ Climate change	➤ Crops are destroyed ➤ Temporary inability to use the land ➤ Many houses also destroyed	➤ Water recession farming whereby the farmer plants following receding water is receding	
Lack of capital	➤ Poverty ➤ Debt leads to loss of capital because proceeds are used to offset debt immediately after harvest	➤ Inability to prepare enough land for farming ➤ Poor nutrition	➤ Farmer cooperatives formed to lend money	
Quelea birds, rodents and insects		➤ Loss of crop ➤ Reduction in harvest	➤ Use of scare crows ➤ Use of pesticides	
Poaching, theft	➤ Insecurity	➤ Loss of crops and money	➤ Formation of vigilante groups ➤ Restriction of movement after 11:00pm ➤ Strange faces are challenged ➤ Cluster farming ➤ Attempt at farm insurance	
Delayed bank loans does not	➤ Official bottlenecks			

meet farming calendar				
Poor extension linkages	➤ Inadequate number of extension agents			
Government interventions don't get to real farmers but to political farmer	➤ Hijack by party members			

SWOT ANALYSIS

Strength

Fertile and large expanse of land for rice farming Good source of water for dry season farming.

Indigenous skills and knowledge in rice farming.

WEAKNESS

Lack of finance

Lack of equipment to practice mechanised farming.

OPPORTUNITIES

Abundant natural resources High population

Access to land

THREATS

Flooding

Climate change

Fulani cattle invaders



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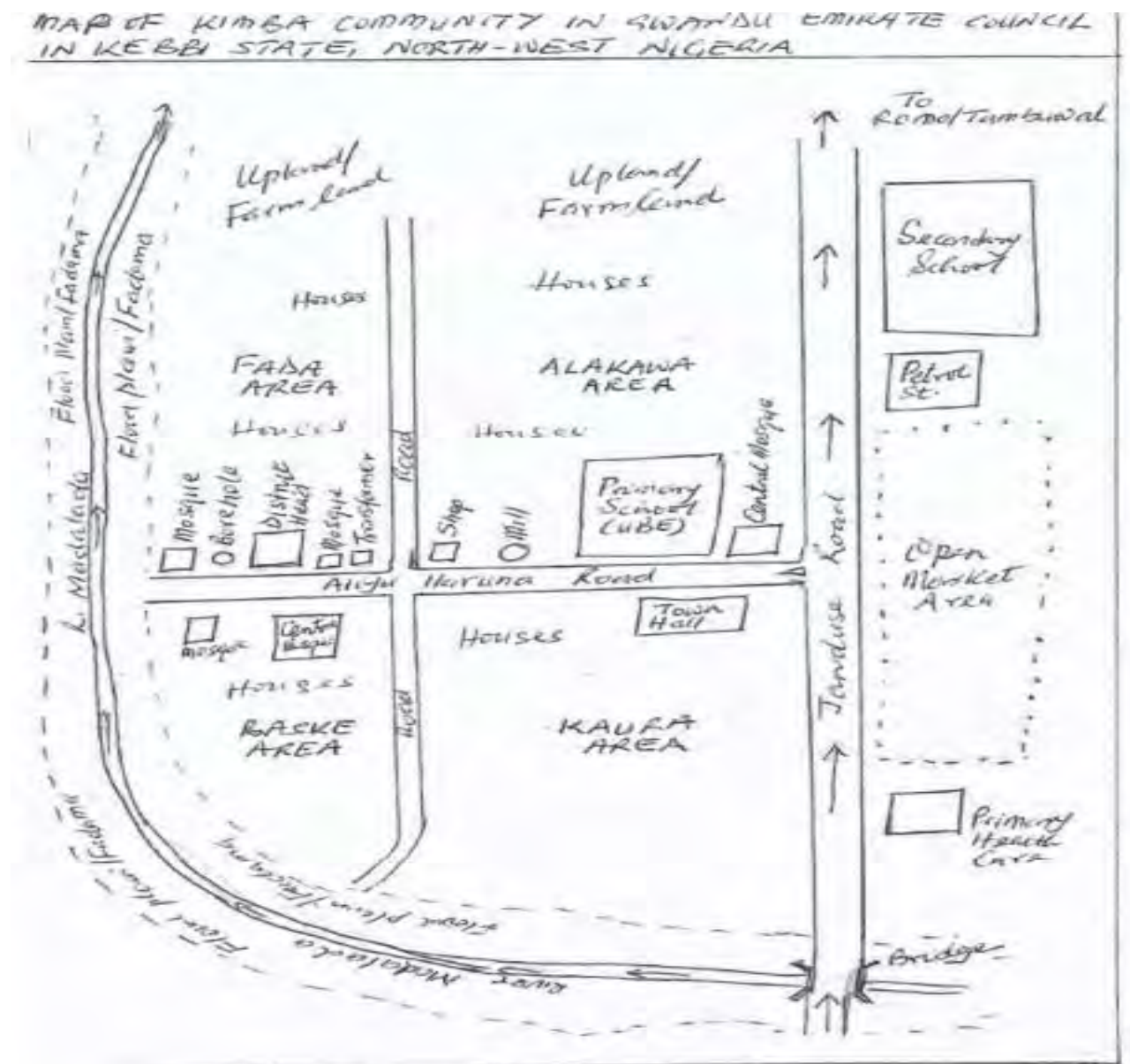
Situational Analysis of the selected project communities (Jega) Kebbi state – Interaction with Male rice and fish producers

NAME OF COMMUNITY: Kimba

Historical profile

-Historical profile of the rice and fishing community prepared by long-term residents

The Kimba is a community that is over 200 years old. They comprise from the Kabawa and Gimbanawa extracts of the Hausa tribe. The people practice Islam and are predominantly crop and livestock farmers.



Seasonal calendar

Activities/Months	1	2	3	4	5	6	7	8	9	10	11	12
Farming												
Land preparation												
Nursery preparation												
Transplanting												
Fertilization												
Weeding												
Irrigation												
Harvesting												
Processing												
Fishing												

Daily activity profiles of men and women

Women

Wake up between 5:00 am to 5:30am to pray. After prayers they prepare breakfast for this household for a 7:30am 8:00am breakfast. After the breakfast the women wash the dishes. They then sweep and clean the house. They also get lunch ready by 1.00-1:30pm, so that the men may come to eat after the after prayers

Men

The men wake up by 5:30am to observe the Islamic prayers. Many go to nearby mosques to observe this prayer. By 7:30am 8:00am they take their breakfast. After this they go about their daily activities but usually come home to eat lunch. On Fridays they rest after the Juma'at prayers, take time to gist and interact. The usual bed time in this community is 8:00pm

Gender Analysis (activities)

Production of goods and services	Who does the work?		Frequency of activities
	women	Men	
Land preparation		Yes/hired labour	Regularly
Nursery preparation		Yes/hire labour	Regularly
Transplanting		Yes/hire labour	Regularly
Fertilization		Yes/hire labour	Regularly
Weeding		Yes/hired labour	Regularly
Irrigation		Yes/hired labour	Regularly
Harvesting		Yes/hired labour	Regularly
Processing		Yes/hired labour	Regularly
Fishing		Yes/hired labour	Regularly

Household tasks	Who does the work?		Frequency of activities
	Women	Men	
Food provision		yes	Daily
House construction		yes	Ocasionally
Cleaning the house	Yes		Daily
Child care	Yes		Daily
Washing clothes	Yes		Regularly
Health care for family	Yes	Yes	Regularly
Cooking/feeding the family	Yes		Regularly

Community tasks	Who does the work?		Frequency of activities
	Women	Men	

Participating in local councils		yes	Regularly
constructing religious buildings		yes	Occasionally
participating on local councils	Yes	yes	Regularly
Community security		Yes	Regularly

Gender analysis (Resources)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
family labour for other businesses	Yes	Yes	yes	Yes
family labour for farming	Yes	Yes	yes	Yes
family labour for household tasks	Yes	Yes	yes	Yes
Hired labour	Yes	Yes	Yes	Yes
Land	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Gender analysis (Benefits)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
income from fish sales		Yes		Yes
Fish for sale		Yes		Yes
food for household use	Yes	Yes	yes	Yes
water for household use	Yes	Yes	Yes	Yes
Income from rice	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Core problems analysis

Core problems	Causes of problems	Effects of the problems	Opportunities to overcome the problems	Assumptions
Flooding	➤ Overflow from dam, ➤ Climate change	➤ Crops are destroyed ➤ Temporary inability to use the land ➤ Many houses also destroyed	➤ Water recession farming whereby the farmer plants following receding water is receding	
Lack of capital	➤ Poverty ➤ Debt leads to loss of capital because proceeds are used to offset debt immediately after harvest	➤ Inability to prepare enough land for farming ➤ Poor nutrition	➤ Farmer cooperatives formed to lend money	
Quelea birds, rodents and insects				
Poaching, theft	➤ Insecurity	➤ Loss of crops and money	➤ Formation of vigilante groups ➤ Restriction of movement after 11:00pm ➤ Strange faces are challenged	
Delayed bank loans does not meet farming calendar	➤ Official bottlenecks			
Poor extension linkages	➤ Inadequate number of extension agents			
Lack of access to fertilizers	➤ Hijack by party members			



Stakeholder engagement and Situational analysis in selected project site -Warra Community- in Kebbi state

Ebonyi north

Iboko –uwaka-alebo road, Ebonyi state

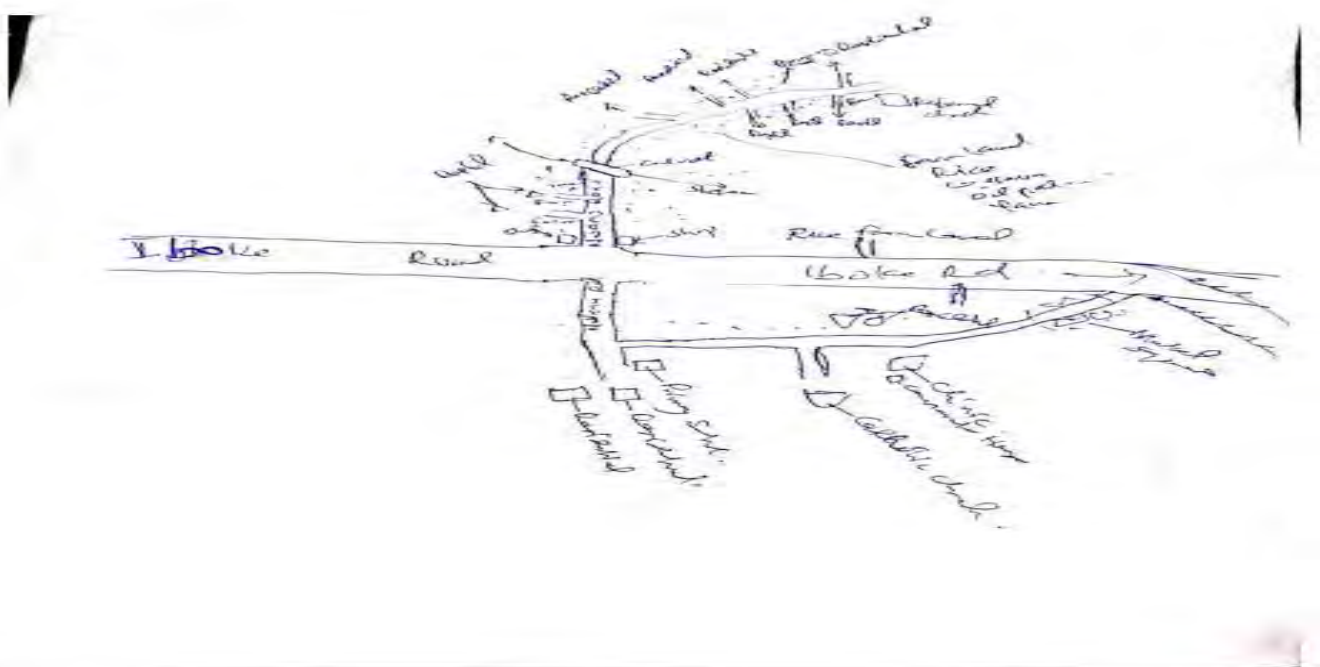
NAME OF COMMUNITY: Nwanu

Nwanu village has been a peaceful town. It is part of Nde ebor Ezza Imegu community in Izzi LGA of Ebonyi state. It has been known to be crises free. They are mainly farmers, with rice as their major focus because it gives them more money. They also cultivate cassava, yam etc. They have a swampy land mass that aids their cultivation of rice.

Members of this community are mainly Christians. There many churches belonging varying denominations - catholic, Anglican, Assemblies of God etc.in the community and they all co-exist peacefully. There is also a primary school and a playground for their gathering. They also have shrines for traditional worshippers. The challenge of the village is water. During the peak of dry season, they travel far to get water. However during the road construction that crossed the area, there was an excavation that traps water which enabled them to get water. They do other forms of business.

Their major occupation is rice farming. They are also able to harvest fish in the dam but it is not a main source of income. They are willing to learn new ways of cultivating their rice and fish. They were having poor yield due to the variety of rice they were cultivating but when an improved variety was introduced to them, they adopted it and it improved their income. This informed their enthusiasm to want to learn and adopt the integrated farming that is being introduced to them. They are very accommodating and hospitable people, obedient to govt, who in turn brings in new things to them.

Map of Nwanu Community



Traditions of the village

August; New yam festival is celebrated

September; Remembering their dead brothers and sister and marriage ceremony.

Seasonal calendar in response to farming activities:

From October to November; clearing of land preparation for farming. December.

To April: cultivation and planting

May to June: Rice farming starts and extends to September

August- testing of the yam and new yam festival

August to December – Harvesting of the yam

Rotational farming

Yam farming is rotated on a yearly basis while rice farming is cultivated yearly on the same land.

Daily activities Men

Farming- take breakfast, go to farm, tilling and making of mounds for the yam or cassava

Women

Wake up in the morning, sweep the house and take care of the children. Cook for the house, go to farm, cultivate groundnut, pepper, cassava, rice etc. Close from farm around 4pm to come back and prepare the dinner

RESOURCES AND BENEFITS FLOW IN THE COMMUNITY

They have good population They have land

They have fruit trees, palm, bush mango, mango, orange etc The dam is a source of water and fish

HOW ARE THE BENEFITS SHARED

Each family has a land and the entire village has a land which which are equally distributed to the taxable adults. The youths are have theirs too. The village gives the land out for farmers to cultivate and the proceeds may be used for the common good of the people such as the construction of local bridge.

Economic tree- the village has some which are free for all indigenes to harvest from. They use to fence their farm to reduce the entrance of Fulani cattles into their source of water.

Socio-economic and Gender Analysis

WOMEN

Taking care of their husband and family

They do intensive farming and cultivate various crops

They do petty trading

They take care of their children and their surrounding

They have meeting where they handle issues concerning women in the community They organise themselves and settle issues among themselves

MEN

They take the children to school

They keep livestock such as goat, chicken etc

They go to farm

In the community, they have community development union where they take decisions about the community

Men also maintain the roads by clearing the pathways periodically

Who has access to land

It is the man that has access and only the men have the right to discuss about land. Women are only allowed access to farm on the land

WHO HAS CONTROL OF RESOURCES

Men are the owners of the land, so they control the resources.

Land may be given to women to farm. A wife has access to the husband's farm, including benefits but the men controls the resources. The proceeds of the farm may be sold and used by both the man and the woman to solve their domestic problem.

WHO PARTICIPATE IN THE DECISION MAKING

The women have a say, they contribute, issues are discussed extensively by all at the village square/play ground and decisions are made by all

Gender Analysis (activities)

Production of goods and services	Who does the work?		Frequency of activities
	Women	Men	
Land preparation	Yes/hired labour	Yes/hired labour	Regularly
Nursery preparation	Yes/hire labour	Yes/hire labour	Regularly
Transplanting	Yes/hire labour	Yes/hire labour	Regularly
Fertilization	Yes/hire labour	Yes/hire labour	Regularly
Weeding	Yes/hired labour	Yes/hired labour	Regularly
Irrigation	Yes/hired labour	Yes/hired labour	Regularly
Harvesting	Yes/hired labour	Yes/hired labour	Regularly
Processing	Yes/hired labour	Yes/hired labour	Regularly

Household tasks	Who does the work?		Frequency of activities
	Women	Men	
Food provision		yes	daily
House construction		yes	Ocasionally
Cleaning the house	Yes		Daily
Child care	Yes		Daily
Washing clothes	Yes		regularly
Health care for family	Yes	Yes	regularly
Cooking/feeding the family	Yes		regularly

Community tasks	Who does the work?		Frequency of activities
	Women	Men	
Participating in local councils		yes	Regularly
constructing religious buildings		yes	Occasionally
participating on local councils	Yes	yes	Regularly
Community security		Yes	Regularly

Gender analysis (Resources)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
family labour for other businesses	Yes	Yes		Yes
family labour for farming	Yes	Yes		Yes
family labour for household tasks	Yes	Yes	Yes	Yes
Hired labour	Yes	Yes	Yes	Yes
Land	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Gender analysis (Benefits)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
income from fish sales				
Fish for sale				
food for household use	Yes	Yes	yes	Yes
water for household use	Yes	Yes	Yes	Yes
Income from rice	Yes	Yes		Yes
Water resources	Yes	Yes		Yes
Economic trees	Yes	Yes		Yes
Cassava and other food crops	Yes	Yes	Yes	Yes

COMMUNITY PROBLEM ANALYSIS

Scarcity of land: no enough land to accommodate those interested in farming.
Lack of finances

No extension agents to educate them

What is causing the problem?

Lack of money to purchase land from other communities

What is the effect of the problem?

Poor production

What are the opportunities to overcome the problems

They establish various cooperatives

They have reached out to government for inputs and assistance

They are ready to receive extension agents

SWOT ANALYSIS

Strength

Good soil for farming

Water availability

Experienced people in rice farming

Weakness

Lack of support from government No
power/electricity

Lack of good source of drinking water

Unavailability of enough land for farming Lack
farm inputs such as chemicals, fertilizers

Opportunities- needs

Electricity Fertiliser,
labour

Threats

Excessive taxation

HOW DO YOU WORK TOGETHER TO HELP INCREASE PRODUCTIVITY

They do community labour

They mobilise their children to scare birds away from the farm

HOW DO YOU ENSURE EFFICIENCY(LAND AND LABOUR)

They practise shifting cultivation to enable the land to recover

They use animals manure and application of fertiliser

Cooperative societies make contributions and people are allowed to borrow money at minimal interest to enable them farm.

Water serves everyone. During dry season, it is fenced round to reduce Fulani cattles.

Once a youth marry, the person is entitled to land and other key activities in the community.

Women who are married, are entitled in their husband's place

They eat yam, maize, ugu, bitterleaf, ficus, garden egg, grasscutter, rabbit, beef and goat.

Biological diversification

They consume many varieties of food that are indigenous e.g. yam, garri, rice, beans etc. They also eat beef and birds which we also keep and sale in our different markets.

Market

There is a market in all villages. They have iboko market, Nwofe market, Nwapu ndeu market. They are all weekly market.

The present government has favoured them by giving the farmers access to loans which aided them in their farming.

INFRASTRUCTURES

Market, school, churches, electric wire passed the village but was not stepped down in the village for them to have electricity.

Any irrigation? Yes , on crops such as pepper during the dry season. LAND

TENURE

Anyone who has money can get a farm to rent for farming

CONSERVATION OF NATURAL RESOURCES

There is the presence of village security that ensures compliance to conservation of any natural resources.

There are laws guiding their activities in the village while defaulters are dealt with according to the law

SOIL FERTILITY AND SOIL HEALTH MANAGEMENT

They use animal droppings, apply fertilizers and practise shifting cultivation



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Situational analysis and stakeholder engagement in the selected project community – Nwanu community- Ebonyi state

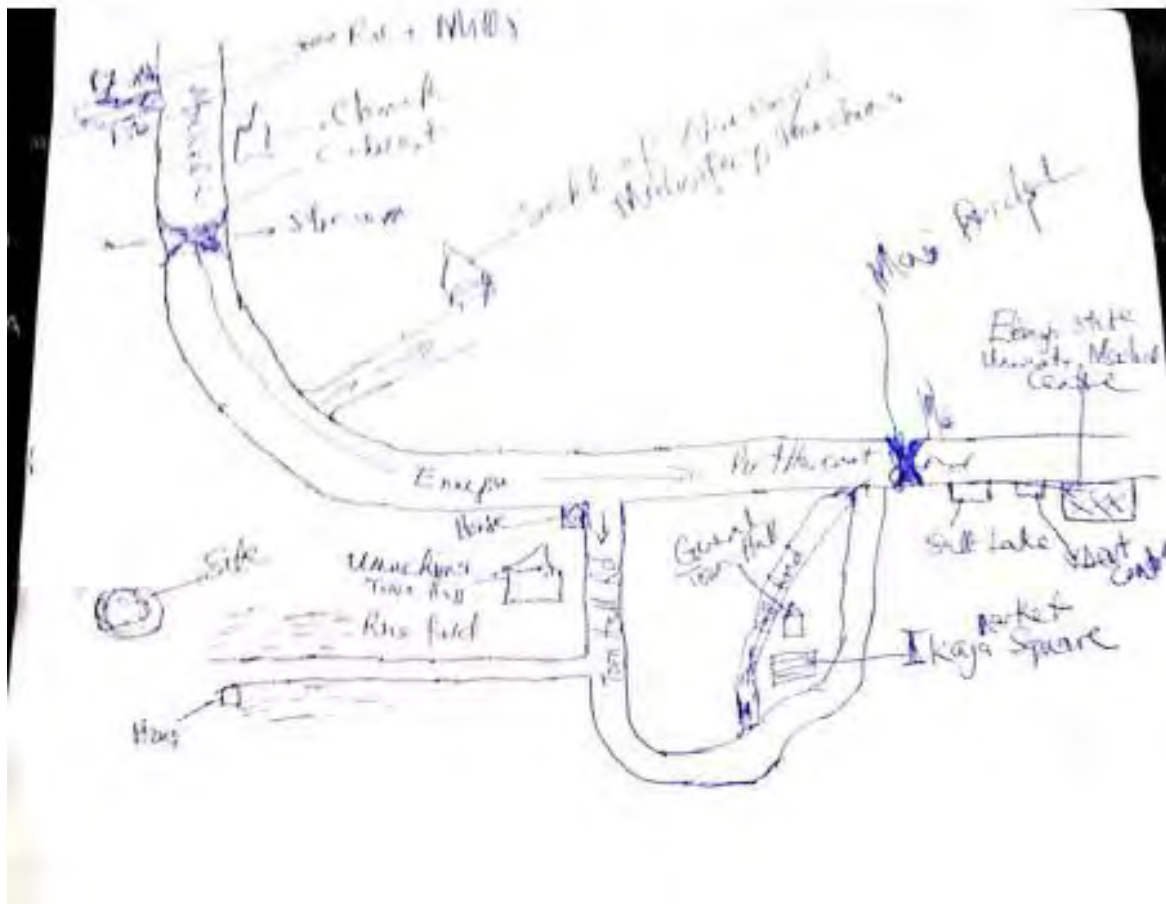
UMUCHIMA EWEZE HALL, UBURU, OHAOZARA LGA EBONYI STATE

UMUCHIMA COMMUNITY

Umuchima is the largest of the 14 villages in Uburu autonomous community. The village started getting developed from 1912 when the white men first came to the village. Though most a Christian population, it is a very traditional community. They are mainly polygamous.

The salt pond from which the state was named “salt of the nation” is from the village. There is high security and orderliness in the village. The village has a boundary with Enugu state. Residents are mainly farmers. They do only one production cycle for rice per year. They have farm settlement and is one of the most populated village in Uburu. They celebrate new yam festival in August and Aju festival in November.

Community map of Umuchima Village



FARMING CALENDER OF THE VILLAGE

January/February: Early farmers start to farm yam. Planting of vegetables March:
Planting of cassava

April/May: Rice farming commences. They practice broadcasting and nursery system.
Weeding of the yam and cassava farm.

June /July: Application of fertilizer (NPK)

August: Harvesting of yam and their new yam festival

October to December: Harvesting of rice

DAILY ROUTINE FOR MEN AND WOMEN

They wake by 5am, say a word of prayer in line with their religious believe. They come out of their house around 6am, exchange pleasantries with their neighbours and other family members. They prepare their farming tools and by 6.30, they go to farm. They work in the farm till late in the evening.

WOMEN

They wake up early as their husband; they clean the house, the surrounding and other domestic duties. They cook the morning food, prepare the children for school and later go to farm. They take the husbands food along to the farm.

THE RESOURCES IN THE COMMUNITY

Land, farm produce, Salt lake, Lead and Zinc, limestone, water and economic trees

RIGHT OVER THE RESOURCES

The land belongs to the community and it is shared to individual families. Whatever individual family plants, belongs to them. Water is owned by the village and all members of the village can fish from it. The mineral resources are owned by the government while they allocate some percentage to the host community.

Individuals also come to mine the minerals and they go to the village head for negotiations. After negotiating with the village head, they will meet with the entire village. They normally bring palm wine, kolanuts and beer while meeting the entire community. The village normally give conditions such as: employment for youths, provide some commission for our elders and women. In essence everyone benefits from the resource proceeds

WHAT DO MEN/WOMEN DO IN FARM

Men do the hard labour such as tilling the soil, making the moulds, cut trees, plant yam while the women plant cassava, rice, pepper, weed the farm etc

WHO HAS ACCESS TO LAND

The land is in the custody of the men but women can inherit from their husbands. Women also have access to farm on the land like their men counterparts.

WHAT DO MEN AND WOMEN DO AT HOME

Everyone comes home to rest.

Men provide money for food

Women go to market and cook the food Women and children clean the house.

Gender Analysis

Production of goods and services	Who does the work?		Frequency of activities
	Women	Men	
Land preparation		Yes/hired labour	Regularly
Nursery preparation		Yes/hire labour	Regularly
Transplanting	Yes	Yes/hire labour	Regularly
Fertilization		Yes/hire labour	Regularly
Weeding	Yes	Yes/hired labour	Regularly
Harvesting	Yes		Regularly
Processing	Yes	Yes	Regularly

Household tasks	Who does the work?		Frequency of activities
	Women	Men	
Food provision		Yes	Daily
House construction		Yes	Occasionally
Cleaning the house	Yes		Daily
Child care	Yes		Daily
Washing clothes	Yes		Regularly
Health care for family	Yes	Yes	Regularly
Cooking/feeding the family	Yes		Regularly

Community tasks	Who does the work?		Frequency of activities
	Women	Men	
Participating in local councils		yes	Regularly
constructing religious buildings		yes	Occasionally
participating on local councils	Yes	yes	Regularly
Community security		Yes	Regularly

Gender analysis (Resources)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
family labour for other businesses	Yes	Yes	Yes	Yes
family labour for farming	Yes	Yes	Yes	Yes
family labour for household tasks	Yes	Yes	Yes	Yes
Hired labour	Yes	Yes	Yes	Yes
Land	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Gender analysis (Benefits)

Resources	Who has access?		Who has control?	
	Women	Men	women	Men
income from fish sales				
Fish for sale				
food for household use	Yes	Yes	yes	Yes
water for household use	Yes	Yes	Yes	Yes
Income from rice	Yes	Yes		Yes
Water resources	Yes	Yes		Yes
Economic trees	Yes	Yes		Yes
Cassava and other food crops	Yes	Yes	Yes	Yes

IN DECISION MAKING, WHAT IS THE CHANNEL

Every community have heads and they are contacted when there is an issue. They youth are also involved before the women. Men primarily make policies and decisions through the HRH and his cabinet, community leaders and family heads.

Women also have their own meeting while some of their members represent then while having a meeting with the men. In the case of any disagreement in the decision taken by the men, they will send their representatives to bring their grievances to the men fold.

CORE PROBLEMS OF THE VILLAGE

Hardship such as lack of money to maintain the farm

Flood destroys their farm

Fulani cattle also destroy their farm.

CAUSES OF THESE PROBLEMS

The community is surrounded by stream which overflows its banks at the peak of the rains hence leads to flooding of the farm.

Inability to access loan from the government to aid their farming

EFFECTS OF THE PROBLEM TO THE COMMUNITY

Poverty

OPPORTUNITY TO OVERCOME THESE PROBLEMS

Through cooperatives and other organisations, they contribute money together and give loans to themselves with little interest. This cooperative system is called *isusu*. They pay up the loan after the harvest of the crop. Their polygamous nature also helps them in farming as it provides many hands hence there is an increased work force.

SWOT ANALYSIS

Strength

Fertile and large expanse of land for rice farming They have a source of water for dry season farming.

They have the indigenous skills and knowledge in rice farming. They have labour for farming.

They have good roads to their farms.

WEAKNESS

Lack of finance

They lack equipment to practice mechanised farming.

OPPORTUNITIES

Abundant natural resources High population

Access to land

THREATS

Flooding

Climate change

Fulani cattle invaders

HOW DO YOU ENSURE EFFICIENT USE OF LAND

Shifting cultivation

Application of herbicides to kill weeds.



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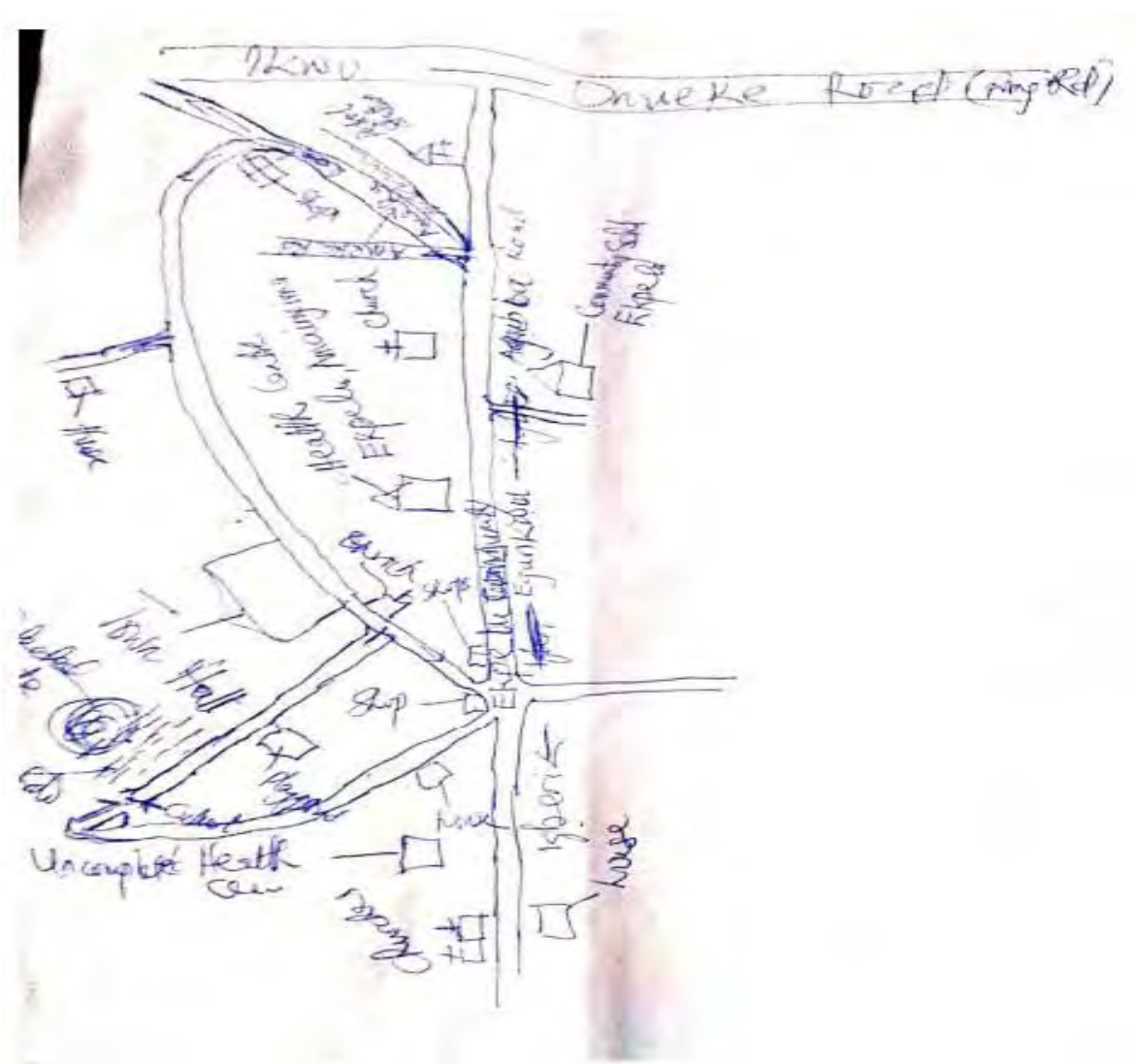
Situational analysis and stakeholder engagement in the selected project community – Umuchima Eweze community- Ebonyi state

COMMUNITY: EKPELU

EKPELU, UMUAKA IKWO, IKWO LGA

This village is the ancestral home of the Ikwo clan. It is a very peaceful village. They have primary school and electric pools and wire (not connected to the national grid) in their village which they built from the proceeds from their farm. Yam has been the traditional crop farmed in the village before rice was brought in by extension workers. Their land communally owned but portions are given out to individuals every year for farming

Map of Ekpelu Community



FARMING CALENDAR

JAN/FEB: Planting of vegetables

March/April: Preparation for yam and rice cultivation

April/May: Preparing of rice nursery

June/July: Transplanting of the rice

August: Harvesting of yam for the new yam festival

September: Early maturity of the rice

Oct to Dec: Harvesting of rice continues

Daily activity profiles of men and women

Men

The men of this village wake up between 5.30 to 6.30 am. They take care of their personal hygiene needs and pray. By 7:00am they come to the village square and hire labourers to work in your farm. They work in the farm till very late in the evening. The workers are paid before returning back to the house.

Women

The women wake up by 6:00am. They sweep the house and its surroundings. They cook and get breakfast ready by 7:00am and also prepare the children for school. They go to the farm by 7.30am along with the husband and hired workers' food. They participate in planting and other less tedious jobs in the farm. If the weather is too hot, they come back early as to rest and prepare for the next day. When they get home they prepare dinner.

RESOURCES IN THE LAND

These include: Farm produce, Land and Fruit trees/economic trees

HOW ARE THE RESOURCES SHARED

Individuals have their own in their land but they have a community rice farm which are shared equally amongst the households

DUTIES OF MEN AND WOMEN

Men do most of the cultivating using hoe while the women do clearing using cutlass

Women sweep the surrounding, cook, wash, and prepare the kids. The youth pound the food.

ACCESS TO LAND

Men own the land though women have access to farm on the land.

BENEFIT SHARING

Both men and women share from the benefits

The community association chairman and the executive members are the decision makers of the village. They ensure there is security in the village. Women are communicated of any decision taken by the men through their husbands. If the women are not comfortable with any of the decision, they send delegates to the men for a review of the decision. The women have their own meeting with their leaders.

Gender Analysis (activities)

Production of goods and services	Who does the work?		Frequency of activities
	Women	Men	
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Cooking/feeding the family	Yes		Daily

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Hired labour	Yes	Yes	Yes	Yes
Land	Yes	Yes		Yes
Water resources	Yes	Yes		Yes

Gender analysis (Benefits)

Resources	Who has access?		Who has control?	
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water for household use	Yes	Yes	Yes	Yes
Income from rice	Yes	Yes		Yes
Water resources	Yes	Yes		Yes
Economic trees	Yes	Yes		Yes
Cassava and other food crops	Yes	Yes	Yes	Yes

PROBLEMS OF THE VILLAGE

Lack of money

No electricity and access road

WHAT ARE THE EFFECTS OF THE PROBLEMS

Lack of money leads to poor production while the bad roads makes it difficult for farmer to bringout their produce to the market.

OPPORTUNITIES

They want the team to take their challenges to government

SWOT ANALYSIS

STRENGTH

Availability of fertile land

Skills and labour for farming availability

WEAKNESS

Lack of funds

Insufficient water

Poor health facility

OPPORTUNITY

Good Access Road Market

Access Robust Literate

Population

THREATS

Insect pestilence damages their crops



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Situational analysis and stakeholder engagement in the selected project community – Ekpelu community- Ebonyi state

Review of findings

The findings are hereby summarised under three headings

- i. **Developmental context:** All the communities live peaceful communal lives, cooperating in the areas of their livelihood, religious activities and civic responsibilities. They have also formed several cooperatives among themselves to increase their bargaining power, help the members and protect mutual interests. There have also been attempts at self-help within the communities. One community in Ebonyi state contributed and installed electric poles to their community in anticipation of when further help will come so that electric cables can be installed and subsequently connected to the national grid.
- ii. **Livelihood analysis:** Most of the villages selected are rice production with less people into fishing and aquaculture. In Kebbi State they also farm other crops like maize, millet, guinea corn, onions and beans. The cycle of rice production is a minimum of two with some others doing three cycles in Kebbi state. In Ebonyi, some of the other crops are yam and cassava. Their rice production is usually once a year, with the long grain variety being preferred. Other livelihood activities include marketing, commercial motorcycle riding and tailoring.
- iii. **Gender analysis:**
Providing for the household as well as the security of the household rest squarely on the shoulders of the men. They are also the ultimate decision makers in the household. Women were solely responsible for taking care of the home front and were skills in several areas such as cooking, cleaning, caring for the children and their husbands as well as general welfare of the family. They also set timetables for most of the activities at the home front. In Kebbi state most of the women stay at home. Those that engage in economic activities do from home and send their children to hawk their products such as groundnuts, boiled potatoes, cooked food etc. In Ebonyi on the other hand, the women were actively involved in outdoor economic activities. They assist their husband on the farm and also have their own crops on the farm. By removing observed gender barriers in these communities will ensure adequate representation of women and youths in the production sector and consequently on economic well-being of the community.
- iv. **Integrated Rice and Fish farming**
Most of the farmers in the selected communities in both states are mainly rice farmers. The land and other resources around these communities showed that they are in good position to diversify their income base through addition of fish farming alongside with rice production activities. This will go a long way in solving the problem of food and nutrition security in these states. Therefore, on the field model need to be conducted as a trial in regard to geography and household conditions to properly capture the production and economic dynamics of this system.

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Annex 2: Fish feed study proposal I (growth performance, immunological responses, the antioxidant status and gene expression of *Clarias gariepinus* to varying inclusion levels of agro-industrial waste products (fish offal meals) from integrated fish farm)

A PROPOSAL

ON

GROWTH PERFORMANCE, IMMUNOLOGICAL RESPONSES, THE ANTIOXIDANT STATUS AND GENE EXPRESSION OF CLARIAS GARIEPINUS TO VARYING INCLUSION LEVELS OF AGRO-INDUSTRIAL WASTE PRODUCTS (FISH OFFAL MEALS) FROM INTEGRATED FISH FRARM.

BY

CHRISTIAN ASHINZE ODEH

224418

DEPARTMENT OF AQUACULTURE AND FISHERIES MANAGEMENT

FACULTY OF RENEWABLE NATURAL RESOURCES,

THE UNIVERSITY OF IBADAN

CHAPTER ONE

1.0 INTRODUCTION

Living things are in constant quest for food as life sustenance. Good nutrition in animal production systems is essential to economical production of a healthy, high-quality product. In fish farming nutrition is critical because feed typically represents approximately 50 percent of the variable production cost. Fish nutrition has systematically improved in recent years with the development of new, balanced commercial diets that promote optimal fish growth and health. In aquaculture, high cost of feeding ingredient is the ultimate challenge affecting increasing productivity (Ugwumba and Ugwumba, 2007). Producing environmentally sustainable and nutritionally sound feeds for farmed fish has proved to be a challenge. Sustainable growth of the aquaculture industry depends upon the information on the type, quantity, quality, seasonality and cost of the fish feeds and availability of suitable and economical feeds. To meet with the mandate of adequate fish supply for growing populations and to fill the gap between demand and supply, proper information should be available as regards to feeds that are less competitive and at cheap rate with replaceable capacity for fish meals which can also make fish to attain table size at reasonable period at low cost. According to Tacon *et.al.*, (2013) the expansion of aquaculture will fill this gap and relieve pressure on capture fisheries, which have been steadily declining. The improvement in the fish industry and the development in aquaculture have become necessary, particularly in developing countries, because of the nutritional, social, and economic value of fish. Mansfield (2012), reported that there are numerous benefits of aquaculture being the main supply of seafood for the world, from a nutritional, economic and social standpoint, however the industry has received much public scrutiny regarding toxins, contaminants, hormones, and antibiotics in farmed fish, which raises questions about public health and safety According to Diana *et.al.*,(2013), the world may be very different in 2050: the global population will likely increase to nine billion, and about 50 percent more food will be needed to sustain the quality of human life .Therefore, improving fish nutrition and development of new species-specific diet formulations that will supports the aquaculture industry as it expands to satisfy increasing demand at affordable, safe, high-quality fish and seafood products which will bridge the gap between problems and solutions in aquaculture will require insight and creative applications. The composition of the feed affects the final composition of the product; therefore, fish nutrition directly impacts consumers and must be considered in terms of safety and human nutrition. Biotechnology research and applications

can help the aquaculture industry develop sustainably, and efficiently produce good and adequate quality food for a growing human population, (Hixson 2014). The application of biotechnology to produce feed ingredients that are specifically enhanced for aquaculture feeds can help alleviate pressure on wild fisheries. That produce fish meal. It is obvious that the use of Fish meal (FM) must be significantly reduced in aquaculture feeds in order to be environmentally sustainable. The high cost of aquatic feed has led to a wide research for the use of inexpensive ingredients. However, using sustainable alternative feed ingredients to feed fish could potentially affect human health, Agriculture creates wastes and by-products that could be hazardous to the environment and therefore researchers have made efforts to use or recycle them. One approach for recycling these agricultural wastes is to use them in aqua feed industry (Akbarzadeh *et al*, 2019). In 1989, the Presidential Task Force on alternative Formulation of Feed identified feeding of fish as one of the major problems facing aquaculture industry development in Nigeria and proffered possible solution geared towards increasing fish production from this sector. One of the suggestions made by the task force was the utilization of non-conventional proteins supplements of both animals and plants origin in practical fish diet. Moreover, this sector provides employment and income in many developed and developing countries (Olsen *et al*, 2012). It becomes necessary to investigate and assess some non-conventional sources of fish feed ingredients in order to boost fish production from the aquaculture sector. Non-conventional feed resources (NCFR) are feeds that are not usually common in the markets and are not the traditional ingredients used for commercial fish manufacture (Madu *et al*, 2003). Non-conventional feed resources are credited for being non-competitive in terms of human consumption, cheap to purchase, and attract little cost values, the by-products or waste products from agriculture and processing industries are able to serve as a form of waste management in enhancing good sanitation. These include all types of feedstuffs from animal (maggot, termite, earthworm, snail, tadpoles etc.), plant/plant waste (jack bean, cottonseed meal, soybean meal, duckweed, maize bran, rice bran, groundnut cake, brewer waste genetic modified plant.) and wastes from animal sources and processing of food for human consumption which can be recycled to improve their value if there are economically justifiable technological means for converting them into useable products (animal dung, offal, viscera, fish silage, bone, blood) (Fasakin *et al.*, 2000). These animal resources have contributed immensely to the supply of protein necessary to balance the amino acid and vitamin deficiencies cereals and other plant products which impair growth and health of fish (Wee, 1988).

The digestibility of feed ingredients is a vital factor that will indicate the nutritional balance of an aquatic animal's diet (Burr *et al*, 2011). Supplementation with amino acids, especially methionine and lysine, in diets high in plant protein ingredients has been shown to improve digestibility and, as a result, improve the growth and health of various fish species (Mukhopadhyay *et al*, 2001). However, Earthworm is less competitive, accessible and abundant protein rich animals source which can be produced locally at little or no cost production (Mariom and Faslul, 2012). Earthworm apart from enhancing soil bioturbation, sediment porosity and ground water movement, it serves the purpose of being a good food source for fish (Bhilave and Nadav, 2012) according to Tomaz, (2013). Earthworm exponentially multiplies in its habitat when environment is favourably conducive, nevertheless in spite of seasonal availability of earthworm in their conducive environment, they have tendency of bioaccumulation of hazardous non-biodegradable substances such as pesticides, antibiotics and heavy metal like lead and cadmium (Tomaz, 2013). To prevent bioaccumulation of these pollutants and ensure safety and availability of earthworm there is need for its culture since its utilization as live fish food, bait and fish meal supplement have been ascertained by Sogbesan and Ugwumba (2010) and Monebi and Ugwumba (2013).

Maggot, studies have shown that maggot meal is of high biological value. The qualities of housefly maggots are indicative that it has the potential to replace few of the high cost protein supplement in livestock feeds if decently processed (Okah and Onwujiariri, 2012) in recent times, novel protein supplement like housefly maggot has been frequently substituted successfully for fish meal at varying levels in fish feeds, (Adenugba, 2012)

Date seed meal (DSM), an example of Non-conventional feed resources rich in potassium, calcium and phosphorus, vitamins, lipids, protein, antioxidants and phenolic compounds. DSM is usually used as complementary feed ingredient for animals including cattle, sheep, camel and poultry (Hossain *et al.*, 2014). It is known that DSM consists numerous favourable properties such as antiviral, antibacterial, and antifungal activity (Jaganathan *et al.*, 2018). DSM has been shown to improve the function and integrity of the immune system (Andriani *et al.*, 2012). For example, polyphenolic compounds of DSM may affect the immune function of shrimp. It is well known that Polyphenolic compounds can modulate the immune system influencing both activation and differentiation of multiple cell types involved in the immune response (Cuevas *et al*, 2013). Therefore, phenolic compounds of DSM may increase the immune responses of shrimp and their resistance against

pathogens. The essential amino acids that cannot be synthesized by the body, methionine and lysine, are obtained from this diet. Supplementing a fish diet with the recommended amounts of synthetic methionine and lysine will help minimize the oxidation of other amino acids and increase their utilization (Chakraborty *et al.*, 2015). Dietary methionine and lysine are needed for protein, lipid, and energy metabolism, as well as carnitine biosynthesis (Espe *et al.*, 2007). A balanced diet helps to protect fish from pathogens. Any imbalances resulting from the substitution of fish meal (FM) are therefore considered potent stressors that adversely affect fish welfare, immune status, and resistance to pathogens. Furthermore, several studies have shown that the duration of experimental diet administration had an impact on the immunological parameters, with immunological reactions often appearing in the first days of feeding (from 7 to 30 days) (Lilleeng *et al.*, 2009). African catfish, *Clarias gariepinus* and *Oreochromis niloticus* are popular commercial fish species found in Africa, Europe, China, and Brazil, and there are most promising species for aquaculture production due to their distinct genetic and productive characteristics. *C. gariepinus* is mainly characterized by its high growth rate, which is estimated to be at least three times that of other fish species (Artemenkov 2017).

This work is focus on Growth performance, Immunological Responses, the Antioxidant Status and gene expression of *Clarias gariepinus* to varying inclusion levels of agro-industrial waste products fish offal meals (fom) from integrated fish and rice culture based diets.

1.1 justification of the study

Aqua feeds incur high production costs in quality fish feed and the importance of feed intake by fish as a determinant of fish performance has been strongly emphasized. The effects of substituting feed meal with cheap economic sources from agricultural waste on immune status, antioxidant activity, gene expression, and disease resistance should be evaluated. Before this potential can be fully realized, its ecological importance must be taken into consideration, as this will dictate the pace for effective management that will lead to its maximum yield. Clear and explicit linkages between aquaculture and the environment need to be defined and the complementary role of aquaculture in contributing to environmental sustainability has to be developed and made known to all stakeholders in *et al*; aquaculture industry for effective and efficient ecological management. Fish feed affects its biochemical composition of blood as well as physiological structure and development of its organs (Taylor, 2011). Therefore, fish health is of utmost importance, in terms of an ethical and production point of view. Proper nutrition plays a critical role in maintaining normal growth and health of aquatic

organisms. Good nutrition can help mitigate the effects of stress, decrease the susceptibility to disease, and boost the immune system. It is important to consider their diet in terms of stress and disease prevention, while the diet may also serve as a primary method of administering medications, immunostimulants and functional ingredients for fish.

1.2 Aims and Objectives

This study aims at determining the growth performance and nutrient utilization of *C. gariepinus* and *O niloticus* fed with varying inclusion levels of fish offal meal (FOM) as replacement for fish meal (FM).

This study will be guided by the following specific objectives:

To determine the growth performance and nutrient utilization of *C. Gariepinus* and *O niloticus* fed with varying inclusion levels of fish offal meal (FOM) as replacement for fish meal (FM).

To assess the immune status and antioxidant activity of the formulated feeds fed at varying inclusion levels of FOM as replacement to fish meal and its effects on the *C. Gariepinus* and *O niloticus*

To evaluate the effects of varying inclusion levels of FOM on pituitary adenylate cyclase-activating polypeptide (PACAP) gene expression.

To assess the level of disease resistance of *C. gariepinus* and *O niloticus*

CHAPTER TWO

2.0 LITERATUR REVIEW

2.1 Fish Production in Nigeria

Nigeria's fish supply comes mainly from four sources namely Importation, Inland, estuaries and coastal artisanal fishery; Industrial trawl fishery and aquaculture (FMARD, 2010). Over the past 35 years, aquaculture production in Nigeria has grown 12 percent a year from a little over 6,000 metric tonnes in 1980 to nearly 317,000 metric tonnes in 2016. This has placed Nigeria as the largest producer in Aquaculture in sub-saharan Africa. Nigeria's aquaculture focuses mainly on freshwater fish - Tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*, *Heterobranchus bidorsalis*, *H. longifilis*). Catfish species account for 64 percent of aquaculture production in 2015 (World fish, 2018). Aquaculture development in Nigeria has been driven by social and economic objectives, such as nutrition improvement in rural areas, generation of supplementary income, diversification of income activities, and the creation of employment (Ozigbo *et al.*, 2014).

The demand for fish outweighs the local production. This is because Nigeria is the largest consumer of fish in Africa and among the largest fish consumers in the world with over 1.5 million tonnes of fish consumed annually (World fish, 2018). Nigeria has been able to meet the demand mainly through importation which resulted to an import about 700,000 MTs of fish valued at about US \$500 million. (FMARD, 2010). According to World fish (2018) if other factors affecting fish demand (e.g. fish price and consumer preference) remain unchanged, demand for fish and fishery product in the early 2020s will be 600,000 metric tonnes higher than in the mid-2010s, because of income and population growth. On the other hand, if the current trend is maintained, aquaculture production in the early 2020s will be 150,000 metric tonnes higher than in the mid-2010s. However, this will only cover a quarter of the 600,000 metric tonnes of increased demand, resulting in a 450,000-metric ton demand-supply gap.

The gap can only be bridged by sustainably increasing the growth rate of the sector by 22 percent a year. This will not only increase production and consumption but also lead to higher youth employment, increased household income, improved nutrition and reduced child mortality (Worldfish, 2018).

2.2 Aquaculture

The aquaculture industry is a substantial global industry supplying a significant proportion of the aquatic food consumed and other aquatic products that are valuable sources of protein and essential nutrient components for global food security (FAO, 2018). It has rapidly expanded to overcome the dependence on fishery resources from the wild, and presently accounts for more than 50 percent of total fisheries production (FAO, 2016). To support the rapidly growing human population globally, food production industries such as aquaculture require an approach toward improving the output with minimal cost (Ajani, 2019). Nigeria as one of the key players in African aquaculture has been tapping the opportunities provided from aquaculture in meeting her food and nutrition security needs through articulated levels of farm methods and operations

2.3 Integrated fish farming

Integrated fish farming is a diversified and coordinated way of farming with fish as the main target (Ayinla, 2003) along with other farm products. According to Asala (1994) the essence of integrated system is productivity of fish as to meet the challenges of food shortage. The items produced are used either as a source of feed, fertilizer or source of additional income (Chen, 1989). Integrated fish farming has become relevant in the livelihood of every segment of the Nigerian population in the provision of food, employment opportunities and recirculation of waste for maximum utilization, the economic and ecological benefit of integrated fish farming. In Nigeria Integrated fish farming has been reported in many states of the federation in which 50 percent of fish farmers integrate, poultry, Piggery or livestock with fish production (AIFP, 2005).

2.4 Fish cum crop production

This is the cultivation of agricultural crops (e.g. vegetables and arable like maize, rice etc.) and aquatic plants (like water spinach, water chestnut, aquatic weeds like Pistia, duckweed, water hyacinth, Azolla etc.) with fish farming (Nnaji *et al.*, 2003). According to AIFP (2005), fish cum crop production is on the rise also in several states. The common practice in fish cum crop production in the country is in cultivation of fish with rice, and vegetables. This is practiced among the farmer in the rural areas, at subsistence level. The vegetables, like water leaf and spinach among others planted on the dykes, while in the case of rice; it is planted right inside the pond. The crops derive water and nutrients from the fish ponds while the crops serves as food, especially for herbivorous fish. Besides, periphytons on the crop may enhance yield of cultured fish species (Nnanji *et al.*, 2003).

2.5 Economic benefit of integrated fish farming

The economic benefit of integrated fish farming cannot be over-emphasized since the integration is varied and diversified in nature. It is one of the most viable, reliable and profitable of any farming enterprise. It contributes immensely to the economic empowerment of many families especially in the rural communities. It enables the farmer to be productive all the year round and fully maximize its production. Its contribution in the enhancement of food security and self sufficiency.

Nigeria is one of the developing countries affected by hunger, deprivation and abject poverty in spite of its enormous natural and human resources (Alamu *et al.*, 2004). With the prevalent economic situation in the country, there is the need for farmers to engage in a result oriented farming system that will guarantee and sustain adequate food security. The supply of proteinous food in Nigeria is very expensive, a problem that needs to be tackled very seriously, considering the limited available resources. Integrated fish farming offers hope in this direction as it serves as food-production that combines cultivation of crops, rearing of livestock and fish farming.

The scope of integrated fish farming can be considerably wide because the fish farm supplies not only enough fertilizer to produce a large quantity of fish, but also produces meat, milk, eggs, vegetable, etc. as it fully utilizes the water body, the water surface, the land and the pond silt to increase the food available for human consumption.. Integration is suitable for poor farmers with remarkably low expenditure pattern and continuous low spending for food and other dietary requirement (Ayinla, 2003). The varied nature of an integrated fish farm make more jobs available than in unitary system of fish farming (Huazhu *et al.*, 1989). The system is all encompassing as the time is well utilized in other farming activities depending on the type of integration involved. In fish cum crop production, crops like the vegetables are harvested continuously even in dry season as water from the pond is used to water the farms adequately. The farmers are engaged in one farming activity or the other throughout the year thus, making them self-reliant and productive all year round.

Regular source of income in integrated fish farming provides the farmer with a steady source of income all year round; this comes from various farm products. For example, in poultry-cum fish farming before the harvesting of the fish, which may take some months, the farmer can sell the eggs which will generate money for some time. Apart from this, money can also be generated from the vegetables or the crops that may be combined in the integrated fish farming. This really endorsed the submission of Nnaji *et al.* (2003) that integrated fish farming is more profitable than unitary system of farming.

2.6 Fish nutrition and nutrient efficiency in aquaculture

The nutritional content of the feed depends on the species of fish being cultured and at what life stage. When fish are reared in high-density indoor systems or confined in cages and unable to forage freely on natural food (e.g., algae, aquatic plants, aquatic invertebrates, etc.). When fish have balanced diet to eat, they grow fast and stay healthy. In natural waters and well-fertilized ponds, microscopic plants (phytoplankton), microscopic animals (zooplankton), insects, crustaceans, copepods and molluscs are examples of natural foods. When natural foods are not available in sufficient quantity to provide adequate they must be provided with a complete diet. Feeds can either be complete or supplement. Complete diets supply all the ingredients necessary for the optimal growth and health of the fish (protein, carbohydrates, fats, vitamins, and minerals). In contrast, supplemental (i.e., incomplete or partial) diets are intended only to help support the natural food normally available to fish in ponds or outdoor. Steven (2017) stated that most fish farmers use complete diets, typically made up of the following components and percentage ranges: protein, 18–50 percent; lipids, 10–25 percent; carbohydrate, 15–20 percent; ash The essential nutrients for fish are amino acids, fatty acids, vitamins, minerals and energy-yielding macronutrients. Diets for fish must supply all essential nutrients and energy needed to meet the physiological needs of growing animals. Guidelines for nutrient adequacy for some farmed fish species suggest the minimum nutrient requirement to promote growth and prevent signs of nutrient deficiency (NRC, 2011).

Protein is the most expensive component of fish feed. It is required to obtain amino acids, which are utilized to maintain body tissues while excess protein is converted to energy. Proteins are formed by individual amino acids linked together into chain by polypeptides bonds. More than 200 amino acids occur in nature, only 20 are common. Of these amino acids, 10 are essential (indispensable) amino acids that cannot be synthesized by fish. These are methionine, arginine, threonine, tryptophan, histidine, isoleucine, lysine, leucine, valine, and phenylalanine. Of these, lysine and methionine are often the first limiting amino acids. Fish feeds prepared with plant protein (e.g., soybean meal) are typically low in methionine (Eyo, 2001). Meanwhile, fish feeds manufactured with bacterial or yeast proteins are often deficient in both methionine and lysine. Therefore, these amino acids must be supplemented to diets when these sources of proteins are used to replace fishmeal. It is important to know and provide the dietary protein and specific amino acid requirements of each fish species and life stage cultured to promote optimal growth and health. Protein levels in aquaculture feeds generally

average 30 to 35 percent for shrimp, 28–32 percent for catfish, 35–40 percent for tilapia, 38–42 percent for hybrid.

Lipids supply essential fatty acids and energy in the diet. The requirement of essential fatty acids can only be met by supplying Long Chain (LC) Polyunsaturated Fatty Acids (PUFA) in the diet, specifically α -Linolenic Acid (LNA, 18:3 ω 3) and Linoleic Acid (LA, 18:2 ω 6), with varying requirements for eicosapentaenoic acid (EPA, 20:5 ω 3) and docosahexaenoic acid (DHA, 22:6 ω 3) depending on species. Dietary lipids are also important structural components of membranes, and act as precursors of steroid hormones and prostaglandins in fish.

Dietary carbohydrates can be a source of energy for fish; however their ability to utilize dietary carbohydrate for energy varies depending on the species and their natural diet. Therefore, depending on species, protein and lipid are the main source of energy for fish. Feeds in aquaculture are formulated with a balance of nutrients in order to meet specific nutrient requirements for different species, life stages and other purposes.

Vitamins are organic compounds necessary in the diet to support normal fish growth and health. They are stored in the body's fatty tissue (Kanokwan *et al.*, 2014). They are often not synthesized by fish and must be provided in the diet. The two groups of vitamins are water-soluble and fat-soluble. Water-soluble vitamins include B vitamins (thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folic acid, and cobalamins), inositol, choline, and vitamin C (ascorbic acid). Of these, vitamin C probably is the most important because it is a powerful antioxidant and it enhances the immune system of fish and shrimp. Fat-soluble vitamins include vitamins A (retinol, betacarotene), D (cholecalciferol), E (tocopherols), and K (phyloquinone). Of these, vitamin E receives the most attention for its important role as an antioxidant. As a feed ingredient, vitamins E and C also inhibit dietary lipid oxidation, thus helping to improve shelf life. Deficiency of each vitamin has specific symptoms, but reduced growth is the most common symptom of any vitamin deficiency.

Minerals are inorganic elements necessary in the diet for normal body functions. They are essential nutrients and their requirement to fish, of all 90 naturally occurring inorganic elements, 29 of these element are essential for all farmed animals including fish (Lall *et al.*, 2008). They can be divided into two groups – macro minerals and micro minerals based on the quantity required in the diet and the amount present in fish. Dietary requirements for macro-minerals are Ca, K, Mg, Na, P and micro-minerals (trace elements) are Cu, Fe, I, Mn, Se, Zn for one or more fish species (NRC, 2011). Studies

have dealt with the functions, deficiency, availability, utilisation, toxicity and the interaction with other nutrients and environment on the aforesaid minerals to several fish species. According to NRC (2011) mineral requirement for fish has been compiled and review of mineral nutrition. Fish can absorb many minerals directly from the water through their gills and skin, allowing them to compensate to some extent for mineral deficiencies in their diet.

2.6 Feedstuffs in Fish Culture

Feedstuffs are classified into major groups in fish culture: energy feedstuffs and protein supplements.

Energy Feedstuffs.

These feedstuffs containing less crude protein. They are basically of plant origin. Examples are cassava, wheat offal, rice bran, maize, guinea corn, etc.

Protein Supplements.

These are feedstuffs containing 20 percent crude protein or more. They can either be of plant or animal materials. Protein of animal origin are of higher quality we compared with those of plant origin. Examples of animal protein sources in fish culture are fishmeal, bone meal, blood meal while plant protein materials include. Soybean meal, groundnut cake and cottonseed cake.

2.7 Choosing the Feedstuffs

Single feed ingredients can be fed to fish as a supplement to available natural food in a pond. However, combining ingredients may make better quality supplemental feed. Fish would grow well on a feed containing 20 to 30 percent crude protein, of which 7 to 10 percent of the protein is from animal sources. When natural food is abundant and fish are stocked at low densities, a 20 to 25 percent protein content is suitable. A 30 percent or more crude protein content is more suitable for commercial operations where fish are stocked at higher densities.

Table 1.0: LIST OF SOME COMMON FEED INGREDIENTS AND THEIR COMPOSITION

INGREDIENTS	CRUDE PROTEIN %	ETHER EXTRACT %	CRUDE FIBRE %	ASH %	ENERGY (ME Kcal/g)
Fish meal (white fish)	68	4.5	1.0	23.6	2860
Blood meal	79.9	1.0	1.0	0.2	2844
Meat and Bone-meal	53.8	10.1	2.3	31.0	2000
Feather meal	85.4	2.6	0.6	3.9	2300
Groundnut cake	45.0	6.0	5.0	4.5	2540
Soya-bean meal	42.0	3.5	6.5	al 5.0	2700
Maize	10.0	4.0	2.0	3.6	3432
Millet	10.0	4.0	8.0	1.9	2560
Guinea corn	11.0	3.0	2.0	2.6	3300
Cassava tuber flour	3.3	0.8	4.2	3.8	3100
Sweet potato(dried)	2.8	1.9	1.0		3200
Palm kernel meal	18.0	6.0	12.0		2175
Wheat meddling	17.0	3.5	6.5	2.8	1870
Rice bran	8.2	2.1	10.1	5.0	2860
Rice polish	13.1	14.7	3.3	3.9	3000
Molasses	8.7	0.3		10.6	1900
Brewer's grain	18.0	6.0	20.0	3.4	1980
Brewer's yeast	48.0	1.2	3.2	6.0	2120

Source: Falaye et al. (1988)

2.8 Immune System

Fish immune system is a large, complex network that includes multiple tissues, organs, cells and molecules focusing on host defence (Zimmerman, *et al* 2010). The cells and molecules of the immune system are equipped to recognize and destroy foreign substances in particular, pathogens, thus protecting organisms against diseases and maintaining homeostasis (Chaplin, 2010). Fish are diverse group of organisms standing for the earliest vertebrates, including the Agnatha (hagfish and lamprey), Chondrichthyes fish (sharks and rays), and Osteichthyes (teleost or bony fish) (Bolis, *et al* 2001).

The immune system of fish is composed of two major components, innate (non-specific) and adaptive (specific) immune responses. The innate immune system in fish has a fundamental importance in preventing pathogen entry, it respond to pathogenic organisms by recognizing pathogen associated molecular patterns (PAMPs} which are not expressed in host cells. Common PAMPs recognized by the innate immune response are lipopolysaccharides (LPS) in Gram-negative bacterial cell wall, lipoteichoic acid (LTA) in Gram-positive bacteria, phospholipomannan, beta-glucan, and chitin in fungi, hemagglutinin in viruses (Silva-Gomes, *et al.*, 2015; Taghavi, *et al.*, 2017). In contrast adaptive immune responses are less efficient compared to mammals. The immunity components recognize pathogens by highly specific receptors generated by V (D) J recombination and somatic hyper mutation, resulting in proliferation and differentiation of specific B and T-cells clones (Bonilla, 2010).

2.9 General Properties of Fish Innate Immunity

The innate immune system in fish is the first line of defence that reacts to pathogens within a very short time and does not provide a long-lasting protection (Turvey and Broide, 2010). In fish, it is a basic component in preventing pathogen entry due to the inefficiency of the adaptive immune response (Kordon *et al.*, 2018). According to Magnadóttir (2006), the evolutionary position and poikilothermic nature of fish affect the efficiency of adaptive immunity due to slow lymphocytes proliferation, maturation and memory formation. Fish contain most of the primary and secondary lymphoid organs present in mammals except bone marrow and lymph nodes. However, the structure of these organs in fish lacks the complexity compared to the mammalian counterparts leading to potential limitation and delay in the generation of fully functional adaptive immune responses (Firdaus-Nawi and Zamri-Saad, 2016). The components of the innate immune system in fish are commonly divided into three compartments: physical parameters, humoral parameters, and cellular factors (Uribe *et al.*, 2011)

The physical barriers include fish scales, a mucus layer, and epithelial cells, which line the skin, gills, and alimentary tract, providing a crucial role in combating infection (Ellis, 2001; Magnadottir, 2010). Goblet cells produce a mucus layer in which antimicrobial substances trap pathogens and inhibit the spread of infection (Alexander and Ingram, 1992). Fish mucus contains a wide range of immune substances, in particular, lectins, pentraxins, lysozyme, complement proteins, antibacterial peptides and IgM), which are capable of inhibiting pathogen entry or elimination (Saurabh and Sahoo, 2008). In addition to the mucus barrier, the epidermis, composed of epithelial cells, prevents the entry of foreign materials and is populated with effector cells, such as macrophages and lymphocytes (Esteban, 2012; Fischer *et al.*, 2006). Both mucus and epithelial cells act as physical and chemical barriers against microorganisms and foreign agents (Firdaus-Nawi and Zamri-Saad, 2016).

The humoral immune parameters include cell receptors or soluble molecules, teleost fish contain a large number of non-specific defense substances, such as transferrin, antimicrobial peptides, lysozyme, lectins, natural antibodies, cytokines, and complement components, which are able to kill microorganisms or inhibit their growth (Kordon et al 2018).

There is a close relationship between the dietary protein ingested by the organisms and its immunity. Protein consist of carbon, nitrogen, hydrogen and oxygen and are present in enzymes, certain hormones and defense mechanisms of any organisms (Karacabey, and Ozdemir, 2012).

According to Karacabey, and Ozdemir (2012), beside the substantial role of protein in the defense mechanisms of the immune system it also provide natural and acquire immunity against pathogens , the immunity reliess on it for the development of active protein compound and cell replication.

Antioxidant defence in fish involves enzymatic and non-enzymatic activities. They protect the cell and tissue from oxidative damage. According to Johnson (2002) they serve as biomarkers of fish health and immune status. The nutritional factors influence antioxidant status based on type and dietary level that exert such influence. The Important antioxidants in organisms include the glutathione system and the antioxidant enzymes superoxide dismutase (SOD) and catalase (CAT). The tripeptide (γ -glutamatic acid, cysteine and glycine) reduced glutathione (GSH) and play a key role in protecting against oxidative stress by directly scavenging ROS (Leggatt and Iwama, 2009) and by regenerating the antioxidant vitamins C and E from their oxidized products (Gao *et al.*, 2014). GSH is synthesized intra cellular and oxidized to GSSG in a reaction catalyzed by selenium-dependent glutathione

peroxidase (GSHpx) and the GSHpx activity of certain isoforms of glutathione S-transferase (GSH) (Solé *et al.*, 2004; Halliwell and Gutteridge, 2007). Both sources of GSHpx activity are able to detoxify organic peroxides produced by lipid peroxidation. Glutathione reductase (GR) is required to regenerate GSH from GSSG and regarded as essential to maintain intracellular GSH redox status. The antioxidant SOD catalyses dismutation of O₂ to H₂O₂, and the resulting H₂O₂ is converted to water and oxygen by CAT or detoxified by GSHpx activity (Kalaimani *et al.*, 2008).

The body has evolved antioxidant defences to protect against free radical-induced damage; for example, cell manufacture repair enzymes that can “destroy free-radical-damaged proteins, remove oxidized fatty acids from membranes, and repair free radical damage to DNA (Rahman, 2007), in additional, extracellular, antioxidant defences also exist. Vitamins E and C, the carotenoids, and coenzyme are potentially involved in these antioxidant defences. However, these defences may not be totally effective. Thus, the concentration of free radicals in the body may continue to increase, more damage can occur, and, as a result, the body suffers oxidative stress. Severe oxidative stress may result in cell injury and destruction (Neeraj *et al.*, 2013). knowledge of the antioxidant enzyme activities, lipid peroxidation and the biochemical compositions in early embryonic and yolk-sac stages are extremely important in understanding the formation of protective mechanisms during early stages of larval development at the start of exogenous feeding. In fish, lipid peroxidation caused by oxygen radicals is a principal cause of several diseases such as jaundice, nutritional muscular dystrophy and haemolysis (Mourente *et al.*, 1999). Consequently, the understanding of antioxidant enzyme dynamics could provide an important contribution for the enhancement of larval and juvenile quality.

Studies reviews that metals can induce oxidative stress by generating free radicals and reactive oxygen species. Fish tissues, particularly liver and kidney have antioxidant defence systems to protect them from oxidative stress caused by metals (Basha and Rani, 2003; Atli *et al.*, 2006; Atli and Canli, 2007). Essential and non-essential metals display different effects on antioxidant enzymes due to their different chemical structures and act as redox active and inactive status (Atli and Canli, 2010). Studies suggest that the antioxidants may play an important role in reducing hazardous effects of metals, and antioxidant responses were suggested to be a useful biomarker for metal exposure of aquatic organisms (Srikanth *et al.*, 2013). Antioxidant enzymes are crucial in the effort to counteract oxidative stress caused by toxicants once the supply of other antioxidant compounds are depleted (Martinez Alvarez *et al.*, 2005).

2.10 Biotechnology to improve fish nutrition

Enhancement in fish nutrition aquaculture will require creative applications. Biotechnology research and applications can help the aquaculture industry develop sustainably, and efficiently produce good quality food for a growing human population. There are many new applications of biotechnology in aquaculture; nevertheless, this will focus on how biotechnology can improve fish nutrition for the purpose of safe, nutritious and sustainable food production. In particular, genetic modification will have the most significant impact on fish nutrition in aquaculture. Producing environmentally sustainable and nutritionally sound feeds for farmed fish has proved to be a challenge. The application of biotechnology to produce feed ingredients that are specifically enhanced for aquaculture feeds can help alleviate pressure on wild fisheries that produce FM and FO. Research on GM crops that are enhanced specifically for fish feeds is in the forefront of both plant and aquaculture research. The limiting factor in using plant oils is the lack of LC ω 3 PUFA, namely docosahexaenoic acid (DHA) and EPA. GM plants that can produce their own DHA and EPA, and that can be grown sustainably, is certainly well sought after by the aquaculture industry. Development of such a crop is in the research and development phase, but is not yet available commercially. A study by Ruiz-Lopez *et al.* (2014) demonstrated fish oil-like levels of DHA and EPA produced by the transgenic oilseed camelina, while avoiding accumulation of undesirable fatty acids. Atlantic salmon fed GM rape seed oil and yeast containing high levels of DHA and EPA showed high retention of LC ω 3 PUFA in the flesh (Thomassen *et al* 2012). The benefits of producing LC ω 3 PUFA in plants are clear: a sustainable and non-contaminated source of important fatty acids essential to human nutrition. GM crops may also have other enhanced features that can directly benefit aquaculture production, such as improving feed efficiency, performance, product quality and health; and can indirectly benefit production, such as pest and disease resistance, and increased yield (Deb *et al.*, 2013).

Aqua Bounty Technologies was the first company to submit an application to the Food and Drug Administration (FDA) for a GM animal for food consumption in 1995 and has been in the regulation system to date. In order to acquire FDA approval, Aqua Bounty has had to demonstrate the food's safety, and gauge the environmental risk of the sterile fish escaping its tanks and successfully breeding with wild salmon. By contrast, the FDA approved the first GM crop for human consumption (the Flavr Savr tomato) after just three years of regulatory consideration (Ledford 2013). Research has shown that growth enhanced transgenic Atlantic and coho salmon (*Oncorhynchus kisutch*), have the capacity

for increased daily feed intake, increased growth rates and improved feed utilization due to an enhanced capacity for protein biosynthesis over non-transgenic fish (Hixton, 2014). Transgenic Coho salmon demonstrate an enhanced ability to utilize dietary carbohydrates (in addition to lipid) as a major source of non-protein energy, which is not typical for non-transgenic salmon (Tibbelis *et al.*, 2013). The utilization of carbohydrate allows for greater amount of dietary protein to be spared for rapid tissue growth (Tibbelis *et al.*, 2013). The altered gene expression and different metabolic enzyme capacity in transgenic salmon allows for a shift towards the use of fatty acids and glucose for energy-production purposes, conserving amino acids for protein biosynthesis (Xu *et al.*, 2013). In a study by (Hixton 2014), transgenic Atlantic salmon consumed a significantly higher amount of feed on a daily basis, but also had better FCRs, higher nitrogen retention efficiency and achieved target weight gain in a shorter period (40 percent) than non-transgenic fish. The transgenic salmon in this study demonstrated a higher cellular capacity to direct dietary non-protein energy towards satisfying their daily metabolic energy requirements, allowing for a higher proportion of dietary amino acids to be directed towards protein biosynthesis rather than catabolized as a dietary.

2.11 Sustainability Issues on Fishmeal Use in Aquaculture Feeds

FM is a widely used protein ingredient in aquaculture feeds, especially those intended for carnivorous marine finfish species (Naylor *et al.*, 2000). This is due to its outstanding amino acid profile, high palatability, and excellent nutrient digestibility (Bendiksen *et al.*, 2011). FM are usually sourced of wild-caught, marine bony fish including herring, menhaden, capelin, anchovy, pilchard, sardines and mackerel (Bostock *et al.*, 2010). However, the demand for these small pelagic fish for direct human consumption is huge in Asian countries (Naylor *et al.*, 2000), where the growth of human population is increasing rapidly. Global uses of FM by market segment in 2012 (Tacon *et al.*, 2015). Recently, Tacon *et al.*, (2015) reported that 70 percent of aquaculture production come from direct-fed species (35.7 million tonnes in 2012), including tilapia, shrimp, salmon and marine fish, with the remaining 30 percent being filter-feeding species. Interestingly, 68 percent of direct-fed species production consumed around 39.6 million tonnes of compound aquaculture feeds, with major consumers being carp (28 percent), tilapia (18 percent), shrimp (17 percent), catfish (11 percent), salmon (8 percent), and marine fish (8 percent) (Tacon *et al.*, 2015).

However, as the marine aquaculture keeps expanding, the consumption of FM by carnivorous finfish tend to increase over the next few years along with its serious implications for the economic viability and health of wild fisheries. For fisheries, escalating demand and the associated rise in price for fish used in feed production could justify the needs for enhancing sustainable management systems, especially in poorly managed fisheries (Tveterås, 2010). The above scenarios should also offer a tremendous opportunity for both research institutions and industry to reduce the reliance on natural fish stocks by searching sustainable alternatives to FM as the main protein ingredient in aquaculture feeds (Olsen *et al.*, 2012). Definitely, lower-priced and widely available ingredients that provide a high level of protein, balanced AA content, high digestibility, and appropriate palatability should be in favour of any alternative to FM. 68 percent Aquaculture 23 percent Pig 7 percent Chicken 2 percent Other. Total estimated usage of commercial aquaculture feeds by major fed species in 2012 (Tacon, 2015). Anticipated growth of commercial aquaculture feeds in demand for 2012, 2015, 2020, and 2025 (Tacon *et al.*, 2015).

Plant-derived Protein Ingredients in Aquaculture Feeds Future growth of aquaculture industry will rely on finding options to substitute FM and FO in aquaculture feeds. Plant protein (PP) sources have been considered as having a great potential to replace marine ingredients in diets for cultured carnivorous finfish species (Król *et al.*, 2016), due to their favourable nutritional profile relative to FM (Gatlin *et al.*, 2007). PP meals are known to be cost-effective, available, and more ecologically friendly protein ingredient than FM (Hardy, 2010). Fish nutrition and nutrient efficiency in aquaculture feeds - present scenario. Feed is a vital determinant of the productivity in aquaculture operations. The common feed evaluation indices of fish feeds are ‘feed efficiency’ and ‘protein retention efficiency’ which refer to the fish or protein produced per unit of feed or protein input, respectively. The primary objective of feed formulation and management practices in aquaculture is to improve the feed or protein retention efficiency. These are largely determined by the nutritional profile of the feeds.

Protein (amino acids) is the primary source of energy for fish, and the most expensive nutrient component of the feed. Therefore, improving the protein retention efficiency through increased inclusion of digestible non-protein energy sources (fat, carbohydrates) is an effective strategy to reduce feed costs, improve growth rates and reduce nitrogenous waste output (Cho and Kaushik, 1990). Besides protein economy, sustainability of aquaculture is often questioned by the use of feeds rich in fish meal (FM) and fish oil (FO) derived from capture fisheries. Current estimates are that at a

global level, aquaculture feeds utilize close to 70 and 90 percent respectively of the available FM and FO (FAO, 2012). Thanks to progress made in the area of FM and FO replacement by alternative protein and oil sources, the total use of such capture fishery-derived ingredients has decreased significantly and will continue to do so (Tacon, 2015).

This decline will possibly influence the performance of the fish feeds due to the inherent changes in the quality of the nutrients supplied and other non-nutritional components present in the alternate feed ingredients. Among the four different nutrient groups (amino acids, fatty, vitamins and minerals), the latter two collectively termed as micro-nutrients have received much less attention with regard to the aforesaid changes in fish feeds.

2.12 Challenges to Aquaculture productivity in Nigeria

In spite of the great potential of aquaculture in Nigeria, Nigeria still has a long way to go. According to According to Zango-Daura (2000), Nigeria requires about 1.5 million tonnes of fish annually to meet the FAO recommended minimum fish consumption rate of 12.5 kilograms per head to satisfy the protein needs. As aquaculture production becomes more intensive, fish feed is a significant factor in increasing the productivity and profitability of aquaculture. Given that feed is the biggest source of nutrient loading in aquaculture production, clear understanding of its impact on the environment is highly essential for sustainable development (Adewumi, 2015). Factors affecting feed include the poor availability of suitable constituents, poor formulation and processing, lack of knowledge and understanding of dietary requirement or in appropriate storage (Southgate, 1993).

The small nature of most of the enterprise is also a constraint to Aquaculture development in Nigeria which was described by Ataguba *et al.* (2013) as the “bane” of aquaculture industry. Sole-proprietorship is the dominant organizational structure of the aquaculture ventures. This has brought about the problem of low capital base and inadequate capital to run the venture. Other challenges include lack of and poor management of brood stock, especially feeding and handling, poor record keeping of all activities regarding induced spawning, care of eggs, fry, feeding, and general management of fingerlings (Atanda, 2007). All these factors have contributed to low productivity experienced by many farmers.

2.13 Some culturable species (Catfish and Tilapia) and their general characteristic

Catfish(*Clarias gariepinus*, *Heterobranchus bidorsalis*, *Clarias nigrodigitatus* and hybrid *Heteroclarias*) Catfish belongs to the order Siluriformes and is one of the largest orders of teleosts containing approximately 4100 species, representing about 12 percent of all teleosts and approximately 6.3 percent of all vertebrates (Eschmeyer and Fong, 2014). Most catfish have a cylindrical body with a flattened ventral to allow for benthic feeding. Catfish are named so because of their whisker-like barbels, which are located on the nose, each side of the mouth, and on the chin. Most catfish possess leading spines in their dorsal and pectoral fins. Catfish are scale less, a characteristic of catfishes distinguishing them from most other teleost fish.

Catfish are highly diverse and distributed worldwide. They are commonly found in inland or coastal waters of all continents, including Antarctica where fossils are found. Catfish are most abundantly distributed in the tropics of South America, Asia and Africa. Due to their worldwide distribution and diversity, catfish are interesting models to ecologists and evolutionary biologists, and are important for biogeographical studies (Lundberg *et al.*, 2011). Catfish are quite hardy such that they are more adaptable for artificial spawning, handling, and culture. They possess all the characteristics necessary for aquaculture including relatively high fecundity, ability for artificial spawning, adaptability to earthen ponds for culture, high tolerance to low dissolved oxygen, relatively high resistance against infectious diseases, and relatively high feed conversion efficiency. It is such characteristics that make catfish one of the most popular groups of fish for aquaculture. In the world, a few major species are widely used for aquaculture, including channel catfish, blue catfish, walking catfish, shark catfish, Thai catfish, and African catfish (Jin *et al.*, 2016).

African catfish is an important aquaculture species that is cultured in various regions in the world. The top producing country is Nigeria followed by the Netherlands, Brazil, Hungary, Kenya, Syrian, Arab Republic, South African, Cameroon, and Mali (FAO, 2016). The total production of African catfish officially reported by FAO is 246,476 tonnes in 2015 (FAO, 2017). However, various Asian countries such as China, Indonesia, Thailand, and Malaysia also produce significant amounts of African catfish, but statistics are currently unavailable by the FAO. Therefore, the overall African catfish production could be substantially under-reported. For instance, production values from the Federal Department of Fisheries from 2001 to 2012 in Nigeria were much higher compared to the official FAO statistics (Anetekhai, 2013). This discrepancy was said to be due to farming of African catfish hybrids that occurs not only in Africa but also in most Asian countries. Therefore, it was difficult to separate the

data for pure African catfish and that of hybrid and FAO did not capture the output under the name African Catfish but were reported as *Clarias sp.* (FAO, 2017; Dauda *et al.*, 2018).

The success in African catfish farming can be linked to the successful development of artificial propagation protocols in the 1980's and its substantial contribution to aquaculture development can be traced to mid-1990 as it is reported on the FAO Fish Stat (FAO, 2016). Increased production was supported by the acceptability of the fish by consumers as well as by farmers due to beneficial characteristics that included fast growth and high market demands. Several performance and production traits are important for aquaculture, which include, but are not limited to, growth rate, feed conversion efficiency, disease resistance, processing yield, stress tolerance, and tolerance to low dissolved oxygen (Liu, 2011). Growth rate is a primary trait for aquaculture because fast growth would allow shorter culture period to reduce the energy and other related costs. Enhanced feed conversion efficiency could reduce feed costs and increase profit margins since feed cost accounts for up to 50 percent of all variable costs. Disease resistance is one of the most important traits because diseases cause major economic losses, up to one third of the industry every year (Jin *et al.*, 2016).

Catfishes is the most commonly cultivated fishes in Nigeria. The growth of aquaculture in Nigeria now is largely being boosted by a steady rise in catfish culture and tremendous progress is now being made. The catfish species in Nigeria aquaculture include: *C. gariepinus*, *Heterobranchus bidorsalis*, hybrid (Heteroclarias) is widely distributed in African freshwater and Middle East (Spataru *et al.*, 1987). It is the most widely distributed fish in Africa and tolerant of many different habitats (Skelton, 2001). The African catfish has wide range and ubiquitous habitat demands. It inhabits a broad range of habitats such as lakes and impoundments, rivers, shallow swamps, seasonal floodplains and even some estuaries (Gutierrez *et al.*, (2013)). *Clarias gariepinus* can tolerate waters high in turbidity and low dissolved oxygen with periodic desiccation. It often the last or only fish species found in remnant pools of drying rivers (Van der waal 1998) due to the possession of a supra-branchial organ which facilitates air breathing. This ability to withstand low oxygen environments in conjunction with early maturity (Bruton 1979) *Clarias gariepinus* is air-breathing fish with flat bony heads, notably flatter and broad, terminal mouths with four pairs of barbels. It is a fish with a scale less, bony and elongated body with dorsal and anal fin with helmet like head with colour varies from dark to light brown dorsally and often mottled with shades of olive and grey. They also have large accessory breathing organs composed of modified gill arches. The pectoral fins have spines. The underside is pale cream

to white (Skelton, 2001). It can grow with maximum of length of 1.7m (IGFA, 2001) and attain mass of 60kg (Robbins *et al* 1991).

2.14 Taxonomy of African catfish

The African catfish *Clarias gariepinus* (Burchell, 1851) belong to the clapius in Actinopterygii, Order Siluriformes, and Family Clariidae. According to Teugeles, (1996) in the family Clariidae, the genus *Clarias* is the largest containing thirty-two (32) species in Africa and twelve (12) species Asia. The Clariid genus is the most cultured species, (Bruton, 1988).

2.15 Performance of African catfish *Clarias gariepinus* in aquaculture

C. gariepinus is mainly characterized by its rapidly high growth rate, which is estimated to be at least three times that of other fish species. According to Sambbu, (2004) catfish is a predator, cannibalistic and has voracious feeding habitat that make culturing in inland water bodies impressive. It is resistant to diseases, stress, and sturdy and highly productively in polyculture (Balogun *et al.*, 1992). It can be raised in a high-intensity culture without daily water exchange because its air breathing capacity allows it to withstand poor water quality and low dissolved oxygen. *C. gariepinus* is distinguished by a wide range of tolerance to high salinity levels the ability to withstand various stresses high fecundity and high palatability.

2.16 Biology of African catfish *Clarias Gariepinu*

Feeding and nutrition

Clarias gariepinus African Catfish is an opportunistic and omnivorous feeder ingesting a wide variety of food items such as algae, macrophytes, zooplankton, insects, fish prey, detritus, Amphibians and sand grains (Admasu *et al.*, 2015). The diet has relatively high dietary protein in the ratio of 40-50 percent (Greenwood, 1990) this composition may vary within season and spatial conditions of the environments (Houlihan *et al.*, 2001). The diet composition may also vary depends upon the fish size, maturity, and habitat differences (Kamal *et al.*, 2010). According to corbet, (1961) the larvae feed on zooplankton and phytoplankton in the first week while the juvenile feed on ostracods, aquatic insect

and insect larvae. Fingerlings feed on micro-crustacean and insect larvae while adult feed on small fish, aquatic insects, crustacea, mollusks and aquatic plant (Nwebara Ndawula, (1984). Prolongkam and Miler, (2016) reported that about 70 percent of feeding in catfish occur at night. According to FAO (2017b) the optimum digestible energy ranging between 14 – 16kj/g.

Culture history and characteristics of Tilapia

Tilapia represents a large number of freshwater fish species within the family Cichlidae (*Andreas and Ulrich, 2013*). Tilapias are the third most important cultured fish group in the world, after carps and salmonids. Tilapia culture is also one of the fastest growing farming activities, with an average annual growth rate of 13.4 percent during 1970–2002 (Wang, 2016). They are widely cultured in about 100 countries in the tropical and subtropical regions. As a result, the production of farmed tilapia has increased from 383,654 mt in 1990 to 4,507.002 mt in 2012, representing about 6 percent of total farmed finfish in 2012 (FAO, 2014). Nigeria is the second largest producer of farm-raised tilapias in Africa, after Egypt (Fagbenro *et al.*, 2010). Tilapias are macrophyte-feeders in which the adult feed mainly on filamentous algae and higher aquatic plants. There are over 25 species of tilapia, out of which about six species are used for aquaculture, namely, *Coptodon zillii*, *C. guineensis* (substrate spawners, macro-phytrophagous (generally herbivorous), *Sarotherodon galilaeus*, *S. melanotheron* (bi-parental mouth-brooders, micro-phytrophagous (planktophagous), *Oreochromis niloticus* and *O. aureus* (maternal mouth-brooders, omnivorous) (Fagbenro *et al.*, 2011). Tilapias are suited to low-technology farming systems. This is because of their fast growth rate, efficient use of natural aquatic foods, propensity to consume a variety of supplementary feeds, omnivorous food habits, resistance to disease and handling, ease of reproduction in captivity and tolerance to wide ranges of environmental conditions; and its use to control aquatic microphytes (Fagbenro *et al.*, 2011). Apart from this great economic importance of tilapia for aquaculture and fisheries, they play a significant role in tropical aquatic ecosystems.

2.1.1 Description of *Oreochromis niloticus*

Oreochromis niloticus is commonly known as Nile tilapia which belongs to family Cichlidae. It is native to Africa from Egypt, South to East and Central Africa (Froese *et al.*, 2015). It is a tropical freshwater and estuarine species. It prefers shallow, still waters on the edge of lakes and wide rivers with sufficient vegetation (Picker and Griffiths, 2011). It is a deep-bodied fish with cycloid scales.

Silver in colour with olive/grey/black body bars, and often flushes red during the breeding season (Picker and Griffiths, 2011). It grows to a maximum length of 62 cm, weighing 3.65 kg (at an estimated 9 years of age) (FAO, 2012). Several species of tilapia are being cultured commercially, but Nile tilapia, *Oreochromis niloticus* and various hybrids are the predominant culture species worldwide (FAO, 2012). The genus *Oreochromis* are microphagous where their feeding regime consists principally of phytoplankton, zooplankton, detritus and benthic organisms (Snoeks *et al.*, 2018). Froese *et al.* (2015) found that several species of this genus, such as *Oreochromis niloticus*, *Oreochromis aureus* and *Oreochromis mossambicus* are primarily omnivores. He also discovered that they are commonly regarded as opportunistic omnivores with a strong tendency towards herbivory due to the diversity of food resources consumed by adult tilapia especially *O. niloticus*.

It is one of the most favoured fish species in aquaculture, due to its high tolerance of a relatively wide range of environmental conditions, which is presumably also a key factor in the marked increase in global production with a production above 3.9 million tonnes in 2015 (Obirikorang *et al.*, 2016).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Experimental site

This experiment will be carried out at the department of Aquaculture and Fisheries Management, the University of Ibadan.

3.2 Sources of experimental materials and procedure

A total of 300 *Clarias gariepinus* and *Oreochromis niloticus* each (mean weight 10g -15g) will be procured from fish hatchery of University of Ibadan, Nigeria, and allow to acclimate to the laboratory conditions, the fishes will be randomly distributed in each of the 30 plastic tanks (46cm × 23cm × 15cm) for 14 days and will be fed on a control diet twice daily to satiation at time range of 8-9am and 4-5pm.

At the end of the acclimatization period, fish will be starved for 24 hours prior the commencement of the experiment to enable the fish emptied their guts after which the initial weight of individual fish

will be taken. Water in tanks will be half remove and new one refill every day in the morning before feeding throughout the study period. This will be done in order to remove all waste products and uneaten feed as well as to maintain the water quality. Following standard methods (APHA, 1998), temperature, dissolved oxygen and pH will be measured once a week.

3.3 Experimental Diet and Design

The basal practical diet for *Clarias gariepinus* will contain approximately 40 percent crude protein (Table 1) while the basal practical diet for *Oreochromis niloticus* will contain approximately 30 percent crude protein (Table 2) calculated according to Pearson Square Method (FAO, 1990). The compounded feeds will be air-sun-dried, packed in polythene bags and stored in a cool dry place until use with labels on them (Sule, 2003). Diets will be formulated to replace 0 (control), 25, 50, 75, and 100 percent FM with FOM in the diets of *Clarias gariepinus* and *Oreochromis niloticus*. These will form the experimental diets (A0, B25, C50, D75 and E100) of two by five (2 by5) factorial experimental design.

Table 1: composition of Experimental Diets (g/100g) for *Clarias gariepinus*

Ingredient (g/kg)	0%	25%	50%	75%	100%
Fish meal	51.43	38.57	25.71	12.60	0.00
Fish offal	0.00	12.86	25.71	40.50	54.00
CORN meal	38.57	38.57	38.57	38.57	38.57
FISH OIL	1.00	1.00	1.00	1.00	1.00
VIT PREMIX	0.50	0.50	0.50	0.50	0.50
LYSINE	0.50	0.50	0.50	0.50	0.50
METHIONINE	0.50	0.50	0.50	0.50	0.50
VIT C	0.50	0.50	0.50	0.50	0.50
SALT	0.50	0.50	0.50	0.50	0.50
Di-calcium phosphate	0.50	0.50	0.50	0.50	0.50
STARCH	6.00	6.00	6.00	6.00	6.00
TOTAL	100.00	100.00	100.00	100.00	100.00

Table 2 Composition of Experimental Diets (g/100g) for *Oreochromis niloticus*

Ingredient	0%	25%	50%	75%	100%
FM	34.29	25.72	17.15	8.57	0.00
FO	0.00	8.57	17.15	25.72	34.29
CORN	55.71	55.71	55.71	55.71	55.71
VIT PREMIX	0.50	0.50	0.50	0.50	0.50
LYSINE	0.50	0.50	0.50	0.50	0.50
METHIONINE	0.50	0.50	0.50	0.50	0.50
VIT C	0.50	0.50	0.50	0.50	0.50
SALT	0.50	0.50	0.50	0.50	0.50
DCP	0.50	0.50	0.50	0.50	0.50
STARCH	6.00	6.00	6.00	6.00	6.00
TOTAL	100.00	100.00	100.00	100.00	100.00

The proximate analyses will be performed on one of the fish and the compounded feed before the commencement of the feeding trial, sacrificed fish will be, oven dried and ground into powdery form and labelled separately for proximate and mineral analysis according to the Association of Official Agricultural Chemists.

3.4 Determination of proximate composition of fish offal meal

The Association of Official Analytical Chemist (AOAC, 2006) methods of analyses will be used to analyse the following parameters: moisture content, crude protein content, crude fibre content, fat content, ash content and free nitrogen extract for the experimental diets.

The fish will be randomly distributed into five groups each, and each group will be in triplicate (60 fish/group with 20 fish/triplicate each) and initial weight of all the fish taken before the commencement of the feeding trial. The fish will be fed manually to satiation twice daily 8am-9am and 4pm-5pm.

Water parameters will be kept at standard values throughout the experimental period. One-fourth of the volume of aquarium water will be exchanged daily.

3.5 Analytical procedures for proximate composition and energy of experimental diets and the fish

The proximate and mineral composition of the experimental fish and diets will be carried out before and after the experiment. Each of the five diets will be analyzed for crude protein, crude fibre, Ash, NFE, moisture, crude lipid and gross energy. After the experiment, the fish will be randomly sacrificed for analysis, according to AOAC (2000). The experiment will be performed in triplicate.

3.6 Moisture content

The empty dish and lid will be dried in the oven at 105°C for 3 hours and then transferred to desiccator to cool; after which it will be weighed. 3g of the sample will be weighed in the dish and spread for uniformity. The dish and the sample will be placed in the oven and dried for 3 hours at 105°C (AOAC, 2000). It is calculated as:

$$\text{Moisture (\%)} = (W1 - W2) \times 100$$

Where: W1 = weight (g) of sample before drying

W2 = weight (g) of sample after drying

3.7 Fat content

Reagents-Petroleum ether

The bottle and lid will be placed in the incubator at 105°C overnight to ensure that weight of bottle is stable. Then 3g of the sample will be weighed in a filter paper and wrapped. The sample will be taken to the extraction thimble and transfer into the soxhlet. The bottle will be filled with 250 ml petroleum ether and taken to the heating mantle. Then the soxhlet apparatus will be connected. The sample will be heated to about 14 h (heat rate of 150 drop/min). After this, vacuum condenser will be used to evaporate the solvent by using the vacuum condenser. Then the bottle will be incubated at 80-90°C until solvent is completely evaporate and bottle is completely dry. After drying, the bottle with partially covered lid will be transferred to the desiccator to cool. Then the bottle and its dried content will be reweighed (AOAC, 2000).

$$\text{Fat (\%)} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100$$

3.8 Crude Protein (Kjedahl method)

The reagents that will be used include

-Kjedahl catalyst: 9 part of potassium sulphate (K_2SO_4) will be mixed with 1 part of copper sulphate ($CuSO_4$)

-Sulfuric acid (H_2SO_4)

-40% NaOH solution

-0.2 N HCl solution

-4% H_3BO_3

-Indicator solution 100 ml of 0.1 percent methyl red (in 95 percent ethanol) will be mixed with 200 ml of 0.2 percent bromocresol green (in 95 percent ethanol)

1.0 g of the sample will be placed in digestion flask. Then 5 g Kjedahl catalyst and 200 ml of conc. H_2SO_4 will be added. A tube containing the above chemical without the sample will be prepared to serve as blank. Both flasks will be placed in inclined position and heated gently until frothing ceases and then briskly boiled until solution boils. The solution will be cooled and 60 ml distilled water will be cautiously added. The flask will be immediately connected to digestion bulb on condenser with the tip of the condenser immersed in standard acid and 5-7 drops of indicator in the receiver. The flask will be rotated to ensure that all the content mixes thoroughly and then heated until all the NH_3 is distilled. The receiver will be removed, the tip of the condenser washed and the excess standard acid titrated with standard NaOH solution (AOAC, 2000).

Calculation

$$\text{Protein (\%)} = \frac{(A-B) \times N \times 1.4007 \times 6.25}{W}$$

W

Where

A= volume (ml) of 0.2 N HCl used sample titration

B = volume (ml) of 0.2 N HCl used in blank titration

N= Normality of HCl

W = weight (g) of sample

14.007 = atomic weight of nitrogen

6.25 = the protein-nitrogen conversation factor for fish and its by-product

3.9 Ash

The crucible and lid will be placed in the furnace at 550°C overnight to ensure that impurities on the surface of crucible are burned off. This will then be cooled in the desiccator for 30 minutes and the crucible with the lid weighed in 3 decimal places.

5 g sample will be weighed into the crucible and heated over low Bunsen flame with lid half covered. When fumes are no longer produced, the crucible and lid will be placed in furnace. And heated at a temperature of 550°C overnight although the crucible will not be covered. The lid will only be placed after complete heating to prevent loss of fluffy ash. Then it will be placed in the desiccator for cooling. After this, the crucible, ash and lid will be weighed (AOAC, 2000).

The calculation will be done using the formulae:

$$\text{Ash (\%)} = \frac{\text{Weight of ash} \times 100}{\text{Weight of sample}}$$

3.10 Nitrogen Free Extract (NFE)

NFE content of the samples will be determined as total carbohydrate by difference, that is, by subtracting the measured protein, fat, ash and moisture from 100 as given by Uzanne (2010):

$$\% \text{NFE} = 100 - \% (\text{Ash} + \text{crude fiber} + \text{moisture} + \text{Fat content} + \text{Crude protein})$$

3.11 Growth performance and nutritional utilization of the experimental fish

At the end of the feeding trial, the weight gained from each treatment will be recorded and the average determined according to Castel and Tiews (1980). Formulae of various growth, feed utilization parameters and digest are:

- a. Feed intake (FI) = $\frac{\text{Weight of feed}}{\text{Weight of fish}} \times \text{No of fish per tank}$ in each treatment of the experiment period.
- b. Mean Weight gain (MWG) = $(W_2 - W_1)$

c. Relative Growth rate (RGR) (%) = $\frac{W_2 - W_1}{W_i} \times 100$

Where, W1 = initial average weight (g) at the beginning of experiment

W2 = final average weight (g) at the end of experiment.

1.

d. Percentage weight increase = $\frac{\text{Mean weight gained}}{\text{Initial mean weight}} \times 100$

2.

3.

e. Specific Growth rate (%): SGR = $\frac{100 \log(W_2 - W_1)}{T_2 - T_1}$

Where; W2 and W1 the logarithms = initial mean and final mean weights of fish, respectively,

T2 – T1 = Experimental period in days.

4.

f. Feed Conversion Ratio (FCR) = $\frac{\text{Dry weight of feed fed (g)}}{\text{Fish weight gain (g)}}$

g. Protein Efficiency Ratio (PER) = $\frac{\text{Wet body weight gain (g)}}{\text{Crude protein fed}}$

5.

h. Survival rate (%) = $\frac{\text{Initial number of fish stocked} - \text{Mortality}}{\text{Initial number of fish stocked}} \times 100$

i. Mortality rate = $100 - \text{Survival rate}(\%)$

6.

j. Performance Index (PI) = $\frac{\text{SR} \times \text{FMW(g)} - \text{IMW(g)}}{\text{Rearing duration in days}}$ (Engle and Valderrama, 2001)

3. 12 Water quality assessment

Dissolved oxygen will be determined by analytical method. 250 ml bottle will be filled with water from the experimental tanks to the brim and labelled O from each experimental unit. The labeled bottle will be fixed with 2 mL of Winkler A and B for the determination of dissolved oxygen. Exactly 100 ml of the fixed water will be neutralized by addition of 2 ml of sulphuric acid. Four drops of starch will be added and titrated with 60 percent sulphuric acid. The DO level will be calculated using:

$$\text{DO (mg)} = \frac{0.02 \times \text{titer value} \times 8 \times 1000}{\text{Volume of water sample}} \quad (\text{AOAC, 2005}).$$

Temperature will be measured using mercury thermometer (AOAC, 2005), while pH will be determined using pH meter. Nitrite and ammonia will be determined by colour change using nitrite kit (Aquasol AE-207) and value will be determined by multiplying the number of drops of indicator by five (5) and expressed as ppm (Bhatnagar and Singh, 2010).

3.13 Hematological and serum biochemical analyses of *C. gariepinus* and *O. niloticus* fed experimental diets

At the end of growth trial, six fish from each treatment in triplicate will be individually caught using a hand net, blade and gauged needles and syringes inserted into the common cardinal vein of each fish. The site chosen for puncture will be wiped dry with tissue paper to avoid contamination with mucus. The needle will be inserted at angle 45° to the vertebral column of the fish and gently aspirated during penetration. It will then be pushed gently down until blood starts to enter as the needle punctures a caudal blood vessel (Omitoyin *et al.*, 2006). Blood will be taken under gentle aspiration and withdrawn. The blood will be gently transferred into a lithium heparin anticoagulant tube at room temperature and transferred to the Clinical Pathology Laboratory of the Department Veterinary Pathology, University of Ibadan for haematology analysis. The blood stain method will be adopted for differential blood cell count, plasma biochemistry and serum biochemical analysis. The slides will be placed in a staining jar containing May-Grunwald's stain freshly diluted with an equal volume of buffered water for five (5) minutes. The slides will be transferred into a second staining jar containing Giemsa's stain freshly diluted with nine volumes of buffered water for 15 minutes (Olukunle, 1996). The slides will be transferred into another stain jar containing buffered water and then rapidly washed in three changes of water and finally stands in buffered water for five (5) minutes for differentiation, air-dried and mounted on light microscope. The following parameters will be measured.

3.14 Determination of Packed Cell Volume (PCV)

The blood samples will be mixed by inverting 20 times. The capillary tubes will be filled with the blood samples and centrifuged at 3000 rpm for five (5) minutes in a Kawksley micro-haematocrit

centrifuge, England. The actual PCV values will be obtained using haemocrit reader and expressed in percentage (Adeyemo and Agbede, 2008).

3.15 Determination of Haemoglobin (Hb)

The Hb will be determined using Drabkin's solution. 2µL of the samples will be taken using micro-pipette, added to the 5ml of Drabkin solution and allowed to stand for 5 minutes. The reading will be taken on photospectrometer (SM23A) with a tube of Drabkin's solution as a blank at 540 nm. The values will be calculated as:

$$\text{Hb} = \frac{\text{Absorbance of the test} \times \text{concentration of standard} \times \text{dilution in g/L}}{\text{Absorbance of standard}} \quad (\text{Adeyemo, 2005}).$$

3.16 Determination of Red Blood cell (RBC)

The samples will be diluted 1:200 with Rees and Ecker's diluent fluid. Few drops will be expelled out and then introduced under cover slip on an improved Neubauer count chamber (Neubauer improved bright line Marienfield, Germany 0.100 mm, 0.0025 mm²) with x 10 objective lens. The amounts were calculated as:

$$\text{RBC} \times 10^{12} \text{ L} = \text{Numbers of cell counted} \times \text{Depth} \times \text{Dilution} \times \text{Area} \quad (\text{Oresegun and Alegbeleye, 2001}).$$

3.17 Determination of White Blood Cell (WBC)

White blood cell counts will be done using Newbauer haemocytometer as described by Kaplow (1955). White blood cell count will be carried out by diluting 1: 200 of blood sample with three (3) percent aqueous solution of acetic acid and gentian violet added to the mixture later. The mixture will be allowed to settle for 2 minutes, mounted on microscope, and counted.

3.18 Platelets counts

Platelets counts will be determined using the direct (Rees and Ecker's) method. 20µL of the blood samples will be added to 1.98mL of diluents at dilution ration 1:100. The suspension will be left for 2 hours but mixed 2 minutes before use. The counting chamber will be filled with a Pasteur pipette and placed in a moist chamber for 20 minutes to allow the platelets to settle.

1 mm² will be count under the microscope. The values will be calculated using Platelets = 1mm² count x 10⁹ (Osuigwe *et al.*, 2005).

(a) **Lymphocytes:** the smear will be observed on the light microscope (x100 objective lens). The small cells containing nuclei, showing granular appearance will be observed and expressed as percentage (Oyewale, 2011).

(b) **Heterocytes:** The cells with an average of 6-9µ with circular shape will be observed with the aid of light microscope. The cells with rod shape, central granules and irregular size will be observed. Also, cells that are not closely grouped, colourless to pink with bilobed or multilobed will be observed and expressed as percentage (Oyewale, 2011).

(c) **Monocytes:** The larger cell with cytoplasm containing orange spheres will be observed under a light microscope. The nuclei will also be observed for irregular shape and azurophilic cytoplasmic granules and expressed as percentage.

(d) **Eosinophils:** The cell with a size of 7µ and circular shape on blood smear will be observed under a light microscope. The pale blue cytoplasm homogenous bodies will be observed and expressed as percentage (Osuigwe *et al.*, 2005).

(e) **Basophil:** The basophil granules will be observed under a light microscope with dots around the nuclei and expressed as percentage (Omitoyin *et al.*, 2006).

3.19 Mean Cell Haemoglobin (MCH)

The average of Hb in pictograms of a simple RBC will be determined using

$$\text{MCH (pg)} = \frac{\text{Hb} \times 10}{\text{RBC}} \quad (\text{Olukunle, 1996}).$$

3.20 Mean Cell Haemoglobin Concnetration (MCHC)

Percentage of Hb of packed RBC was determined using

$$\text{MCHC (g/dL)} = \frac{\text{Hb} \times 100}{\text{PCV}}$$

3.21 Mean Cell Volume (MCV)

Average volume of a single cell was determined using

$$\text{MCV (Fl)} = \frac{\text{PCV} \times 10}{\text{RBC}} \quad (\text{Olukunle, 1996}).$$

3.22 Gut ecology analysis

At the end of feeding and growth trials, three fishes will be randomly selected from each treatment tank in triplicate for gut ecology parameter analysis. The selected fish will be killed by keeping them in ice-cold distilled water. The intestinal tissue will be aseptically dissected from the selected fish and gently rinsed three times with cold and sterile saline solution (0.85 percent w/v). Midgut samples will be taken by removing an approximately 2 cm section of intestine from the center of the intestine. After collection, the sections of midgut will be immediately fixed in 4 percent paraformaldehyde (PFA) solution overnight for histological analysis of gut morphology. Intestinal tissue homogenates will be prepared by mixing the sample with two volumes of sterile saline solution and mechanically homogenized for 5 min. These intestinal tissue homogenates will be used for bacterial nutritional enzyme activity.

3.23 Histological study of gut morphometry

Gut morphometry will be examined using standard methods. The organs (intestine) of *C. gariepinus* and *O. niloticus* will be taken for histological examination at the Histopathology Laboratory of the Department of Veterinary Pathology, University of Ibadan. The fixed guts will be prepared on slides based on Culling,(1974) and Drury *et al.* (1967) for the organs and tissues. Measurements of villus length (VL, cm), depth of the crypt (DC, cm), villus width (VW, cm) and area of absorption (AA, cm²) will be taken using light microscope (HE x40) (Olympus CX21, Japan) in triplicates with a micrometer rule as described by Spadoni *et al.* (2005) and Eyarefe *et al.* (2008). As many villi as possible will be measured up to 10 villi per slide.

3.24 Haematological and serum biochemistry Procedures

Experimental location

The haematological procedures will be carried out at the department of Haematology, University College Hospital, (UCH), Ibadan, Nigeria.

Haematological assessment of the fish will be done before and after the experimental feeding.

At the end of the feeding trial period, 9 fish per treatment will be randomly caught using a hand net and bled serially using tuberculin syringes with 24 gauge needles inserted into the caudal vein of each fish (Omitoyin, Ajani, Adesina, and Okuagu, 2006).

Blood per treatment will be gently transferred into two separate groups of Eppendorf tubes, one with sodium heparinate (20 U/L) as anticoagulant for packed cell volume (PCV), haemoglobin (Hb), red blood cells (RBC), white blood cells (WBC) and platelets counts and a second group without anticoagulant which will be allowed to clot at 4°C and centrifuged at 5,000 g for 10 min at room temperature for serum biochemical analysis. Fresh blood from samples will be placed in glass capillary tubes and centrifuged for 10 min in a microhaematocrit centrifuge for PCV value estimation.

3.25 Measures Of Oxidative Stress

A total of nine fishes each will be analysed per treatment. They will be homogenized on ice in sodium carbonate buffer for each treatment. It will be centrifuged at 4,000 rpm for 10 minutes and the supernatant decanted and stored below -4°C for the oxidative stress assay. Oxidative stress before and after the challenge with pathogenic *Aeromonas hydrophilla* will be measured by these indicators: superoxide dismutase (SOD), Glutathione peroxidase (GPx), Total protein (TP), Nitric oxide (NO), Myeloperoxidase (MPO), Malondialdehyde (MDA) and Reduced Glutathione activities (GSH) as follows.

3.26 ANTIOXIDANTS

Superoxidase Dismutase (SOD)

Principle

The ability of superoxide dismutase to inhibit the autoxidation of epinephrine at pH 10.2 makes this reaction a basis for simple assay for this dismutase. Superoxide (O_2^-) radical that will be generated by Xanthine oxidase reaction will cause the oxidation of epinephrine and the yield of adrenochrome produced per O_2^- introduced. This increases with increasing pH and also increases with increasing content of epinephrine. The results will lead to the proposal that autoxidation of epinephrine proceeds by at least two distinct pathways, one of which is a free radical chain involving superoxide (O_2^-) radical and hence inhibited by SOD.

3.27 Immune Response Parameters

Experimental location

The experiment will be carried out at the department of Haematology, University College Hospital, (UCH), Ibadan, Nigeria.

Blood Sampling

Blood and tissue samples will be collected (n=5/group/replicate) at the end of experimental period to evaluate the innate immunity of fish groups; Oxidative burst and lysozyme activities as well as some immune genes expression such as TNF- α and liver hepcidin. The whole blood samples will be drawn from the caudal vessels onto 100 IU/ml sodium heparin to estimate the respiratory burst activity and without anticoagulant to determine the serum lysozyme activity.

3.28 Bacterial infection (Challenge test)

An experimental infection will be induced in *C. gariepinus* and *O. niloticus*) (n=10/ group/replicate) with pathogenic bacteria *Aeromonas hydrophila* LC012347 (P. Kongchum *et al.*, 2011). The bacteria will be grown overnight in trypticase soya broth (TSB, Difco, USA) and the concentration will be adjusted to 1.0×10^6 CFU/ml in PBS. Fish groups will be injected with 0.2 ml of the bacterial suspension intra-peritoneally (I.P.). Two days post infection; five fish/group/replicate will be sampled to collect blood and tissue samples for immunological and histopathological evaluations post infection.

3.29 Expression of Pituitary Adenylate Cyclase-Activating Polypeptide Gene

The same nine fish each of the studied fish species will be used for the collection of blood samples at the end of the experiment (30 days) will be euthanized using a benzocaine solution overdose (250 mg/l) and used for gene expression analysis to collect spleen samples. The total RNA was extracted using the QIAamp RNeasy Mini Kit according to the manufacturer's protocol. Complementary DNA will be synthesized following the manufacturer's instructions. Quantitative real-time polymerase chain reaction (PCR) analysis will be performed with the SYBR green PCR master mix (Step One Plus, Applied Biosystem, Waltham, MA, USA). The amplification efficiency of the used primer will be determined by standard curve assay.

Challenge Test

Seven fish/replicate each for the two experimental fish species (21 fish/group) will be challenged by intraperitoneal injection with pathogenic Aeromonas aeruginosa. The fish will be observed for 15 days, and their clinical signs, post-mortem lesions, and daily mortality will be recorded. For confirmation, the pathogenic bacterial strain will be re-isolated from the liver, kidney, and intestine of dead fish.

Statistical Analysis

One-way ANOVA (SPSS version 61.0) will be performed to detect the difference among experimental groups within the same period. The group means will be analyzed with Duncan's multiple range tests and presented as the mean $\pm$ SE. Two-way ANOVA (Statistical software, version 8) will be used to determine the interaction between the levels of FM substitution with FOM and the feeding duration.

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Annex 3: Fish feed study proposal II (growth performance, immunological responses, the antioxidant status and gene expression of *clarias gariepinus* and *oreochromis niloticus* to varying inclusion levels of agro-industrial waste product (rice bran) from integrated fish and rice culture based diets

A PROPOSAL

ON

GROWTH PERFORMANCE, IMMUNOLOGICAL RESPONSES, THE ANTIOXIDANT STATUS AND GENE EXPRESSION OF *Clarias gariepinus* and *Oreochromis niloticus* TO VARYING INCLUSION LEVELS OF AGRO-INDUSTRIAL WASTE PRODUCT (RICE BRAN) FROM INTEGRATED FISH AND RICE CULTURE BASED DIETS.

BY

ROSEMARY ONIZE, OKOVIDO

227999

**FACULTY OF RENEWABLE NATURAL RESOURCES,
DEPARTMENT OF AQUACULTURE AND FISHERIES MANAGEMENT.**

SUPERVISOR:

PROFESSOR E. K. AJANI

CHAPTER ONE

INTRODUCTION

1.0. Background of the Study

Nigeria as one of the leading players in African aquaculture has been tapping the opportunities provided from aquaculture in meeting her food and nutrition security needs. In addition, aquaculture serves as a veritable source of employment and livelihood enhancement in Nigeria. With current efforts at intensifying the food production systems in Nigeria for improved livelihood and food and nutrition security, constraints to aquaculture production especially in area of fish feed development need to be well addressed. It worthy to note that achieving the highest profit percentage with the lowest cost percentage is critical to the growth of any industry. In the aquaculture industry, the prices of certain feed ingredients are among the major challenges affecting the industry's success or failure.

A critical ingredient in aquafeed is Fishmeal (FM) as it is the costliest and imported in Nigeria. This is due to its highly palatable dietary protein source in aquafeed as it contains balanced amino acids, essential n-3 fatty acids, vitamins, and minerals. Efforts is now tailored towards finding a cost effective and cheaper local alternative to the FM. The FOM, a byproduct of fish processing activities could be a good alternative to fish meal. Therefore, there is need to develop knowledge base on the best ways of utilizing FOM as replacement for FM in diets of two most commonly cultured fish species (*Oreochromis niloticus* and *Clarias gariepinus*) in Nigeria.

Feed is one of the major inputs in aquaculture production and fish feed technology is one of the least development sectors of aquaculture particularly in Africa and other developing countries of the World (Gabriel *et al.*, 2007). High cost of fish feed was observed as one of the problems hampering aquaculture development in Nigeria (Gabriel *et al.*, 2007).

Many unconventional sources are of very good nutrient profiles which when incorporated into feeds can meet parts of the protein and energy requirements of the fish. Most of these indigenous fish feed resources are non-competitive in terms of human consumption, their prices are relatively very low and sometimes are of no cost value. They are usually by-products or waste products from agricultural industries, domestic waste, and wild plants, thus their utilization as feed resources can help to reduce the cost of fish feeds and fish production in Nigeria (Agbugui *et al.*, 2010).

The need to meet the optimum demand for fish production had in earlier times opened the way for researchers to gear into the search for local feedstuff consumed by man that could adequately compete

with fishmeal. Over time, this did not seem to solve the problem of fish feed ingredients because of the constant rise in the price of the feedstuff and increasing demand for these same food products by the human population. This recent measure may reduce the high cost of feed ingredients which is the major problem of the fish farmers in Nigeria, especially fish meal that is generally considered the most expensive cost item in intensive fish farming (Madu *et al.*, 2003).

According to the FAO (Food and Agriculture Organization of the United Nations), presently 52 percent of the 600 wild fish species with economic value are heavily depleted, 17 percent overfished, and the 7 percent fully exploited. Supply from capture fisheries will be static over the next 30 years. A growing percent of world aquatic production derives from aquaculture, whose importance is set to increase dramatically as a result of overfishing of the world's waters and an increasing demand for seafood (FAO, 2010).

In fact, aquaculture production has increased from representing nine percent of the fisheries resources in 1980 to a current 43 percent, actually, and it is thought that production will need to double in the next 25 years, according to the FAO. The FAO promotes aquaculture not only for being an important source of money and employment, but also for its great contribution to food security and social development of many countries. The success of modern aquaculture is based on the control of the reproduction, a good knowledge of the biology of the farmed fish, on technology innovation, and on the development of a specific feed. Nevertheless, there are some important challenges to develop productive, feasible, and sustainable aquaculture in present superintensive systems. One of these challenges is that in large-scale production facilities where aquatic animals are exposed to stressful conditions, problems related to diseases and deterioration of environmental conditions often result in economic losses (Balcazar *et al.*, 2006). Control of such pathogens (most of which are bacterial) in fish farms has been routinely achieved by the administration of antimicrobial agents. However, the excessive use of these antimicrobials has led to the emergence of antibiotic-resistant bacteria, due to those drug-resistant strains carrying a transferable R-plasmid, making the treatments less successful (Akinbowale *et al.*, 2006). In addition, the transference of resistant genes between bacteria (Schwarz *et al.*, 2001) could have a risk to human health (Kesarcodi-Watson *et al.*). The modern aquaculture industry demands alternative preventative practices that may help to maintain a high animal welfare as well as a healthy environment, resulting in better production and higher profits. Furthermore, the emergence of generic “green” values among consumers and a new heightened environmental

awareness make the development of a sustainable aquaculture necessary. A better knowledge of the immune system of cultured fish will help to achieve these aims.

Egypt is Africa's leading aquaculture country, followed by Nigeria with similar production systems. The dominant species of fish cultured in Egypt and Nigeria are Tilapia and African catfish, respectively. The aquaculture industries in these two countries are very promising, as there is a presence of water bodies, some institutional commitment, and high demand for fish among others. Despite some gains made by the countries and the huge potential of the aquaculture sector, it is however bedeviled with constraints such as low technology adoption, inadequate supply of fingerlings, high cost of fish feed, etc.

Fish farming is considered an important agricultural activity that is capable of ending nutritional deficiencies of the world and contributing to poverty reduction. Its proponents argue that aquaculture will meet the food security needs of millions of people in developing countries who will benefit from relatively inexpensive protein, while depleted capture fisheries are allowed to replenish. Farming of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants, is aquaculture. Farming requires some form of interference in the breeding process to increase yield, such as daily storage, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated (Billard and Dabbadie, 2017; Enciso-López and García-Trejo, 2019). Fish farming is regarded as a key agricultural and food-producing sector throughout the world. The promoters argue, while depleted fish catches can be re-filled, that aquaculture can meet the food security needs of millions of people in developing countries who will benefit from relatively cheap protein (Hagar Dighiesh, 2014; Wally, 2016).

The aquaculture industry, which accounts for over 50 percent of global fish production, is the fastest-growing food-producing sector. About 424 aquatic species are cultivated globally, benefiting millions through the provision of nutrition, food security and sustainable livelihood, and poverty reduction (Galappaththi *et al.*, 2020).

Over the past two decades, world aquaculture has developed tremendously to become an economically significant industry. The industry continues to grow at an average global annual growth level of 8.8 percent per year compared with all other animal food production industries (Onada and Ogunola, 2017).

Nigeria is the largest fish consumer in Africa and among the largest fish consumers in the world (Adelesi, 2019) with about 3.2 million metric tonnes of fish consumed annually (The Embassy of the Kingdom of the Netherlands, 2019). The aquaculture sub-sector is considered a very viable alternative to meeting the nation's need for self-sufficiency in fish production. This is based on its high reliability in return on investment and low capital intensity relative to capture fisheries.

(Jerimoth, *et al.*, 2017). The focus of aquaculture in Nigeria is on fish culture with *Clarias* and *Heterobranchus* spp. (catfish), *Tilapia* spp. (Tilapia), *Cyprinus carpio* (Common carp), *Heterotis niloticus* (Slap water) the most commonly cultured species of fish (Omeje, *et al.*, 2020).

Over the past 35 years, aquaculture production in Nigeria has grown 12 percent a year (compared to the world average of 8 percent), from a little over 6000 metric tonnes in 1980 to nearly 307,000 metric tonnes in 2016. The country is the largest aquaculture fish producer in sub-Saharan Africa, accounting for 52 percent of the total farmed fish production in the region. Nigeria's aquaculture focuses mainly on freshwater fish, with catfish species accounting for 64 percent of aquaculture production in 2015 (WorldFish, 2018). Nigeria is one of the top aquaculture producers in Africa and the leading producer in Sub-Saharan Africa (SSA), with numerous opportunities for large-scale production, and 80 percent of production is from small-scale farmers who are involved in brackish and freshwater cultivation, except mariculture, which has several setbacks. Nigeria's aquaculture production systems are in the forms, A) Extensive system-seaweed culture, coastal bivalve culture, coastal fish ponds, and pen and cage culture, B) Semi-intensive system-Fresh and brackish water pond, C) Integrated agriculture-aquaculture, D) sewage-fish culture, E) intensive systems and others like raceways, silos, and tanks, etc. In addition to the use of ponds, fish are also cultured in various water holding facilities, such as pens, happas, tanks, cages, raceways, etc. (Orobator, *et al.*, 2020). The aquaculture production systems in both Nigerian and Egypt are almost producing the same percentages of their top farmed fish species; however, Nigeria has about a 2 percent higher per capita consumption than Egypt, even though Egypt's production is much higher than that of Nigeria (Obwanga, *et al.*, 2018).

1.1. Justification

Feed determines to a large extent the sustainability in aquaculture since the survival and growth of the fish larvae depend on the quality of feeds used (Jamabo *et al.*, 2019). Quality fish feed production in aquaculture is one of the major determinants of significant growth, efficiency in feed utilization, and

flesh quality of the fish produced (Ogueji *et al.*, 2020). Fish feed represents almost 65–70 percent of the fish culture inputs (Soliman *et al.*, 2018a). Research is being done to find innovative sources of fish feed with the right nutritional values that can replace or augment conventional aquaculture or fish feed.

The demand of fish food is increasing throughout the world due to the recognition of its nutritional value (Tingman *et al.*, 2010). In addition, the rise of food price and rapid human world population growth increase the demand of fish consumption (FAO, 2010; 2012). For these reasons, there are varieties of farming fish species get a special consideration to increase the world fish production. Tilapia is the second largest farmed fish group in the world next to carp (El-Sayed, 2006 and FAO, 2012). The most commercially cultured fish species in the global tilapia farming is dominated by *Oreochromis aureus* (Bentsen *et al.*, 1998; Pillay and Kutty, 2005 and El-Sayed, 2006). The expansion of *Oreochromis niloticus* farming is due to its tolerance to a wide range of environmental conditions including factors such as pH, temperature, nitrogen wastes, low dissolved oxygen concentration and its easiness for handling practices (Noor *et al.*, 2010). However, most tilapia does not eat and grow at lower water temperature. Thus, temperature is the natural limiting factors that influence the growth performance of tilapia (Pandit and Nakamura, 2010). "It is considered as driving force in the life of the fish as its effect is more than any other single factor" (Azevedo *et al.*, 1998). Although, there are several researches that have been done worldwide, it is hard to get information about the optimum water temperature required for *Oreochromis niloticus* in Ethiopia. Therefore, the present study was planned to investigate the growth performance, feed utilization efficiency and survival rate of juvenile *Oreochromis niloticus* reared at different water temperature.

Aquaculture production has been globally increasing and gaining economic importance over the last decade (Janssen *et al.*, 2017). Due to the large production of ready-to-use products and meals, the fish industry generates a large amount of wastes. These residues in fisheries are mainly composed of heads, skin, and viscera and account for 20–75 percent of fish weight (Ferraro *et al.*, 2010). In this sense, great efforts are being made to exploit these fish wastes, ensuring the sustainability of the aquaculture industry. This strategy is supported by the presence of natural antioxidants and other bioactive components in these residues.

Fish have been identified as a source of inexpensive protein for the nutritional benefit of human beings. Fish production can lead to poverty reduction and ensure food security. The traditional practice of

growing fish in the wild has proven to be inadequate and is faced with a lot of challenges, among which is low catch. Therefore, aquaculture can be a solution to the world's dwindling fish production.

1.2. General objective

The aim of this study is to evaluate the growth performance, immunological response, the antioxidant status and gene expression of *Clarias gariepinus* and *Oreochromis niloticus* fed varying inclusion levels of agro industrial waste product (rice bran) from integrated fish and rice culture based diets.

1.3. Specific objectives

1. To determine the growth performance and nutrient utilization of *C. gariepinus* and *O. niloticus* fed varying inclusion levels of rice bran as replacement for maize.
2. To assess the immune status and antioxidant activity of *C. gariepinus* and *O. niloticus* fed varying inclusion levels of rice bran as replacement for maize.
3. To evaluate the effects of varying inclusion levels of rice bran of *C. gariepinus* and *O. niloticus* on pituitary adenylate cyclase-activating polypeptide (*PACAP*) gene expression.
4. To assess the disease resistance of *C. gariepinus* and *O. niloticus*.

CHAPTER TWO

LITERATURE REVIEW

2.1 Status of Aquaculture in Nigeria

Nigeria is the most populous country in Africa. Although it has made significant socioeconomic progress over the past 15 years, the country continues to face massive development challenges, which include reducing its dependency on oil and diversifying the economy, addressing insufficient infrastructure, and building strong and effective institutions, as well as improving governance, public financial management systems and human development indicators. Inequality in terms of income and opportunities has been growing rapidly, adversely affecting poverty reduction and leading to poor living conditions for most of the population. The north-south divide has widened in recent years because of the Boko Haram insurgency and a lack of economic development in the north. Large pockets of the population live in poverty, without adequate access to basic services, and could benefit from more inclusive development policies. The lack of job opportunities is at the core of the high poverty levels, regional inequality, and social and political unrest. The private sector is the main driver of the Nigerian economy. However, its potential has not been fully exploited as it faces its own set of challenges. Increasing the availability and accessibility of nutritious food, reducing food insecurity and improving health is a significant challenge that has become a state priority in recent years.

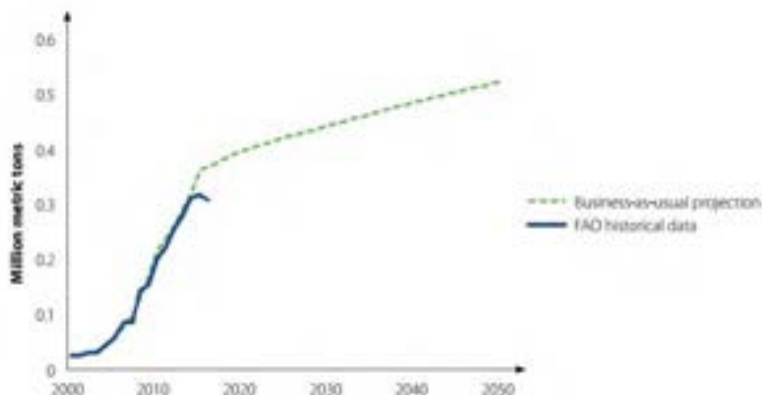
Fisheries is a major economic sector, estimated to employ over 8.6 million people directly and a further 19.6 million indirectly, 70 percent of whom are women. Currently, Nigeria produces just over one million metric tonnes of fish, leaving a deficit of over 800,000 metric tonnes, which is imported annually. Recognizing the importance of fish within the agriculture sector for its potential contribution to alleviating poverty, improving food and nutrition security, reducing youth unemployment and building profitable business ventures, both capture fisheries and aquaculture are gaining increased attention, in both the public and private sectors.

Over the past 35 years, aquaculture production in Nigeria has grown 12 percent a year (compared to the world average of 8 percent), from a little over 6,000 metric tonnes in 1980 to nearly 307,000 metric tonnes in 2016. The country is the largest aquaculture fish producer in sub-Saharan Africa, accounting for 52 percent of the total farmed fish production in the region. Nigerias aquaculture focuses mainly on freshwater fish, with catfish species accounting for 64 percent of aquaculture production in 2015. The increase in fish production in Nigeria accounted for 55 percent of the increase of its apparent total

fish consumption between 1980 and 2013, the remaining 45 percent was covered by the increase in its net import (i.e. import minus export) of fish. The fish trade deficit increased from 350,000 metric tonnes to nearly 2 million metric tonnes between 2000 and 2011, before declining to 940,000 metric tonnes in 2013 thanks to a rapid increase in domestic fish production.

WorldFish updated the IMPACT fish model to 2050. The result suggests that if other factors affecting fish demand (e.g. fish price and consumer preference) remain unchanged, demand in the early 2020s will be 600,000 metric tonnes higher than in the mid-2010s, because of income and population growth. If the current trend is maintained, aquaculture production in the early 2020s will be 150,000 metric tonnes higher than in the mid-2010s. This will only cover a quarter of the 600,000 metric tonnes of increased demand, resulting in a 450,000 metric ton demand-supply gap. The gap can only be bridged by sustainably increasing the growth rate of the sector by 22 percent a year. This will not only increase production and consumption but also lead to higher youth employment, increased household income, improved nutrition and reduced child mortality (Figure 1).

Figure 1: Projection of aquaculture production in Nigeria.

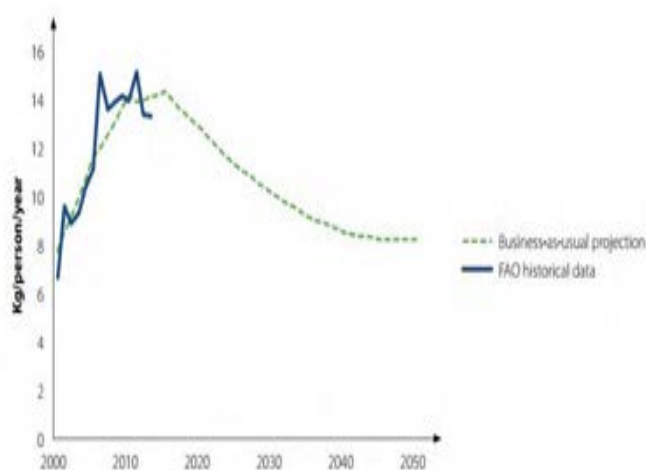


Source: World Fish (IMPACT fish model).

Although Nigeria accounts for per capita fish consumption of 13 kg/year, accurate data on gender- and wealth disaggregated consumption, intra-household consumption, consumption during the first 1000 days of life and other critical data are totally lacking. The social, economic and environmental value of small-scale fisheries is poorly understood. Considering the current market prices of fish (NGN 800–900 for a kg of tilapia and NGN 600–700 for a kg of catfish), and meagre rural incomes in an era of economic recession, it is unlikely that fish consumption among the rural poor reflects the national average. If business as usual continues, over the coming decades, per capita fish consumption

in Nigeria will be significantly reduced, with major implications for the country's nutritional status (Figure 2).

Figure 2: Projection of per capita fish consumption in Nigeria.



Source: WorldFish (IMPACT fish model)

The Nigerian government has underlined poverty reduction and improved food and nutrition security as priorities, and it regards aquaculture as a means to increase fish production and youth empowerment. The policy of backward integration, which encourages all fish importers to invest in aquaculture, has realized an estimated annual increase of 20,000 metric tonnes. Yet although strong political will exists to support aquaculture development, resulting in sector growth of nearly 12 percent per annum, many aquafarmers have failed to become profitable. This may be the result of high input costs, economic recession, a lack of adequate support services, a lack of investments, a lack of incentives to initiate an aquaculture business and a lack of conducive national policies. Better alignment between producers, service providers and the state is necessary to make the sector profitable, especially for small-scale producers and farming households.

Integrating agriculture and aquaculture can contribute to alleviating food insecurity, malnutrition, and poverty through the provision of high nutritional value for food, income, and job creation reduced production risk, improved access to water, sustainable management of resources and increased farm sustainability (Omofunmi, *et al.*, 2017).

In Nigeria, to help smallholder farmers improve their production, food security, and profits, the West and Central African Council for Agricultural Research and Development (WECARD) and the University of Ibadan (UI) have recently promoted the integration of fish, poultry/pig, and rice farming. This will translate into viable and sustainable aquaculture (Adewumi, 2015). The rising cost of production of fish, chemical fertilizers, and available space are the main drivers of the system. The combination of fish culture with crop production and animal husbandry is an environmentally sound farming system that gives an inexpensive source of protein for the rural people, a better farm income, and increased output per small land area and increases the supply of feed for the livestock farming system. Integrated aquaculture in Nigeria is in the form: Livestock – fish integrated systems, Crop – fish integrated systems including rice integrated with the fish system, horticulture integrated with the fish system, sericulture integrated with the fish system, and mushroom integrated with the fish system. There is also the concept of integrated multitrophic aquaculture-recycling of resources in which discharged nutrients from higher trophic levels become the input to the lower trophic levels (Melaku and Natarajan, 2019).

The nature of and types of integrated fish farming in Nigeria are of the following types: Fish Cum Poultry-This system utilizes poultry dropping of fully built-up poultry litter for fish culture, and Fish Cum Piggery-This system has certain advantages over others. Pig farming is widely practiced across the southern and middle belt of Nigeria. It offers the farmer husbandry that is easier than chicken farming, Fish Cum Rice, and Vegetable-This is the cultivation of crops (e.g., vegetables and arable like maize, rice, etc.) and aquatic plants (like water spinach, water chestnut, aquatic weeds like Pistia, duckweed, water hyacinth, and Azolla, etc.) with fish farming. The common practice in fish cum crop production in the country is in the cultivation of fish with rice and vegetables (Zira *et al.*, 2015).

A wide range of fish species have been tested in rice fields, including cichlid (*Oreochromis niloticus*), common carp (*Cyprinus carpio*) and major Indian carp such as Catla (*Catla catla*) Mrigal (*Cirrhinus mrigala*) and Rohu (*Labeo ruita*). Other fish species that have shown good results and are highly acceptable in Asia and China include Chinese carps such as silver carp (*Ctenopharyngodon Idella*), freshwater prawns, etc. (Nwosu, 2017).

In Nigeria for instance, more than 1.5 million hectares of swamp areas in the Niger Delta and also in the Niger flood plains between Yauri and Lokoja (Kebbi and Kogi) and the Benue flood plains have good prospects for rice-cum-fish cultivation. Currently, rice-cum-fish farming is not practiced as a

culture system in Nigeria. The capture method is a common practice. It is also the first method initially adopted by Asian countries before being concurrent or rotational. The traditional method refers to the practice in which wild fish species, mainly catfish; *Clarias*, and *Hetrobranchus*, which enter flooded rice paddies from streams or irrigation canals, are trapped and allowed to grow along with rice. When rice is harvested, fish are caught for sale or consumption. Catfish species (*Clarias* and *Hetrobranchus*) are mostly caught in this type of system as they can move 169m from one environment to another with or without water (Ujoh *et al.*, 2016). In Egypt, common carp and tilapia (*Oreochromis niloticus*) are the main species used in traditional rice-fish culture (Suloma and Ogata, 2006).

2.2 Feeding in aquaculture

A majority of fish farmers in developing countries including Egypt and Nigeria use locally made fish feeds or commercially imported feeds for Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) production. The imported fish feed is more expensive than the locally made ones. Hence, many fish farmers use locally made fish feed usually produced and stored in large quantities to reduce production costs and increase profit margins. The locally-made feeds are usually from locally available plant and animal wastes like rice, maize, and wheat bran, blood meal, cottonseed cake, and sunflower seedcakes, and soybeans, and cassava. These ingredients can be ground manually and mixed in a hand-operated mixer and then made into pellets using a pelleting machine. Such ingredients are often subjected to contamination by molds during preharvest and/or due to poor storage conditions (Marijani *et al.*, 2019).

Two or more ingredients should be mixed in a home-made, laboratory, and commercial feed formulations. Supplementary fish feed may consist of by-products such as wheat bran, copra meal, wheat flour, oilseed cakes (e.g. rapeseed, peanuts, and soya), green feed, corn bran, poultry waste and/or food scraps. A broad range of ingredients is used in the preparation of aquafeeds, including aquatic and terrestrial plants and animals, plant or grain processing products and by-products e.g. Oiled Cakes and Meals, Beans, Grains and Brans and animal by-products e.g. Meat and Bone Meal, Bone Meal, Blood Meal, Feather Meal. Potential alternatives are non-conventional ingredients with little or no use as human food. Potential alternatives are non-conventional ingredients with little or no use as human food, such as blood meal, brewery waste, and poultry and fish by-products (Hailu, *et al.*, 2019).

One type of home-made fish feed is prepared from a blender of rice bran, corn grain, wheat, shrimp grain, fish grain, oil cake, soybean, fat, vitamins, and minerals. Another home-made feed is a blend of

corn grain, wheat, spirulina, shrimp grain, soybean, fat, vitamins, and minerals. One problem with homemade aquafeed is that it can contain heavy metals (Hossain *et al.*, 2016).

There are now increasing attempts to develop standard practical diets for farmed fish in Nigeria. A wide range of feedstuffs is produced as a by-product of the animal processing industry. Some of these feedstuffs are currently used in animal and fish rations. Two sources of fish feed have been identified, namely farm-based and commercial feed. There are few commercial sources of fish feed specializing only in animal feed and also engaged in the production of fish feed on demand, as the majority of fish feed produced (69–75 percent) is farm-made. There are two major types of fish feed produced by the fish feed industry in Nigeria, namely herbivorous fish (Tilapia) feed containing 30–35 percent crude protein and carnivorous fish (catfish) feed containing 45–50 percent crude protein (Ahmad MK, 2016).

Some of the notable commercially prepared imported fish feeds in Nigeria are Coppens, Aqua, Ranna, Pira, and Durante with the Crude protein, Crude lipid, Crude fibre, and Ash being the proximate composition of the feeds. There were significant differences in the feed brands concerning the weight gain, specific growth rate, feed conversion ratio, protein efficiency ratio, survival rate as well as feed cost per kg weight gain (Tunde *et al.*, 2016).

2.3 Growth performance in fish

Growth performance is the assessment of growth, especially in organisms following assimilation of food. It is the study of an increase in size, number, significance, feed efficiency, carcass quality etc. There are different ways to measure growth performance. They are the growth parameters such as mean weight gain (MWG), specific growth rate (SGR), feed conversion ratio (FCR), feed efficiency (FE), protein efficiency ratio (PER) and net protein utilization (NPU).

1. Mean Weight Gain (MWG) (g) = $W_2 - W_1$ (g)

Where; W_1 = mean initial weight (g)

W_2 = mean final weight (g)

$$2. \text{ Specific Growth Rate (SGR) \%} = \frac{\text{Loge } W_2 - \text{loge } W_1}{T_2 - T_1} \times 100$$

Where: T_1 and T_2 are time of experiment in days.

W_2 = final weight at T_2

W_1 = initial weight at T_1

Log_e = natural logarithm.

$$3. \text{ Feed Conversion Ratio (FCR)} = \frac{\text{Feed Intake (g)}}{\text{Wet Weight Gain (g)}} \times 100$$

$$4. \text{ Feed Efficiency (FE)} = \frac{\text{Weight gain}}{\text{Food fed}}$$

$$5. \text{ Protein Efficiency Ratio (PER)} = \frac{\text{Weight Gain (g)}}{\text{Protein Intake}} \times 100$$

$$6. \text{ Net protein utilization (NPU)} = \frac{BP_1 - BP_0}{CP} \times 100$$

Where:

BP_0 : Initial body protein content (g)

BP_1 : Final body protein content (g)

CP : Consumed Protein (g)

2.4 Immunological response of fish

Immunology is the study of the immune system and is a very important branch of the medical and biological sciences. The immune system protects us from infection through various lines of defence. If the immune system is not functioning, as it should, it can result in disease, such as autoimmunity, allergy and cancer. The immune response is how the body recognizes and defends itself against bacteria, viruses, and substances that appear foreign and harmful. The immune system protects the body from possibly harmful substances by recognizing and responding to antigens. Antigens are substances (usually proteins) on the surface of cells, viruses, fungi, or bacteria. Nonliving substances

such as toxins, chemicals, drugs, and foreign particles (such as a splinter) can also be antigens. The immune system recognizes and destroys, or tries to destroy, substances that contain antigens.

The vertebrate immune system is comprised of numerous distinct and interdependent components. Every component has its own inherent protective value, and the final combination of them is likely to be related to an animal's immunological history and evolutionary development. Vertebrate immune system consists of both systemic and mucosal immune compartments, but it is the mucosal immune system which protects the body from the first encounter of pathogens.

The basal position of fish in vertebrate phylogeny makes them very attractive for genomic and functional comparative immunity studies. Adaptive immunity arose early in vertebrate evolution, 450 million years ago between the divergence of cyclostomes and cartilaginous fish. The fundamental immune molecules, which include Ag-recognizing lymphocytes, immunoglobulins (Abs and Ig-family TCR), MHC products, and recombination-activating (RAG) 1 and 2 genes and the recombination mechanisms (cause of diversity in TCRs and Igs are similar in fish and mammals. These molecules and their immune response mechanisms unravelled the primordial vertebrate immune system repertoire and adaptive radiations (Rauta *et al.*, 2012).

The vertebrate immune system includes lymphoid organs that, according to their ontogeny and functional characteristics, are considered to be either primary or secondary. One of the secondary organs is the MALT (mucosa-associated lymphoid tissue) (Johnson *et al.*, 2000). Among MALTs particular interest (given its extension) has been given to the GALT (gut-associated lymphoid tissue) (Maaser and Kagnoff, 2002).

The fish immune system, comprised of numerous distinct and interdependent immune components, is necessary for organisms to defend themselves against invading pathogens (Ellis 2001). Every component of the immune system has its own inherent protective value, and the final combination of these components is likely to be related to a satisfactory immune response (Whyte 2007). According to anatomical location, the MALT in teleost fish is subdivided into gut-associated lymphoid tissue (GALT), skin-associated lymphoid tissue (SALT), and gill-associated lymphoid tissue (GIALT) (Salinas *et al.*, 2011). Mucosal immunity in fish is a very rarely studied research field, although there is currently great interest in this knowledge, and the study of the GALT has intensified in recent years (Fuglem *et al.*, 2010, Rombout *et al.*, 2011). The fish MALT has defense mechanisms (both innate and adaptive) that constitute the first line of defense opposite to the infectious agents (Woof and

Mestecky 2005). Since the majority of the infectious agents affects or initiates the process of infection in the mucous surfaces, the mucosal immune response plays a crucial role in the course of the infection (McNeilly *et al.*, 2008), and different studies have begun to examine their cellular and molecular composition in different species (Rajan *et al.*, 2011). Skin, gill, and gut constitute a large area (much greater than that of other vertebrates) for the possible invasion of pathogens (Wilson and Laurent), which is also influenced by the fact that there is an intimate contact between the Fishes are the main group of vertebrates and a major component of the aquatic fauna. Evolutionary pressure from pathogens may have led to this divergence in the adaptation of the immune system in different fish species. The functions of immune parameters at the individual, species, and population levels are ambiguous, and the relationships between the various immune parameters remain poorly understood. Increased knowledge of the mucosal innate immune factors could be advantageous in the fish farming and possibly human health, beyond the area of immune evolution.

Fishes are the main group of vertebrates and a major component of the aquatic fauna. Evolutionary pressure from pathogens may have led to this divergence in the adaptation of the immune system in different fish species. The functions of immune parameters at the individual, species, and population levels are ambiguous, and the relationships between the various immune parameters remain poorly understood. Increased knowledge of the mucosal innate immune factors could be advantageous in the fish farming and possibly human health, beyond the area of immune evolution.

Skin is considered the largest immunologically active organ, but its molecular mechanism remains unclear in fishes, mainly local signaling network of pivotal importance for the initiation, orchestration, effectuation, and modulation of immune responses (Londenstrom *et al.*, 2004).

Fish skin mucus has important bactericidal properties, and thus it could be regarded as a potential source of novel antibacterial components of interest in aquaculture practices (as therapeutic agents or as antifouling substances) (Rajanbabu and Chen, 2010). Because the external epithelial surfaces of fishes are often the points of pathogen entry, a basic understanding of the inductive immune mechanisms and immune cell interactions in the skin and gills is extremely important with regard to new vaccine developments. Insight into the immune effector molecules on mucosals is crucial for the development of new vaccines capable of generating robust immune responses in the mucosa. For that, a deeper knowledge of the mucosal immunity and of the immunological progression from mucosal

innate to acquired immune systems is needed in order to prevent and control infectious diseases (Sansonetti, 2011) in fishes.

2.5 Antioxidants

An antioxidant is a substance that inhibits oxidation, especially one used to counteract deterioration. Several types of antioxidative compounds are found in all fish species to protect their lipids against damage caused by reactive oxygen species. These compounds belong to various chemical groups and make use of their antioxidative effects via different modes of action. These include antioxidant enzymes, amino acids, peptides, ascorbic acid, carotenoids and phenolic compounds such as tocopherols and ubiquinones.

The antioxidant systems in living organisms may be divided in to two types. One is represented by enzymes, such as superoxide dismutase, catalase and the peroxidases, which remove reactive oxygen species. The other group of antioxidative compounds scavenges free radicals, they are generally of low molecular weight and may be water or lipid soluble. These antioxidants reduce free radicals and are themselves oxidized. After that they may be reduced to their active forms by other reducing systems. In biological systems the initiation of oxidation is balanced by the presence of natural antioxidants. Lipid-soluble antioxidants donate a hydrogen atom (H) to a fatty acid based free radical more readily than does an unoxidised fatty acid. Water-soluble antioxidants interacting between the aqueous and lipid phases can then reduce the lipid soluble antioxidant so they can continue to participate in these antioxidative reactions. The ability of an antioxidant to reduce another antioxidant or a lipid derived radical is determined by their reduction potentials (Buettner and Jurkiewicz, 1996). In post mortem muscle tissue the ability to keep the antioxidants in the reduced state diminishes with time because of the loss of reducing compounds, the ability to stabilize lipid free radical is lost, and the lipids will eventually oxidize. Antioxidants can act at different stages in the oxidation process and some may have more than one mechanism of action (Symons 1998).

2.6 Gene expression

Gene expression is the process by which information from a gene is used in the synthesis of a functional gene product that enables it to produce end products, protein or non-coding RNA, and ultimately affect a phenotype, as the final effect. It is simply the process the cell uses to produce the molecule it needs by reading the genetic code written in the DNA (Krebs *et al.*, 2017) To do this, the

cell interprets the genetic code, and for each group of three letters it adds one of the 20 different amino acids that are the basic units needed to build proteins.

Measuring gene expression is an important part of many life sciences, as the ability to quantify the level at which a particular gene is expressed within a cell, tissue or organism can provide a lot of valuable information. For example, measuring gene expression can:

- Identify viral infection of a cell (viral protein expression).
- Determine an individual's susceptibility to cancer (oncogene expression).
- Find if a bacterium is resistant to penicillin (beta-lactamase expression).

Similarly, the analysis of the location of protein expression is a powerful tool, and this can be done on an organismal or cellular scale. Investigation of localization is particularly important for the study of development in multicellular organisms and as an indicator of protein function in single cells. Ideally, measurement of expression is done by detecting the final gene product (for many genes, this is the protein); however, it is often easier to detect one of the precursors, typically mRNA and to infer gene-expression levels from these measurements (Kohler *et al.*, 2007).

2.7 Agro-industrial waste products

Agricultural residues are rich in bioactive compounds. These residues can be used as an alternate source for the production of different products like biogas, biofuel, mushroom, and tempeh as the raw material in various researches and industries. The use of agro-industrial wastes as raw materials can help to reduce the production cost and also reduce the pollution load from the environment. Agro-industrial wastes are used for manufacturing of biofuels, enzymes, vitamins, antioxidants, animal feed, antibiotics, and other chemicals through solid state fermentation (SSF). A variety of microorganisms are used for the production of these valuable products through SSF processes.

Agricultural-based industries produced the vast amount of residues every year. If these residues are released to the environment without proper disposal procedure that may cause to environmental pollution and harmful effect on human and animal health. Most of the agro-industrial wastes are untreated and underutilized, therefore in maximum reports it disposed of either by burning, dumping or unplanned landfilling. These untreated wastes create different problems with climate change by increasing a number of greenhouse gases. Besides this, the use of fossil fuels also contributing the effect on greenhouse gases (GHG) emission (Bos and Hamelinck 2014). So now, it is a worldwide

concern to dictating the improvement of alternative cleaner and renewable bioenergy resources (Okonko *et al.*, 2009). These wastes cause a serious disposal problem (Rodríguez-Couto 2008). For examples, the juice industries produced a huge amount of waste as peels, the coffee industry produced coffee pulp as a waste, and cereal industries produced husks. All over the world approximately 147.2 million metric tonnes of fiber sources are found, whereas 709.2 and 673.3 million metric tonnes of wheat straw residues and rice straws were estimated, respectively, in the 1990s (Belewu and Babalola 2009). As per the composition of these agro-industrial residues are concerned, they have high nutritional prospective, therefore they are getting more consideration for quality control and also categorized as agro-industrial by-products (Graminha *et al.*, 2008).

Various studies reported that different kinds of waste such as pomegranate peels, lemon peels and green walnut husks can be used as natural antimicrobials (Adamez *et al.*, 2012 and Katalinic *et al.*, 2010). Wastes from the organic compounds although a risk to the atmosphere, but they represent a possible source for making of mushrooms as foodstuffs and other bio-based products like bio-energy and biofertilizers. Some of the agricultural residues are used for animal food. However, such wastes contain variability in composition like high amount of proteins, sugars, and minerals. Due to high nutritional composition, these residues not described as “wastes” but considered as raw materials for other product formation and developments. The availability of these nutrients in raw materials offers appropriate environments for the growth of microorganisms. These microorganisms have got the ability to reuse the raw materials with the use of fermentation processes.

Agro-industrial wastes or residues are rich in nutrient composition and bioactive compounds. Such wastes comprise variability in composition such as sugars, minerals, and proteins; consequently, they should be considered as “raw material” instead of “wastes” for other industrial processes. The occurrence of such nutrients in these residues offers suitable conditions for the prolific growth of microorganisms. The microorganisms have potential to reuse the waste as raw materials for their growth through fermentation processes. The agro-industrial wastes can be used as solid support in SSF processes for the production of a range of significant beneficial compounds. The use of agricultural and agro-based-industry wastes as raw materials can help to reduce the production cost and contributed in recycling of waste as well to make the environment eco-friendly.

2.8 Types of agro industrial waste products

There are two different types of agro-industrial wastes, i.e., agriculture residues and industrial residues. Agriculture residues can be further divided into field residues and process residues. Field residues are residues that present in the field after the process of crop harvesting. These field residues consist of leaves, stalks, seed pods, and stems, whereas the process residues are residues present even after the crop is processed into alternate valuable resource.

2.9 Fish offal meal (FOM)

Fish offal means the heads, viscera and other parts of fish taken off in preparing for canning, preserving, packing and preparing for consumption in a fresh state. Fish offal meal has high amount of protein which may possibly contain essential amino acids and poultry litters may support algal development and indirectly promote fish production.

To increase the productivity of *Oreochromis niloticus* in aquaculture requires the use of complete diets since the natural feed is not able to meet the requirements of fish when raised in tanks and pond, where nutrient deficiencies or unbalanced diets can lead to productivity losses and consequently lower economic profit. In intensive fish farming, the feeding factor can reach up to 70 percent of the total production cost, a fact that has stimulated studies on finding alternative foods that meet the nutritional requirements of animals, without, altering the quality of diets (Zootec, 2012).

2.10 Rice bran

Bran, also known as miller's bran, is the hard outer layers of cereal grain. It consists of the combined aleurone and pericarp (Watson and Ramstad, 1987). Corn bran also includes the pedicel. Along with germ, it is an integral part of whole grains, and is often produced as a byproduct of milling in the production of refined grains. It consists of the combined aleurone and pericarp. It is often produced as a byproduct of milling in the production of refined grains. Bran is present in cereal grain, including rice, corn (maize), wheat, oats, barley, rye and millet. Bran is not the same as chaff, which is a coarser scaly material surrounding the grain but not forming part of the grain itself, and which is indigestible to humans.

2.11. Nutrient composition of rice bran

Rice bran has a highly nutritious chemical composition, containing 12–17 percent protein, 13–23 percent fat, 34–54 percent carbohydrates, 6–14 percent fibre and 8–18 percent ash (Saunders

1985). The oil from bran is valued for its bioactive phytochemicals like γ -oryzanol, tocopherols and tocotrienols (Orthoefer 1996).

2. 12. Benefits of using rice bran in feeds.

Rice bran has the potential to be used as an additive to improve the storage stability in food due to its antioxidant properties. Rice bran oil has industrial potential, especially in the preparation of snack food due to the great stability of frying, whereas rice bran fiber can be used as both a nutritional and functional ingredient. Chicken coated with stabilized rice bran fiber tends to absorb less fat during frying, and the small amount of fat present naturally in rice bran fiber can act as a carrier of flavors (Mohd Esa *et al.*, 2013). The nutritional and functional properties of rice bran are suitable for baked products, namely, cookies, muffins, bread, crackers, pastries, and pancakes. The addition of rice bran into the wheat flour further increased the protein, lysine, and dietary fiber contents in bread and cookies. The color, flavor, protein extractability, and solubility of bran, as well as other properties, such as water and fat absorption and emulsifying and foaming capacity, have demonstrated improvements that further enlighten us on the potential use of bran in foods (Tuncel *et al.*, 2014). Due to its naturally occurring enzymatic activity (lipases) and subsequent hydrolytic rancidity, rice bran needs to be stabilized to control these undesirable reactions. The antioxidants present in bran destroy the fungi, bacteria, and insect infestations, hence enhancing the shelf life of rice bran. The stabilized rice bran was successfully incorporated in up to 20 percent of the production of yeast bread because the hygroscopicity of the rice bran may improve its moisture retention in the baked products, while its ability to foam improved the air incorporation and leavening processes (Gul *et al.*, 2015). Defatted rice bran can be used to substitute for up to 10–20 percent of the wheat flour used for making cookies without adversely affecting the quality. Biscuits prepared with broken rice powder were highly acceptable in terms of taste and feel in the mouth. Besides oil, rice bran also has 10–15 percent protein content, consisting of 37 percent watersoluble, 31 percent salt-soluble, 2 percent alcohol-soluble, and 27 percent alkali-soluble storage proteins. Rice bran proteins have been found to be of high quality and application in food and pharmaceutical industries. Its unique properties, hypoallergenicity, and anticancer effects make it a superior cereal protein with a wide range of possible applications (Gul *et al.*, 2015; Tuncel *et al.*, 2014). Supplementation of rice bran has been successfully carried in various foods like bread, cakes, noodles, pasta, and ice creams without significantly affecting the functional and textural properties. The primary use of rice bran as an additive in food is due to its high fiber

content, which mildly promotes stool regularity. From a marketing point, the most commonly available rice bran-derived product is the oil.

2.13. Integrated fish and rice culture

The burning problems like scarcity of food for ever-growing human population in the present world are addressed by adapting various methods for production of protein, carbohydrate, oils and other food materials. One of the methods to produce high amount of food is integrated farming including rice-aquaculture farming, which produces protein and carbohydrate as major components besides others. Rice-aquaculture farming produces grain (carbohydrate) and animal protein without affecting the quality and quantity of rice yield on the same piece of land and renders additional financial gain besides main crop (rice) like conventional monoculture. The aquatic species grown in the integrated culture are mainly distinct types of fishes, selected crustaceans and other selected species. Profitable rice-aquaculture integrated farming is popular in Asian countries than in Western countries.

Integrated aquaculture farming, defined broadly, is a concurrent or sequential link between two or more activities, of which at least one is aquaculture. They may occur directly on-site or indirectly through off-site needs and opportunities, or both (Fregene, 2017).

The integrated rice-aquaculture is a mixed farming, where various rice varieties are grown along with selected aquatic cultural species depending on the local biological and physical factors. However, the selection of one aquatic species or more influences the yield of aquaculture protein. Because of this, the selection of aquatic species plays the most important role for the profit to the farmer and helps to improve the economy of the country (Pamuru *et al.*, 2018).

One of the forms of integrated fish farming in Egypt is a rice field aquaculture. There are two methods for rearing fish in the rice field: 1. the simultaneous method, 2. the Alternate method. The most common method in Egypt is simultaneous, in which both rice and fish are grown together, and it is the real rice-fish cultivation (Shaheen *et al.*, 2013). The potential of rearing fish in rice fields in an integrated system in Egypt has increased. Rice-fish farming has attracted the attention of many rice farmers in recent years and has been very successful (Cai *et al.*, 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study site

The study will be carried out in the wet laboratory, at the department of Aquaculture and Fisheries Management, university of Ibadan, Ibadan, Oyo state, Nigeria.

3.2. Fish

A total of 300 *C. gariepinus* (mean weight 50g) and 300 *O. niloticus* (mean weight 25.00g) will be procured from fish hatchery of University of Ibadan, Nigeria. To allow acclimatization to the laboratory conditions, the fish will be randomly distributed in the glass aquaria (80 × 40 × 30 cm, water capacity 60 L) for 14 days and will be fed twice daily with a basal diet (to satiation). During this period of acclimatization, there will be a check and maintenance of good water quality in the tank.

3.3. Water quality assessment

3.3.1. Dissolved oxygen

Dissolved oxygen will be determined by analytical method. 350 mL bottle will be filled with water from the experimental tanks to the brim and labelled O from each experimental unit. The labeled bottle will be fixed with 2 mL of Winkler A and B for the determination of dissolved oxygen. Exactly 100 ml of the fixed water will be neutralised by addition of 2 mL of 10 sulphuric acid. Four drops of starch will be added and titrated with 60 percent sulphuric acid. The DO level will be calculated using:

$$\text{DO (mg)} = \frac{0.02 \times \text{titer value} \times 8 \times 1000}{\text{Volume of water sample}} \quad (\text{AOAC, 2005}).$$

3.3.2. Temperature

Temperature will be measured using mercury thermometer (AOAC, 2005), while pH will be determined using pH meter. Nitrite and ammonia will be determined by colour change using nitrite kit (Aquasol AE-207) and value will be determined by multiplying the number of drops of indicator by five and expressed as ppm (Bhatnagar and Singh, 2010).

3.3.3. pH

pH will be determined using pH meter (Melter Teldo-320 model U.K) Comparative pH determination will be made by colorimetry method in which 5 drops of prepared chemical in the test kit will be added to 10 mL of sample water. The colour change will be compared with the colour chart provided by the manufacturer to determine the pH range.

3.4. Experimental Diet and Design

Five isocaloric and isonitrogenous (40 percent crude protein for African catfish and 30 percent crude protein for Nile tilapia) diet will be formulated to replace 0 (control), 25, 50, 75 and 100 percent maize with rice bran in the diet of African catfish and Nile Tilapia. These will form the experimental diet (AC0, AC30, AC50, AC70 and AC100 - African catfish and NT0, NT30, NT50, NT70 and NT100 – Nile Tilapia) respectively. The experimental diet will be supplemented with methionine and lysine (as synthetic amino acids) and dicalcium phosphate to maintain the dietary requirements. The proximate amino acid and chemical analyses will be performed according to the Association of Official Agricultural Chemists.

The fish will be randomly distributed into five groups, and each group will be in triplicate (60 fish/group with 20 fish/replicate each). The fish will be fed manually to satiation twice daily (08:00 and 15:00). Water parameters will be kept at standard values throughout the experimental period. One-fourth of the volume of aquarium water will be exchanged daily. The experimental process will last for a period of twelve (12) weeks.

The fishes will be starved for 12 hours prior to the experiment to empty their gut and increase their appetite for the reception of the new feed. The new diets will then be fed to triplicate groups of fishes to apparent satiation twice daily (8:00 and 15:00 hours) for 12 weeks. The amount of feed given at each feeding time will be recorded and uneaten feed siphoned daily will be used to determine daily feed in take as described by Helland, Grisdale-Helland, and Nerland (1996). Fish will be weighed fortnightly with the use of a sensitive digital scale.

3.5. Growth performance assessment

The growth performance and nutrient utilisation of the *O. niloticus* will be determined using these parameters: mean weight gain (MWG), specific growth rate (SGR), feed conversion ratio (FCR), feed efficiency (FE), protein efficiency ratio (PER) and net protein utilization (NPU).

$$1. \text{ Mean Weight Gain (MWG) (g) } = W_2 - W_1 \text{ (g)}$$

Where; W_1 = mean initial weight (g)

W_2 = mean final weight (g)

$$2. \text{ Specific Growth Rate (SGR) \% } = \frac{\text{Loge } W_2 - \text{loge } W_1}{T_2 - T_1} \times 100$$

Where: T_1 and T_2 are time of experiment in days.

W_2 = final weight at T_2

W_1 = initial weight at T_1

Log_e = natural logarithm.

$$3. \text{ Feed Conversion Ratio (FCR) } = \frac{\text{Feed Intake (g)}}{\text{Wet Weight Gain (g)}} \times 100$$

$$4. \text{ Feed Efficiency } \text{FE} = \frac{\text{Weight gain}}{\text{Food fed}}$$

$$5. \text{ Protein Efficiency Ratio (PER) } = \frac{\text{Weight Gain (g)}}{\text{Protein Intake}} \times 100$$

$$6. \text{ Net protein utilization (NPU) } = \frac{BP_1 - BP_0}{CP} \times 100$$

Where:

BP_0 : Initial body protein content (g)

BP_1 : Final body protein content (g)

CP: Consumed Protein (g)

Table 1: Proposed experimental diet composition (g/100g) for *O. niloticus* at 30 percent CP

Ingredients	0% (Control)	25%	50%	75%	100%
Fish Meal	40.98	40.98	40.98	40.98	40.98
Maize	49.02	36.77	24.51	12.26	0.00
Rice Bran	0.00	12.26	24.51	36.77	49.02
Starch	6.00	6.00	6.00	6.00	6.00
Fish oil	1.00	1.00	1.00	1.00	1.00
Vit premix	0.50	0.50	0.50	0.50	0.50
Methionine	0.50	0.50	0.50	0.50	0.50
Lysine	0.50	0.50	0.50	0.50	0.50
Vitamin C	0.50	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50	0.50
DCP	0.50	0.50	0.50	0.50	0.50

Table 2: Proposed experimental diet composition (g/100g) for *C. gariepinus* at 40 percent CP

Ingredients	0% (Control)	25%	50%	75%	100%
Fish Meal	49.75	49.75	49.75	49.75	49.75
Maize	40.25	30.17	20.13	10.06	0.00
Rice Bran	0.00	10.06	20.13	30.17	40.25
Starch	6.00	6.00	6.00	6.00	6.00
Fish oil	1.00	1.00	1.00	1.00	1.00
Vit. premix	0.50	0.50	0.50	0.50	0.50
Methionine	0.50	0.50	0.50	0.50	0.50
Lysine	0.50	0.50	0.50	0.50	0.50
Vitamin C	0.50	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50	0.50
DCP	0.50	0.50	0.50	0.50	0.50

3.6. Procedures for proximate composition and energy of experimental diets

The proximate and mineral composition of the experimental fish and diets will be carried out before and after the experiment. Each of the diets will be analyzed for crude protein, crude fiber, Ash, NFE, moisture, crude lipid and gross energy. After the experiment, two fish each from *C. gariepinus* and *O. niloticus* will be randomly sacrificed for analysis, according to AOAC (2000). The experiment will be performed in triplicate.

3.6.1. Moisture content

The empty dish and lid will be dried in the oven at 105°C for 3 hours and then transferred to desiccator to cool; after which it will be weighed. 3g of the sample will be weighed in the dish and spread for

uniformity. The dish and the sample will be placed in the oven and dried for 3 hours at 105°C (AOAC, 2000). It is calculated as

$$\text{Moisture (\%)} = \frac{(W1 - W2) \times 100}{W1}$$

Where: W1 = weight (g) of sample before drying

W2 = weight (g) of sample after drying

3.6.2. Fat content

The reagents to be used will be petroleum ether. The bottle and lid will be placed in the incubator at 105°C overnight to ensure that weight of bottle is stable. Then 3g of the sample will be weighed in a filter paper and wrapped. The sample will be taken to the extraction thimble and transfer into the soxhlet. The bottle will be filled with 250 ml petroleum ether and taken to the heating mantle. Then the soxhlet apparatus will be connected. The sample will be heated to about 14 h (heat rate of 150 drop/min). After this, vacuum condenser will be used to evaporate the solvent by using the vacuum condenser. Then the bottle will be incubated at 80-90°C until solvent is completely evaporate and bottle is completely dry. After drying, the bottle with partially covered lid will be transferred to the desiccator to cool. Then the bottle and its dried content will be reweighed (AOAC, 2000).

$$\text{Fat (\%)} = \frac{\text{Weight of fat} \times 100}{\text{Weight of sample}}$$

3.6.3. Crude Protein (Kjedahl method)

The crude protein will be determined thus; Kjeldahl catalyst: 9 part of potassium sulphate (K₂SO₄) will be mixed with 1 part of copper sulphate (CuSO₄). Sulfuric acid (H₂SO₄), 40 percent NaOH solution, 0.2 N HCl solution, 4 percent H₃BO₃ and an indicator solution 100 ml of 0.1 percent methyl red (in 95 percent ethanol) will be mixed with 200 ml of 0.2 percent bromocresol green (in 95 percent ethanol).

1.0 g of the sample will be placed in digestion flask. Then 5g Kjeldahl catalyst and 200 ml of conc. H₂SO₄ will be added. A tube containing the above chemical without the sample will be prepared to

serve as blank. Both flasks will be placed in inclined position and heated gently until frothing ceases and then briskly boiled until solution boils. The solution will be cooled and 60 ml distilled water will be cautiously added. The flask will be immediately connected to digestion bulb on condenser with the tip of the condenser immersed in standard acid and 5-7 drops of indicator in the receiver. The flask will be rotated to ensure that all the content mixes thoroughly and then heated until all the NH_3 is distilled. The receiver will be removed, the tip of the condenser washed and the excess standard acid titrated with standard NaOH solution (AOAC, 2000).

Calculation

$$\text{Protein (\%)} = \frac{(A-B) \times N \times 1.4007 \times 6.25}{W}$$

W

Where

A= volume (ml) of 0.2 N HCl used sample titration

B = volume (ml) of 0.2 N HCl used in blank titration

N= Normality of HCl

W = weight (g) of sample

14.007 = atomic weight of nitrogen

6.25 = the protein-nitrogen conversation factor for fish and its by-product

3.6.4. Ash

The crucible and lid will be placed in the furnace at 550°C overnight to ensure that impurities on the surface of crucible are burned off. This will then be cooled in the dessicator for 30 mins and the crucible with the lid weighed in 3 decimal places.

5 g sample will be weighed into the crucible and heated over low Bunsen flame with lid half covered. When fumes are no longer produced, the crucible and lid will be placed in furnace and heated at a temperature of 550°C overnight although the crucible will not be covered. The lid will only be placed after complete heating to prevent loss of fluffy ash. Then it will be placed in the desiccator for cooling. After this, the crucible, ash and lid will be weighed (AOAC, 2000).

The calculation will be done using the formulae:

$$\text{Ash (\%)} = \frac{\text{Weight of ash} \times 100}{\text{Weight of sample}}$$

3.6.5. Nitrogen Free Extract (NFE)

NFE content of the samples will be determined as total carbohydrate by difference, that is, by subtracting the measured protein, fat, ash and moisture from 100 as given by Uzanne (2010):

$$\% \text{NFE} = 100 - \% (\text{Ash} + \text{crude fiber} + \text{moisture} + \text{Fat content} + \text{Crude protein})$$

3.6.6. Determination of Gross Energy

This will be measured using oxygen bomb calorimeter using benzoic acid as the substrate. 1g of the sample will be dried and pelleted and the thread plug firmly embedded. The pellet will be weighed and transferred into a cup and place in a supporting ring. A piece of nickel chromium wire will be stretched between the electrodes of the bomb winding the cotton wick. After this, oxygen will be introduced to a filling pressure of 25-30 lb/mm or atmospheric pressure. The bomb will be placed in a bucket of distilled water not greater than 28°C and placed inside the calorimeter. The stirrer will be switched on and the thermometer placed inside while ensuring that it is immersed in the water. After taking note of the temperature, the button will be pressed. The final temperature will be noted down

Calculation:

$$\text{Gross energy (Kcal/gm)} = \frac{\{\text{rise in temperature} - \text{initial temperature}\} \times \text{bomb equivalent} - 23 \times 100}{\text{Weight of sample}}$$

3.6.7. Blood Sample Collection

Blood samples will be collected for serum separation after 15 and 30 days each for the two experiments. At each point in time, 9 fish/group each will be collected and anesthetized with 100 mg/L of benzocaine. Blood samples will be collected from caudal vessels without anticoagulant for the separation of serum (centrifugation at 3000 rpm/15 min at 4 °C). The serum samples will be held at -20 °C until analysis. For the analysis of total and differential leukocyte counts, the blood samples (9 fish/group each) will be collected after 30 days using EDTA-rinsed (Ethylenediaminetetraacetic

acid) 1-mL syringes. Total Leukocyte Count (TLC) test measures the total number of all the leukocytes in the blood. Differential leukocyte count gives the relative percentage of each type of white blood cell and also helps to reveal abnormal white blood cell. A differential leukocyte count can also detect immature white blood cells and abnormalities, both of which are signs of potential issues. After completing the blood sampling collection, the 9 fish each will be dissected to obtain samples for gene expression analysis.

3.7. Hematological and serum biochemical analyses of *C. gariepinus* and *O. niloticus* fed experimental diets

At the end of the trial, five fish from each treatment in triplicate will be individually caught using a hand net and bled serially using tuberculin syringes with gauge needles inserted into the common cardinal vein of each fish. The site chosen for puncture will be wiped dry with tissue paper to avoid contamination with mucus. The needle will be inserted at angle 45⁰ to the vertebral column of the fish and gently aspirated during penetration. It will then be pushed gently down until blood starts to enter as the needle punctures a caudal blood vessel (Omitoyin *et al.*, 2006). Blood will be taken under gentle aspiration and withdrawn. The blood will be gently transferred into a lithium heparin anticoagulant tube at room temperature and transferred to the Clinical Pathology Laboratory of the Department Veterinary Pathology, University of Ibadan for haematology analysis. The blood stain method will be adopted for differential blood cell count, plasma biochemistry and serum biochemical analysis. The slides will be placed in a staining jar containing May-Grunwald's stain freshly diluted with an equal volume of buffered water for 5 minutes. The slides will be transferred into a second staining jar containing Giemsa's stain freshly diluted with nine volumes of buffered water for 15 minutes (Olukunle, 1996). The slides will be transferred into another stain jar containing buffered water and then rapidly washed in three changes of water and finally stands in buffered water for 5 minutes for differentiation, air-dried and mounted on light microscope. The following parameters will be measured:

3.7.1. Determination of Packed Cell Volume (PCV)

The blood samples will be mixed by inverting 20 times. The capillary tubes will be filled with the blood samples and centrifuged at 3000 rpm for 5 minutes in a Kawksley micro-haematocrit centrifuge, England. The actual PCV values will be obtained using haemtocrit reader and expressed in percentage (Adeyemo and Agbede, 2008).

3.7.2. Determination of Haemoglobin (Hb)

The Hb will be determined using Drabkin's solution. 2µL of the samples will be taken using micro-pipette, added to the 5ml of Drabkin solution and allowed to stand for 5 minutes. The reading will be taken on photospectrometer (SM23A) with a tube of Drabkin's solution as a blank at 540 nm. The values will be calculated as:

$$\text{Hb} = \frac{\text{Absorbance of the test} \times \text{concentration of standard} \times \text{dilution in g/L}}{\text{Absorbance of standard}} \quad (\text{Adeyemo, 2005}).$$

3.7.3. Determination of Red Blood cell (RBC)

The samples will be diluted 1:200 with Rees and Ecker's diluent fluid. Few drops will be expelled out and then introduced under cover slip on an improved Neubauer count chamber (Neubauer improved bright line Marienfeld, Germany 0.100 mm, 0.0025 mm²) with x 10 objective lens. The amounts were calculated as;

$$\text{RBC} \times 10^{12} \text{ L} = \text{Numbers of cell counted} \times \text{Depth} \times \text{Dilution} \times \text{Area} \quad (\text{Oresegun and Alegbeleye, 2001}).$$

3.7.4. Determination of White Blood Cell (WBC)

White blood cell counts will be done using Newbauer haemocytometer as described by Kaplow (1955). White blood cell count will be carried out by diluting 1: 200 of blood sample with 3 percent aqueous solution of acetic acid and gentian violet added to the mixture later. The mixture will be allowed to settle for 2 minutes, mounted on microscope, and counted.

3.7.5. Platelets counts

Platelets counts will be determined using the direct (Rees and Ecker's) method. 20µL of the blood samples will be added to 1.98mL of diluents at dilution ration 1:100. The suspension will be left for 2 hours but mixed 2 minutes before use. The counting chamber will be filled with a Pasteur pipette and placed in a moist chamber for 20 minutes to allow the platelets to settle.

1 mm² will be counted under the microscope. The values will be calculated using Platelets = 1mm² count x 10⁹ (Osuigwe *et al.*, 2005).

Monocytes: The larger cell with cytoplasm containing orange spheres will be observed under a light microscope. The nuclei will also be observed for irregular shape and azurophilic cytoplasmic granules and expressed as percentage.

Heterocytes: The cells with an average of 6-9μ with circular shape will be observed with the aid of light microscope. The cells with rod shape, central granules and irregular size will be observed. Also, cells that are not closely grouped, colourless to pink with bilobed or multilobed will be observed and expressed as percentage (Oyewale, 2011).

Lymphocytes: the smear will be observed on the light microscope (x100 objective lens). The small cells containing nuclei, showing granular appearance will be observed and expressed as percentage (Oyewale, 2011).

Eosinophils: The cell with a size of 7μ and circular shape on blood smear will be observed under a light microscope. The pale blue cytoplasm homogenous bodies will be observed and expressed as percentage (Osuigwe *et al.*, 2005).

Basophil: The basophil granules will be observed under a light microscope with dots around the nuclei and expressed as percentage (Omitoyin *et al.*, 2006).

3.7.6. Mean Cell Haemoglobin (MCH)

The average of Hb in pictograms of a simple RBC will be determined using

$$\text{MCH (pg)} = \frac{\text{Hb} \times 10}{\text{RBC}} \quad (\text{Olukunle, 1996}).$$

3.7.7. Mean Cell Haemoglobin Concentration (MCHC)

Percentage of Hb of packed RBC will be determined using

$$\text{MCHC (g/dL)} = \frac{\text{Hb} \times 100}{\text{PCV}}$$

3.7.8. Mean Cell Volume (MCV)

Average volume of a single cell will be determined using

$$\text{MCV (fl)} = \frac{\text{PCV} \times 10}{\text{RBC}} \quad (\text{Olukunle, 1996}).$$

3.8. Histological study of gut morphometry

Gut morphometry will be examined using standard methods. The organs (intestine) of *C. gariepinus* and *O. niloticus* will be taken for histological examination at the Histopathology Laboratory of the Department of Veterinary Pathology, University of Ibadan. The fixed guts will be prepared on slides based on Culling, (1974) and Drury *et al.* (1967) for the organs and tissues. Measurements of villus length (VL, cm), depth of the crypt (DC, cm), villus width (VW, cm) and area of absorption (AA, cm²) will be taken using light microscope (HE x40) (Olympus CX21, Japan) in triplicates with a micrometer rule as described by Spadoniet *al.* (2005) and Eyarefe *et al.* (2008). As many villi as possible will be measured up to 10 villi per slide.

3.8.1. Gut ecology analysis

At the end of feeding and growth trials, three fishes will be randomly selected from each treatment tank in triplicate for gut ecology parameter analysis. The selected fish will be killed by keeping them in ice-cold distilled water. The intestinal tissue will be aseptically dissected from the selected fish and gently rinsed three times with cold and sterile saline solution (0.85 percent w/v). Midgut samples will be taken by removing an approximately 2 cm section of intestine from the center of the intestine. After collection, the sections of midgut will be immediately fixed in 4 percent paraformaldehyde (PFA) solution overnight for histological analysis of gut morphology. Intestinal tissue homogenates will be prepared by mixing the sample with two volumes of sterile saline solution and mechanically homogenized for 5 min. These intestinal tissue homogenates will be used for bacterial nutritional enzyme activity.

3.8.2. Leukogram, Serum Total Protein, and Electrophoretic Fraction Analysis

Total and differential leukocyte counts will be examined by using Automated Haematology Analyzer. Serum total protein (g/dl) and albumin (g/dl) will be estimated using standard procedure and total

globulin will be calculated by subtracting albumin from total protein. Serum protein will be analyzed according to Laemmli (1970).

3.8.3. Serum Total Protein, Albumin and Globulin

Serum protein will be estimated by Biuret method and serum albumin by bromocresol green method using Pars Azmun kits (Iran) and Auto analyzer (Ependorf). Serum globulin will be estimated by subtracting these two amounts. (Soltani *et al.*, 2010).

The principle of this reaction is that serum proteins react with copper sulfate in sodium hydroxide to form a violet "biuret" complex. The intensity of the violet color is proportional to the concentration of protein. The biuret method is a colorimetric technique specific for proteins and peptides. Copper salts in alkaline solution form a purple complex with substances containing two or more peptide bonds. The absorbance produced is proportional to the number of peptide bonds that are reacting and therefore to the number of protein molecules present in the reaction system.

The reagent is obtained by dissolving 1–5 g of copper(II) sulfate and 6 g of sodium potassium tartrate tetrahydrate in 3 percent sodium hydroxide.

Procedure

The biuret method is based on the fact that proteins (and, as a rule, all substances containing two or more peptidic bonds) react with copper to form a colored complex whose absorption ($\lambda_{\text{max}} = 454 \text{ nm}$), in the presence of excess copper, is proportional to the amount of protein present. Bovine serum albumin is used as standard.

3.8.4. Serum Oxidant/Antioxidant Status

Serum levels of total antioxidant capacity (TAC) (mm/l), superoxide dismutase (SOD) (U/ml), catalase activity (CAT) (U/l), and reduced glutathione (GPx) (mmol/l) will be estimated using commercial ELISA test kits.

3.8.5. Measurement of Superoxide dismutase (SOD)

SOD activity can be measured by both activity assays and activity gels. But in this study, the biochemical method of the activity assay will be used.

Principle

The ability of superoxide dismutase to inhibit the autoxidation of epinephrine at pH 10.2 makes this reaction a basis for simple assay for this dismutase. Superoxide ($O_2^{\bullet-}$) radical hat will be generated by Xanthine oxidase reaction will cause the oxidation of epinephrine and the yield of adrenochrome produced per $O_2^{\bullet-}$ introduced. This increases with increasing pH and also increases with increasing content of epinephrine. The results will lead to the proposal that autoxidation of epinephrine proceeds by at least two distinct pathways, one of which is a free radical chain involving superoxide ($O_2^{\bullet-}$) radical and hence inhibited by SOD. Xanthine-xanthine oxidase will be used to generate Superoxide ($O_2^{\bullet-}$) and nitroblue tetrazolium (NBT) reduction will be used as an indicator of $O_2^{\bullet-}$ production. SOD will compete with NBT for $O_2^{\bullet-}$; the percent inhibition of NBT reduction is a measure of the amount of SOD present. Catalase will be included to remove H_2O_2 produced by SOD. In the laboratory, SOD activity is measured using a modification of a published method (Oberly and Spitz, 1985, Spitz and Oberly, 1989). The specific activity of both enzymes is reported as units per mg protein, per μg DNA, or per cell. The order of the addition of the reagents into the assay solution is critical. Bovine serum albumin (BSA) will be added to keep the solution from forming precipitates when bathocuproine disulfonic acid (BCS) is added. BCS (an electron chain-associated free radical production inhibitor) and diethylenetriaminepentaacetic acid (DETAPAC) will both be added to inhibit iron-associated redox cycling and free radical production. The original concentration of sample protein should be around $20 \mu g \mu l^{-1}$. Various amounts of protein will be added into tubes until maximum inhibition of NBT reduction (~80 percent) is obtained.

Procedure

800 μL of Tris-KCL buffer will be added into the test tube, 250 μL TCA added, 250 μL of TBA and 200 μL of sample will then be added. The mixture formed would be incubated in water bathe at 800C for 45 minutes, cooled in ice and centrifuged at 4,000 rpm for 5 minutes. The supernatant would be decanted and placed in micropipette plate reader and the absorbance would be measured against a reference blank of distilled water at wavelength 490 nm. (Misra and Fridovich, 1972).

3.8.8. Reduced glutathione (GSH) determination

3.8.8.1. Description

The reduced form of glutathione comprise in most instance a bulk of cellular non-protein sulfhydryl groups. Therefore, this method is based upon the development of a stable yellow colour when 5', 5'-dithiobis – (2-nitrobenzoic acid, DTNB) (Ellman's reagent) is added to sulfhydryl compounds. The chromophoric product resulting from the reaction of Ellman's reagent with the reduced glutathione, 2 – nitro-5-thiobenzoic acid possesses a molar absorption of 412 nm. Reduced glutathione is proportional to the absorbance at 412 nm.

3.8.8.2. Procedure

This will be measured according to the method of Sedlak and Lindsay (1968). 200µL sample will be placed into the tubes and 0.5 ml of the precipitating solution would be added. The mixture would be centrifuged at 4000 rpm for 5 minutes. 200µL of of the supernatant would be put in another test tube and 4.5ml of Ellman's reagent will be added. This will be read at 412 nm against the blank (distilled water). The optical density would be measured at 412 nm and the estimate will be obtained from GSH standard curve.

3.8.9. Malondehyde (MDA)

MDA is an index of lipid peroxidase and will be determined by the method of Farombi *et al.*, (2000). 200µL of the sample will be pipetted into the test tube and 800 µL of tris-KCL buffer (PH 7.4) will be added. 250 µL of TBA and TCA will be added. The mixture will be placed in hot bath at 800C for 45 minutes and then allowed to cool on ice. Flocculent materials will be removed by centrifuging 3000 rpm for 15 mins. 200 µL of the supernatant would be pipetted out and the absorbance would be read at 532nm against a blank of distilled water. Lipid peroxidation in units/mg protein or gram tissue would be computed with a molar extinction coefficient of $1.56 \times 10^5 \text{ M}^{-1} \text{ Cm}^{-1}$

$$\text{MDA (Units/mg protein)} = \frac{\text{Absorbance} \times \text{volume of mixture}}{E_{533 \text{ nm}} \times \text{volume of sample} \times \text{mg protein}}$$

3.8.10. Total protein

Protein form a coloured complex with cupric ions in an alkaline solution as exemplified by the biuret reagent containing CuSO₄ KI and Potassium iodide tartrate. The protein and biuret reagent form a complex with maximum absorbance at 540 n. The procedure is usually calibrated with a standard BSA (Bovine Serum Albumin) curve.

Preparation of standard BSA curve by the Biuret method.

Several dilutions of the stock containing 2-10 mg protein/ml will be made into 1 ml of each protein standard solution in a test tube and 4 ml of biuret reagent will be added. The mixture will be allowed to stand at room temperature for 30 minutes and the optical densities of the resulting violet against protein concentration will be plotted.

Procedure

Estimation of protein in the samples is measured by the method of Lowry (1951). 3g of CuSO₄, 5H₂O, would be dissolved in 500 ml of 0.2 M NaOH, 9g of Sodium tatarate and 5 g of Potassium iodide, KI will be added and the solution made up to a litre with 0.2 M NaOH.

3.8.11. Nonspecific Immune Analysis

Nonspecific immune parameters such as serum alternative complement pathway C3 activity will be examined using a C3 kit. A C3 standard curve will be created using the same process. C3 levels will be determined according to Thomas (1998). For serum nitric oxide (NO) (μmol/L), will be measured using a spectrophotometric method (Rajaraman *et al.*, 1998).

3.8.12. Measurement of Oxidative Stress Indices (OSI)

For the OSI analyses, liver tissue and kidney of five fish per treatment in triplicate will be taken and preserved immediately in ice for Nitric Oxide content (NO), Hydrogen Peroxide (H₂O₂) Malondialdehyde (MDA), Reduced Glutathione (GSH), catalase (CAT), glutathione peroxidase (GPx), Superoxide Dismutase (SOD). Renal nitric oxide (NO) will be measured as described by Olaleye *et al.* (2007). The concentration of nitrite in the sample will be determined from a sodium nitrite (NaNO₂) standard curve and expressed as micromole nitrite per milligram protein. Hydrogen

peroxide generation will be determined as described by Wolff (1994). The hydrogen peroxide (H_2O_2) generated will be extrapolated from hydrogen peroxide standard curve. The MDA will be determined according to the method of Varshney and Kale (1990). The absorbance will be measured against a blank of distilled water at 532 nm. Lipid peroxidation in units/mg protein will be calculated with a molar extinction coefficient of $1.56 \times 10^5 \text{ M}^{-1} \text{ cm}^{-1}$. The cardiac and renal reduced glutathione (GSH) will be estimated by the method of Jollow *et al.* (1994). The absorbance will be read at 412 nm against distilled water as blank. Catalase (CAT) activity will be determined by the method described by Montavon *et al.* (2007). The definition of the enzyme-activity unit of CAT will be the amount that caused the decomposition of 1 μmol of H_2O_2 per min under the experimental conditions. The activity was expressed in U/g FW. The cardiac and renal glutathione peroxidase (GPx) activity will also be measured according to Buetler *et al.* (1963). The absorbance will be read at 412 nm using distilled water as blank. Protein concentrations will be determined by method described by Gornal *et al.* (1949). The mixture will thereafter be read with spectrophotometer at 540 nm using distilled water as blank. The final value for total protein will be extrapolated from total protein standard curve. Superoxide dismutase (SOD) activity will be determined using assay kit (Randox Kit SOD Kit 0223).

3.8.13. Serum Nitric Oxide (NO) determination

Greiss reagent was first described in 1879 and has been used extensively in the analysis of numerous biological samples including tissue, plasma (serum), urine and saliva. Nitrite will be first treated with diazotizing reagent e.g Sulfanilamide, in acidic media to form a transient diazonium salt. This is allowed to react with a coupling reagent, N-naphthylethylenediamine (NED) to form a stable azo compound. The intense purple colour of the product allows nitrite assay with high sensitivity and can be used to measure nitrite concentration. The absorbance of this adduct at 540nm is linearly proportional to the nitrite concentration in the sample.

3.8.13.1. Procedure

The procedure will be carried out by the method of Williams *et al.*, (2008), using the Greiss reagent. 100 μL of the sample would be pipetted in a micro plate and 100 μL (Greiss, 1879) would be added. After incubation at room temperature for 10 minutes, the absorbance at 540 nm would be measured by micropipette plate reader. The concentration of nitrite in the sample will be determined from a sodium nitrite (NaNO_2) standard curve and be expressed as μmol nitrite/mg protein.

3.8.14. Expression of Pituitary Adenylate Cyclase-Activating Polypeptide Gene

The same 9 fish each for each of the two studied fish species will be used for the collection of blood samples at the end of the experiment (30 days) will be euthanized using a benzocaine solution overdose (250 mg/L) and used for gene expression analysis to collect spleen samples. The total RNA will be extracted using the QIAamp RNeasy Mini Kit according to the manufacturer's protocol. Complementary DNA will be synthesized following the manufacturer's instructions. Quantitative real-time polymerase chain reaction (PCR) analysis will be performed with the SYBR green PCR master mix (Step One Plus, Applied Biosystem, Waltham, MA, USA). The amplification efficiency of the used primer will be determined by standard curve assay.

3.8.15. Analysis of growth and immune response related microsatellite markers in the liver of experimental fish

Total RNA of *Clarias gariepinus* and *Oreochromis niloticus* will be isolated from the liver of three fishes randomly selected from each treatment in triplicate at the end of feeding trial and after the challenge test using the Zymol Complete RNA Purification Kit (Invitrogen, USA) according to the manufacturer's protocol. The total RNA sample will be quantified using a Nano Drop ND-1000 spectrophotometer (Nano Drop Technologies, Inc., Wilmington, DE, USA). Total RNA samples will be adjusted to a final concentration of 100 ng/L according to Mu *et al.* (2018).

3.8.15.1. Gene expression and PCR analysis

Primer sequences for growth-related microsatellite loci (PRL I-MS01, PRL I-MS02, IGF-II-MS01, and IGF-II-MS03) (table 3) designed according to the methods of Aksakal *et al.* (2010), antioxidant and immune response-related genes (SOD1, SOD2, CAT, GPx, Nrf2, Arg I, IL 10, TNF α , IL1 β , TLR2 and TLR4) (table 3) according to the method of Mu *et al.*, (2019) will be profiled using the quantification of expression of genes involved in the liver of *Clarias gariepinus* and *Oreochromis niloticus*.

The qRT-PCR will be performed in LightCycler[®] 480 II real-time PCR detection system (Roche, Germany) in a 10 μ l reaction volume containing 1 μ l cDNA, 0.25 μ l each of forward and reverse primer, 5 μ l Green I master mix (Roche, Germany) and 3.5 μ l PCR grade water. PCR amplifications will be performed in triplicate wells. Thermal cycling will be initiated with the incubation at 95°C for 90 sec for hot-start iTaq TM DNA polymerase activation. Thirty five steps of PCR will be performed,

each one consisting of heating at 95°C for 20 s for denaturing, and at 59°C for 30 s for annealing and extension of the target genes. For negative control, qRT-PCR reaction without cDNA will be considered. Following the final cycle of the PCR, melting curves will be systematically monitored (with a gradient of 0.5°C/10 s from 55°C to 94°C) to ensure that only one fragment will be amplified. In a 1 percent agarose gel, 8 µl of the real-time PCR products will be loaded to verify the specificity of the product size.

The relative quantification of the target gene transcript with that of β-actin reference gene transcript will be determined following the method of Pfaffl (2001) and Pfaffl *et al.*, (2002). This mathematical algorithm will be computed as an expression ratio, based on real-time PCR efficiency and the crossing point deviation of the unknown sample versus a control group which is calculated as:

$$R = \frac{((E_{\text{target gene}})^{\Delta CT_{\text{Target gene}} (\text{mean control} - \text{mean unknown sample})})}{((E_{\beta\text{actin}})^{\Delta CT_{\beta\text{actin}} (\text{mean control} - \text{mean unknown sample})})}$$

Where E is PCR efficiency determined by standard curve using serial dilution of cDNA (cDNA dilutions from 1/16 up to 1/512);

ΔCT being the crossing point deviation of an unknown sample versus a control.

3.8.16. Challenge Test

Seven fish/replicate each for the two experimental fish species (21 fish/group) will be challenged by intraperitoneal injection with pathogenic *Aeromonas aeruginosa*. The fish will be observed for 15 days, and their clinical signs, postmortem lesions, and daily mortality will be recorded. For confirmation, the pathogenic bacterial strain will be re-isolated from the liver, kidney, and intestine of dead fish.

3.8.17. Statistical Analysis

One-way ANOVA (SPSS version 61.0) will be performed to detect the difference among experimental groups within the same period. The group means will be analyzed with Duncan's multiple range tests and presented as the mean ± SE. Two-way ANOVA (Statistical software, version 8) will be used to determine the interaction between the levels of FM substitution with FOM and the feeding duration.

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Plan activities

	Activities	Year 2022 (quarterly)			
		1	2	3	4
1	Objective 1: To determine the growth performance and nutrient utilization of <i>C. gariepinus</i> and <i>O. niloticus</i> fed varying inclusion levels of Fish offal as replacement for Fish meal				
i	Procurement and Acclimation of the fish				
ii	Diet formulation and experimental set up				
iii	Blood sample collection				
iv	Data analysis and result development				
2	Objective 2: assessing its effect on immune status, anti-oxidant activity, pituitary adenyate cyclase-activating polypeptide (PACAP) gene expression, and resistance of <i>C. gariepinus</i> and <i>O. niloticus</i>				
i	Leukogram, serum Total protein, and Electrophoresis Fraction Analysis				
ii	Serum oxidant/antioxidant status				
iii	Nonspecific immune Analysis				
iv	Expression of pituitary Adenylate Cyclase-activating polypeptide Gene				
v	Challenge test				
vi	Statistical analysis				
vii	Data analysis and result development				
viii	Draft dissertation preparation and presentation				
ix	Oral examination				
x	Submission of project and development of finding for publication				

Annex 4: Fish feed study proposal III (assessment of the agricultural waste products (rice bran and fish offal meals) availability from integrated fish and rice culture in ebonyi and kebbi states, nigeria and their apparent digestibility study in the diets of *Oreochromis niloticus* and *CCClarias gariepinus*)

A PROPOSAL

ON

ASSESSMENT OF THE AGRICULTURAL WASTE PRODUCTS (RICE BRAN AND FISH OFFAL MEALS) AVAILABILITY FROM INTEGRATED FISH AND RICE CULTURE IN EBONYI AND KEBBI STATES, NIGERIA AND THEIR APPARENT DIGESTIBILITY STUDY IN THE DIETS OF *Oreochromis niloticus* and *Clarias gariepinus*

**BY
GEORGINA FIYINFOLUWA, LERAMO
226848**

**FACULTY OF RENEWABLE NATURAL RESOURCES, AQUACULTURE AND
FISHERIES MANAGEMENT**

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CHAPTER ONE

1 INTRODUCTION

Background of the Study

Nigeria as one of the leading players in African aquaculture has been tapping the opportunities provided from aquaculture in meeting her food and nutrition security needs (Ajani, 2019). In addition, aquaculture has serves as a veritable source of employment and livelihood enhancement in Nigeria. With current efforts at intensifying the food production systems in Nigeria for improved livelihood and food and nutrition security, constraints to aquaculture production especially in area of fish feed development need to be well addressed. It is good to note that achieving the highest profit percentage with the lowest cost percentage is critical to the growth of any industry. In the aquaculture industry, the prices of certain feed ingredients are among the major challenges affecting the industry's success or failure (Omitoyin *et al.*, 2019; Falaye, 2013).

Rice bran and fish offal are two major agricultural by-products produced from integrated rice and fish farming system. Many tonnages of these produced without any clear measure of sustainable utilization of these products. For instance, rice brans are generally taking a low value something used without any refinement in livestock feed or at best in pond water fertilization. Fish offal meal (FOM) is a by-product from the fish processing industry, consisting of discarded parts (head, bones and internal organs) generally regarded as unfit for human consumption (Farahiyah *et al.*, 2015). These by-products are being wasted and dumped, at most are used in an unrefined manner for feeding fish something lead to water pollution and disease infestation. These by-products can be however be utilized to produce fish feed and indirectly helps towards a greener environment (Thongprajukaew *et al.*, 2015). A critical ingredient in aquafeed is Fishmeal (FM) as it's the costliest and imported in Nigeria. This is due to its highly palatable dietary protein source in aquafeed as it contains balanced amino acids, essential n-3 fatty acids, vitamins, and minerals. Efforts is now tailored towards finding a cost effective and cheaper local alternative to the fishmeal. The fish offal meal, a byproduct of fish processing activities could be a good alternative to fish meal (Farahiyah, *et al.*, 2015). Therefore, there is need to develop knowledge base on the best ways of utilizing fish offal meal as replacement for fishmeal in diets of two most commonly cultured fish species (*Oreochromis niloticus* and *Clarias gariepinus*) in Nigeria.

Rice bran is one of the main byproducts in the process of the rice milling. It is the outer brown layer of brown rice and is separated during the milling process. All over the world, >63 million tonnes of rice bran is produced each year (Webber *et al.*, 2014). Rice bran contains lipid (rice bran contains 15–20 percent oil), and high activities of lipases and lipoxygenases result in easy rancidity of the lipid due to lack of economic stabilization methods (Lakkakula *et al.*, 2004). To improve utilization of rice bran, development of feasible stabilization methods and the value-added processes of the nutrients and active compositions are necessary. Oil, proteins, and carbohydrates are the main nutrients in rice bran. There are also plenty of other nutrients and active compositions, such as nonstarch polysaccharides, phenolic acids, flavonoids, tocopherols, tocotrienols, γ -oryzanol, and phytic acid. Most of these compounds have antioxidant and anticancer activities (Goufo and Trindade, 2014, Henderson *et al.*, 2012). There are an abundance of nutrients in rice bran. In the fatty phase, the oil is most important. However, other nutritional ingredients such as γ -oryzanol, vitamins, and phenolics are also of great significance to human health (Goufo and Trindade, 2014). Rice bran is prone to rancidity, has a high phytate content, contains an enzyme inhibitor (trypsin inhibitor), and is high in fiber (Gallinger *et al.*, 2004).

Protein, which has been described as the most expensive and important component in fish diet (Ajani *et al.*, 2016), is mostly supplied by fishmeal. This is because of its excellent amino acid profile and high digestibility. However, its increasing cost and scarcity resulting from the shortfall in world fishmeal production has necessitated the search for alternative sources of protein in fish diet. Fishmeal has been replaced by single animal protein sources such as maggot meal (Adewolu 2001), poultry by-product meal (Turker *et al.*, 2005), black soldier fly pupae meal (St Hilaire *et al.*, 2007), poultry viscera meal (Usman *et al.*, 2007), and feather meal (Adewolu *et al.*, 2010) among others. None of these sources was shown to completely replace fishmeal, because of lack of one or more of the essential amino acids in them. The NRC (1993) reported lysine, methionine and isoleucine as the limiting amino acids in most animal protein sources used as a replacement for fishmeal. Clariid offal is a postharvest by-product generated in large quantities in most cities in Nigeria. This offal, like the poultry offal, constitute nuisance if not properly disposed (Salami, 1997). However, they are potential sources of animal protein. The utilization of fish offal in diet preparation will not only reduce the cost invested in feed, but also promote environmental sustainability. Mondal *et al.* (2011) reported that 50 percent replacement of fishmeal by fermented carp offal meal in the diet of Indian Minor Carp, resulted in a total positive benefit of 134 percent as compared to fish fed diet without fish offal. The

use of fish offal meal at 100 percent replacement level for fishmeal in the diet of *Oreochromis niloticus* was found to reduce the cost of feed and enhanced nutrient utilizations indicators such as specific growth rate, protein efficiency ratio and food conversion ratio (Farahiyah *et al.*, 2015).

Fish feed composition is a fundamental factor for estimating the productivity and quality of the final products. The fish meal was the main protein source of tilapia feeds, constituting up to 60 percent of fish diets. Tilapia feed must contain appropriate protein content and essential micronutrients (Sampantamit *et al.*, 2020). For example, feed demand has increased, and fish meal as a limited resource has also increased in price. At present, there are no inexpensive and quality feeds and suitable aquaculture production systems for tilapia culture. Moreover, the farmer's necessity balances the demand for a high-quality product with feed costs. Therefore, there is a crucial requirement to improve aquaculture production to meet the growing demand for fish through active aquaculture systems. The rice bran is currently the main ingredient of commercial fish feed. Due to increasing demand, the price of rice bran has recently risen. Consequently, many substitutes have been tested to reduce feed costs. Considerable research has focused on using animal or plant proteins to replace fish meal in formulated fish diets (Kubitza, 2019).

Many studies have been conducted using by-products from poultry (Mardhati *et al.*, 2010; Farahiyah *et al.*, 2014) and agro-industrial by products (Ng and Chong, 2002; Thongprajukaew *et al.*, 2015) in aquaculture feeding. Use of fisheries by-products including fish protein concentrate and hydrolysates, shrimp meal, krill meal and squid meal as partial or total replacement in tilapia diet has been reported earlier (El-Sayed, 1999). However, limited studies have been conducted on the use of fish by-products namely discarded parts of fish (USDA, 2010) as aquaculture feed.

In certain parts of the world the fish processing plant by-products are used and transformed into low-market value products such as animal feed, fishmeal and fertilizer Chalamaiah *et al.*, (2012).

However, in recent years, more studies have been done on transforming the by-products into more valuable products known as fish protein hydrolysates. In countries such as Norway, 97 percent of by-products from Norwegian aquaculture are being utilized. Fish offal meal (FOM) is a by-product from the fish processing industry, consisting of discarded parts (head, bones and internal organs) which are not fit for human consumption. This by-product, instead of being wasted and dumped, can be utilized to produce fish feed and indirectly helps towards a greener environment.

The nutrient content of fish offal meal as protein content 54.59 percent, lipid 13.56 percent, fibre 0.76 percent, with a gross energy value of 18.5 MJ/kg (Farahiyah *et al.*, 2015). Fish offal meal may be variable in its nutritional quality depending on the source of its raw materials and also the processing method employed.

Recent trends all over the world, point to a decline in landing from capture fisheries, an indicator that fish stocks have approached or even exceeded the point of maximum sustainable yield. Aquaculture, therefore, remains the only viable alternative for increasing fish production to meet the protein need of the people.

Catfishes of the family Claridae comprise the most commonly cultivated fishes in Nigeria. The growth of aquaculture in Nigeria now is largely being boosted by a steady rise in catfish culture. Inadequate availability of seed for stocking and feed used to be a major problem. Tremendous progress is now being made. The total value of the industry today is US\$800 from the value of fingerlings, feed, and farmed fish. Since the culture of *Clarias gariepinus* through hypophysation was initiated in Western Nigeria in 1973, the procedure has been widely practiced throughout Nigeria thus leading to an increase of farm-raised catfishes from the 80's to date. The favoured catfish species in Nigeria aquaculture include *C. gariepinus*, *Heterobranchus bidorsalis*, *Clarias* × *Heterobranchus* hybrid (Heteroclarias), and *Clarias nigrodigitatus*. *Heterobranchus* sp. is the more commonly cultured fish in the southeastern parts of Nigeria. African catfish is popular in the market and has great potentials to boost the rapidly growing Nigerian aquaculture. African catfish is an important aquaculture species that are cultured in various regions in the world. The top producing country is Nigeria followed by the Netherlands, Brazil, Hungary, Kenya, Syrian Arab Republic, South African, Cameroon, and Mali (FAO, 2016). Tilapia is likely to be the most important of all aquaculture fish in the 21st century (Fitzsimmons, 2000). Tilapia has certain favorable characteristics, which make its cultivation most tolerant to adverse environmental conditions. Also, it can survive at low dissolved oxygen, euryhaline, have relatively fast growth and efficient food conversion (Asad *et al.*, 2010). Tilapia is farmed in at least 85 countries, making it the most widely farmed finfish worldwide and second in volume only to carps and salmonid. Tilapia production has expanded dramatically in recent years, from about 1 million metric tonnes in 1998, to nearly 2.4 million tonnes in 2006, of which almost 2 million tonnes were contributed by a single species, the Nile tilapia (FAO, 2006). Because of their high protein content, large

size, rapid growth (6–7 months to grow to harvest size), and palatability, tilapia is the focus of major aquaculture efforts.

When *O. niloticus* is cultured in earthen ponds, it has shown to thrive on supplementary diets made from agro-byproducts augmented with fertilization based on its omnivorous feeding behaviour (Abdel-Tawwab *et al.*, 2007). Different plant based diets such as wheat bran (Liti *et al.*, 2005), maize, wheat and rice brans (Liti *et al.*, 2006), have all been studied with varying results on their effects on growth, survival and yield on *O. niloticus*. Residues such as husk, shell, back, etc., gotten from most agricultural products have been identified as waste and constitute environmental hazards. Oire and Ricketts (2013) reported that these wastes could be utilized effectively as feed ingredients for fish and livestock feeds. Most of these crop residues have been found to contain a good amount of fiber, ash, lipid, and protein (Obi, Kolo and Oire, 2011; Oire, and Ricketts, 2013). Nile tilapia (*Oreochromis niloticus*) is the second-largest cultured species in Nigeria and is widely cultivated in earthen/concrete ponds, cages, and reservoirs in Nigeria (Fagbenro, 2004).

Justification of the study

Fish farming is a growing food production system within Nigeria, greatly supported by the government through the economic stimulus programme. The aquaculture sub-sector holds many prospects for Nigeria in terms of meeting consumer demand for fish, livelihood for a large number of people who directly or indirectly engage in aquaculture, and its value chain. However, the aquaculture sub-sector is faced with some challenges which include inadequate capital, seed, and feed (Hiheglo, 2008; Kassam, 2014). Furthermore, the most singular challenge to the aquaculture business is the decreasing availability and rising cost of feed (Cobbina, 2010). Globally, the cost of conventional feed resources keeps on rising. A well-compounded agro-industrial-based diet for fish is therefore important for the development of sustainable aquaculture in Nigeria and would contribute to national efforts to improve cost efficiency, nutrition, and food security. Furthermore, the availability of these feed sources in the future is uncertain (Rao *et al.*, 2012; Makkar *et al.*, 2014). Fishmeal is the most singular essential protein ingredient needed by fish; however, it is the most expensive ingredient in formulated feed and thus increasing the cost of production (Nguyen *et al.*, 2009; Hussain *et al.*, 2011).

The African catfish and Nile tilapia were chosen for this study because they are the most commercially important aquaculture fish species in Nigeria; constituting over 80 percent of farmed fish (Kassam, 2014) and globally, it forms about 71 percent of the world farmed catfish and tilapia (FAO, 2012; Ng and Ramano, 2013). Fish feed production relies on the use of many imported feedstuffs and hence subject to global price fluctuations and availability. The consequent high cost of these imported fish feed makes production of fish from integrated fish farming unsustainable. The way out is to explore cheap, largely unutilized locally available agro-byproducts as fish feed thus enhance food security. Presently, there is very little information which assesses the availability and utilization of these feed resources in rural and peri-urban areas of Nigeria (Falaye, 1993). Feed resource assessment is important to diagnose the problems and suggest intervention measures to be taken by farmers and policy makers.

In addition, measurement of their digestibility is important in order to evaluate the nutritive value of these feed ingredients for formulating the diets. This study will therefore assess the bioavailability and evaluate nutritive value of agro-byproducts from integrated rice-fish farming in Ebonyi and Kebbi state, Nigeria.

Objectives of the Study

1. To assess the two major available feed resources (fish offals and rice bran) from agro-byproducts of integrated rice -fish farming system in Ebonyi and Kebbi state, Nigeria
2. To evaluate nutritive value of these feed resources (fish offals and rice bran) in the diets of *Clarias gariepinus*
3. Determine the nutritive value of these feed resources (fish offals and rice bran) in the diets of *Oreochromis niloticus*

CHAPTER TWO

LITERATURE REVIEW

Trends in Aquaculture

According to FAO (2020), Aquaculture, in recent time had been the alternative to capture fisheries contributing to global supply of fish. FAO (2020) defined Aquaculture as a form of agriculture that involves the propagation, cultivation and marketing of aquatic plants and animals in a more-or less controlled environment. Recent global growth is connected to reasons that include water sources, water quality, types and methods of aquaculture, production phases, market and trade. It also implies ownership of the stock being cultivated. Aquaculture is also defined as a diverse and important rural activity encompassing production and sale of fry and fingerlings and the raising of wild or artificially-reared fry and fingerlings in enclosed or semi-enclosed water bodies, such as ponds, rice fields and fish cages, for both sale and home consumption (Ajani, 2019).

The historic origin of aquaculture dated back to the eastern civilization before 4,000 years. European aquaculture began sometimes in the middle age and transformed the ‘art’ of Asian aquaculture into a science that studied spawning, pathology, and food web (Rabanal, 1988). There is a belief as it was commenced in China by fishermen who kept their surplus catch alive temporarily in baskets submerged in rivers or small bodies of water created by damming one side of a river bed, possibly due to the desires of an emperor to have a constant supply of fish. Another possibility is that aquaculture developed from ancient practices for trapping fish, with the operations steadily improving from trapping-holding to trapping holding-growing and finally into complete husbandry practices (Rabanal, 1988). For over 3,000 years, fish have been farmed in China, a country that continues to dominate the industry by producing 83 percent of the world's aquaculture output (Jian-Fang *et al.*, 2018). The other key producers include India (6 percent), Philippines (4 percent), Indonesia (3 percent), Republic of Korea (2 percent), and Bangladesh (1 percent), a list overwhelmingly concentrated in the developing world (FAO, 2020).

Aquaculture, in spite of being an age old practice that originated in China, its significance to the contribution of ‘human food basket’ is of only three to four decades old. According to Jian-Fang *et al.* (2018), aquaculture was mostly practiced as an art. It began to transform into a modern science in the second half of the 20th century.

Aquaculture in recent time has been developing, expanding and intensifying in almost all regions of the world. It is the fastest growing sector of the world food economy increasing by more than 10 percent per year and currently accounts for more than 30 percent of all fish consumed (FAO, 2020). This may be due to increase global population demand for aquatic food products, and decline in the production from capture fisheries. Sustaining fish supplies from capture fisheries, therefore, will not be able to meet the growing global demand for aquatic food. Aquaculture has the potential to make a significant contribution to this increasing demand for aquatic food in most regions of the world (FAO, 2020). Two key criteria, ownership of stock and deliberate intervention in the production cycle (husbandry), distinguish aquaculture from capture fisheries. Fish farming typically involves the enclosure of fish in a secure system under conditions in which they can thrive.

A number of different types of aquaculture practices exist; the implication there is that practices are diverse, ranging from single pond subsistence farming to highly intensive pump-ashore abalone farms (Roy, *et al.*, 2021). Among these practices, the simplest is the releasing of young organisms (hatchlings) into the wild to increase the natural population size. The next level of aquaculture contains the organisms in a pen or cage open to water and nutrients, however, that restrains them from leaving the site. The most complex aquaculture type is a closed system. In this situation, there is no exchange between the aquaculture facility and the environment.

Aquaculture, in Africa, is unevenly developed and relatively a slow growing phenomenon though in spite of the potentials. The total aquaculture production of Africa amounts to 2.31 million tonnes in 2018 (FAO, 2020). In 2018, Africa as a whole contributed 2.02 percent to world aquaculture fish production while Asia contributed 88.71 percent. According to Table 1, Egypt was the largest contributor to African aquaculture (71.1) followed by Nigeria (13.26 percent) (Adeleke *et al.*, 2020).

Table 1. Top 10 aquaculture producers in Africa in 2018

No.	Country	Production (metric tonnes)	Regional share (%)	Global share (%)
1	Egypt	1,561,457	71.10	1.90
2	Nigeria	291,233	13.26	0.35
3	Uganda	103,737	4.72	0.13
4	Ghana	76,630	3.49	0.09
5	Zambia	24,300	1.11	0.03
6	Tunisia	21,756	0.99	0.03
7	Kenya	15,124	0.69	0.02
8	Malawi	9014	0.41	0.01
9	Madagascar	7421	0.34	0.01
10	South Africa	6181	0.28	0.01

Source: Adapted from Adeleke *et al.* (2020).

Freshwater, brackish water and marine environments are used for aquaculture practices for various organisms. In 2018, over 89 percent of African aquaculture is done in inland waters, lakes, reservoirs and rivers (FAO, 2020). Brackish water aquaculture is done mainly in fish ponds located in coastal areas. Marine culture employs either fish cages or substrates for mollusks and seaweeds such as stakes, ropes, and rafts. Brackish-water aquaculture is practiced at a low level in Nigeria. There is some marine aquaculture, mainly in the Mediterranean and the Indian Oceans, while activities on the Atlantic coast have been very limited until now. Marine culture in Sub-Saharan Africa is restricted mainly to shrimp culture in Madagascar and Mozambique, Seychelles and abalone aquaculture in South Africa and also experimental shrimp (*Penaeus species*) culture in Kenya (FAO, 2020).

More than 220 species of finfish and shellfish are farmed in world; the range includes giant clams, which obtain most of their nutrients from symbiotic algae; mussels, which filter plankton; carps, which are mainly herbivorous; and salmon, which are carnivorous. The main species cultured includes finfish (96.2 percent), aquatic plants (1.8 percent), crustaceans and mollusks (0.6 percent). Freshwater finfish make up about 80 percent of total aquaculture production. Nile tilapia is the

dominating cultured species in Egypt. In 2020, tilapia production in Egypt accounted for over 60 percent of the total aquaculture production of the country (FAO, 2020). In recent years, however, aquaculture has been developed in other countries like Congo Democratic Republic, Nigeria, Madagascar, South Africa, Tanzania, Uganda, Zambia and Zimbabwe. In Nigeria, it is particularly catfish farming that has contributed to this development. In 2020, production of catfishes accounted for over 70 percent of the total Nigerian aquaculture production (FAO 2020). Although a large number of fish species are being cultured, the bulk of aquaculture and fisheries enhancement production is accounted for by a small number of species which have been introduced widely beyond their native ranges (FAO, 2020). Tilapia and carp species are a case in point, having been introduced throughout the tropics and accounting for about 80 percent of tropical inland aquaculture production. Like the common agricultural animal domesticates, these species have attributes that make them particularly attractive for raising in captivity (Bilio, 2008).

In the case of Sub-Saharan Africa, the main reasons for poor aquaculture development have been discussed in details by (Adeleke *et al.*, 2020; Ajani, 2019). These include poor aquaculture development policies, few fish farming traditions, lack of access to quality feed, lack of quantity of fingerlings, inadequate research and extension services, limited coordination between research and development sector and inaccessibility of capital.

The Contribution of Fish Intake to Improving Nutritional Status

The contribution of fish to human nutrition and its impact on health has been examined from different aspects in both developed and developing countries. In developed countries, researchers and consumers have been interested in the health benefits of polyunsaturated fatty acids (PUFAs), which lower blood pressure, reduce the risk of heart disease (Wang *et al.*, 2006), and possibly benefit infant growth and cognitive development (Koletzko *et al.*, 2007). On the other hand, in developing countries, under nutrition, micronutrient deficiencies, and HIV/AIDS are the main public health problems related to nutrition. The role of fish in contributing to nutritional needs has been highlighted in public health and fisheries literature, although the data are negligible compared to studies from developed countries. This focuses on the situation in developing countries and examines the potential role of fish in improving nutrition and combating health problems.

The fisheries and aquaculture sector is crucial to improving food security and human nutrition and has an increasingly important role in the fight against hunger, as articulated in the 2030 Agenda. People

have never consumed as much fish as they do today, with per capita global fish consumption has doubled since the 1960s. Trade-in fish products are also rising, particularly from and among developing countries (Thompson and Amoroso, 2014), and the demand is likely to continue to grow. The United Nations Decade of Action on Nutrition for 2016–2025, led by FAO and the World Health Organization (WHO), provides a critical opportunity to raise awareness about the role of fish and to ensure its mainstream incorporation into food security and nutrition policy. Food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Progress towards food security differs markedly within countries as well as across regions. It is estimated that in the period 2014–2016 more than one in nine people in the world suffer from hunger, while 13 percent of developing region populations were undernourished (FAO, IFAD, and WFP, 2015). In addition to providing nutrients, fish also contributes to the food and nutritional security of poor households in developing countries through livelihood diversification and income generation (Thompson and Amoroso, 2014; Béné *et al.*, 2015).

Fish Nutrition

Nutrition is one of the most important factors to consider in fish farming because it contributes to up to 50 percent of fish production costs (Omoruwou and Edema, 2011). Nowadays, it is necessary to increase fish production for satisfying the increasingly growing demand for protein. Therefore, fish breeding has been found necessary to increase fish production to make fish/protein available to the population. However, one of the major constraints facing aquaculture is feeding. The prominence of fish meal in the production of animal feeds cannot be disputed but constitute the highest cost, thereby making the price of the feed rise exponentially (Olaniyi and Salau, 2013). In formulating a nutritive diet for fish breeding, fish meal is used as the main dietary protein source because of its nutritional quality and palatability properties (Hardy and Tacon, 2002). It is, therefore, very crucial to find an alternative to replace a fish meal to reduce fish feeding cost and halieutics resources pressure (Monebi and Ugwumba, 2013).

Integrated fish farming

Integrated fish farming is the production, comprehensive use and management of aquaculture, agriculture and livestock. The principle of productive waste recycling makes it a very sustainable and environmentally friendly form of agriculture. This offers great opportunity for resource utilization

because waste or by products from one system is effectively utilized as inputs in the other system. These strategies could be regarded as alternatives for efficient utilization of available resources, waste recycling, energy saving, and maintenance of ecological balance and circulation (Osho, 2013).

Integrated fish farming is the combination of one or two agricultural practices with fish farming. Ayinla (2003) therefore observes that “Integrated fish farming is a diversified and coordinated way of farming with fish as main target”. In integrated fish farming, many organic wastes are re-used as component of fertilizer (Oribhabor and Ansa, 2006), composting substrate and compounded feed ingredient. The need to maximize food production at minimal production cost, concern for energy conservation (Mukherjee, 1995), competition for land and demographic increase appears to be driving this innovative approach of integrating fish farming system with either animal husbandry or crops. Though integrated fish farming system has long been practised in China and other Asian countries (Mukherjee, 1995), the concept is a recent development in Nigeria. Integrated farming activity leads to increased production per unit area at low input and better utilization of land. The use of livestock waste to fertilize fish ponds leads to greater fish yield as the manure provides active nutrients (NPK) that promotes the growth of plankton which is a natural food for fish (Ansa and Bashir, 2003). Some fish farmers build chicken pen over fish ponds where excess poultry droppings and chicken feed can be washed into the pond.

The effectiveness of any farming system can be compared with a similar practice but with varied inputs and its respective output. Integrated farming is considered to have taken its origin over 2,400 years from China (Hu B, 1989), and it involves a dynamic system of fish poly-culture (a systematic way of rearing fish), production of poultry, livestock and crops, and the “integrated” (combined) use of manure, grass and other crops as feeds and fertilizers (NACA, 1989). Integrated fish farming refers to the coordinated growing of crops as well as rearing of fish in the same plot. This could also involve the rearing of animals and fish. The most commonly known integrated systems of farming are expressed in terms of “Fish-Cum”; meaning “Fish and” others as the case may be (Shashank Singh, 1991).

In Nigeria, over 1.5 million hectares of swamp areas in Niger Delta as well as in the Niger flood plain between Yauri and Lokoja (Kebbi and Kogi States respectively) as well as the Benue flood plains show good prospects for rice-cum-fish culture. It could also be noted that potential land areas that would be put under rice production in Nigeria is estimated at about 4-6 million hectares. However,

only 40 percent (a total of about 2 million hectares) of these lands are currently cultivated (Millier J., 2003). A 2003 report on potentials of rice production in Nigeria revealed that virtually all the states in Nigeria have records of rice production. However, Adamawa, Benue, Borno, Kaduna, Kano, Niger and Taraba states (just about seven states out of the thirty-three) make up 50 percent of the total area of rice cultivation in the country. In Nigeria, Integrated farming is practised either as capture or traditional method or as a culture method (Millier J., 2003).

Culture Method

Most of the rice-cum-fish culture methods in Nigeria have been on experimental basis (Anil Kumar, 1990). The cost-benefit analysis of rice monoculture, fish monoculture and rice-cum-fish culture and that rice-cum-fish culture system gives an increase in rice yield and increase in revenue due to inclusion of fish in the culture system has been a means for justification. According to Yaro (2001), rice- cum-fish farming started in Nigeria at New Bussa on a farmer's plot at Karabande, New Bussa, where a farmer used the run-off from water running through the power generation turbines at Kainji dam to grow rice and fish twice in a year. They further noted that the trials, however, did not last long as the farmer lost his source of water in the later years (Okoye FC, 1998). This attempt paved way for a series of studies with National Cereals Research Institute (NCRI) at their Rice Experimental Farm, Badeggi (Niger State) and at Iddo and Gwagwalada farms of Abuja in the FCT through the Agricultural Development Projects (ADPs) and at the Dadin-Kowa (Gombe State) sub-station of the institution and their results were encouraging (Yaro I, 2001). Presently, conscious efforts by NSPFS to sensitize and create awareness of the rice-cum- fish Technology through farmer participatory demonstrations are in place. All the efforts are research work to demonstrate and show rural farmers the technical and economic viability of rice- cum-fish farming in Nigeria (Millier J., 2003).

Livestock-cum-fish

Different livestock production systems can be combined with fish production. The use of livestock waste to fertilize fish ponds leads to greater fish yield as the manure provides active nutrients (NPK) that promotes the growth of plankton which is a natural food for fish (Ansa and Bashir, 2003). This can reduce the cost of fish production considerably. Piggery pen may be built with flooring that allows waste to fall or swept directly into the pond. Pig excreta contain 70 percent digestible food and can therefore be utilized directly by fish as food. Pig fed with 16-17 percent protein mash produces

manure containing 1.36–2.0 percent nitrogen, 0.36–0.39 percent phosphorous, potash and other secondary nutrients. Therefore, pig manure acts as a good organic fertilizer which helps in producing phytoplankton and zooplankton in fish pond. A programme of integrated pig-fish farm totally eliminates the cost of application of extra fertilizer to fish pond and supplementary feeding to the cultured fish, thereby reducing the cost of fish production by as much as 50 – 60 percent. According to Fasakin *et al.* (2000) animal waste may contain variable quantities of essential nutrients required by fish including non-digested feed, metabolic excretory products and residues resulting from microbial synthesis. These can be utilized to replace reasonable part of foodstuff used in conventional fish feed thereby causing decrease in fish feed production cost. Research to determine the proximate composition of dried pig excreta and their use in graded levels in fish feed formulation must be encouraged.

Poultry-cum-fish

This is the commonest type of integrating fish farming systems. Some fish farmers build chicken pen over fish ponds where excess poultry droppings and chicken feed can be washed into the pond. Adewumi and Adewumi (1996) reported that a layer produced an average of 161 g of droppings/bird day. Typically, poultry droppings contain 2.1 percent nitrogen, 64.3 percent phosphorous, 5.31 percent calcium, and 2.11 percent magnesium (Odoemena, 2005). Since the digestive tract of a chicken is very short, measuring just six times its body length, some of the eaten foodstuffs are excreted by the chicken before being fully digested (Abdul-Mohsein and Mahmoud, 2015; Adewumi *et al.*, 2011). According to Akinwumi *et al.* (2011) only 80 percent (dry weight) of ration fed to fish is utilized and digested by the poultry, making 20 percent available to the fish in an integrated fish cum poultry culture system. Up to 10 percent of the food fed to chickens is lost but drop directly into the pond for fish consumption (Adewumi *et al.*, 2011). Two birds per square meter are recommended for this system; otherwise the water quality will deteriorate. Obasa *et al.* (2009) converted poultry manure to fish flesh by successfully replacing up to 60 percent of soybean meal with dried poultry manure in the diets of *C. gariepinus* advanced fry. Ducks are aquatic birds and they are well suited for integration for fish farming in terms of utilizing their droppings as supplementary ingredients. Though, they prey on the fishes and eat fry or fingerlings. About 100 to 200 ducks per hectare may be kept in the fish ponds providing each about 50 to 100 square metre for movement and feeding.

Rice-cum-fish

This is an old practice in many rice growing regions of the world including Nigeria. It involves raising fish in irrigated rice fields. Traditionally various species of wild fish which enter into the flooded rice field are trapped in the rice fields and grow along with the rice and are cropped at the time of harvesting the rice (Mukherjee, 1995). Over the past several decades, various species of fish are now intentionally introduced into rice fields. The operating principle is that waste product from one enterprise or system serves as input in another. Herbivorous species benefit from the system by feeding on weeds whose growth is stimulated by fertilizers applied to the rice field. *Clarias* spp catfishes, *Tilapia*, *Bonytongue* and *Heterotis* are suitable candidates for rice-cum-fish integrated system. Rahman *et al.* (2012) found that farmers in Bangladesh earned about 3 times higher profits from the rice-cum-fish culture than the rice-mono culture. The system ensures more economic utilization of land because fish and rice are obtained from the same piece of land. According to Ahmed *et al.* (2007) and Nhan *et al.* (2007) the benefits of integrating fish culture with rice farming includes improvement on diversification, intensification, productivity, profitability, and sustainability. Giap *et al.* (2005) and Dugan *et al.* (2006) suggest that “integrated rice-fish farming is ecologically sound because fish improve soil fertility by increasing the availability of nitrogen and phosphorus”. We suggest that this system should be encouraged in rice growing belts of Nigeria and it is envisaged as a panacea to rural poverty. Suitable fish species adapted to life in rice field condition have to be identified.

Fish that are used for these systems could withstand low water level e.g. Carp, *Clarias* etc. The advantage of this system is that fish recycle (to process used or waste material so that it can be used again) nutrients through feeding and depositing their faeces in the submerged soil and this act as fertilizer. Up-take of important nutrients like phosphorus and nitrogen by rice plants is significantly improved in comparison with rice monoculture.

Agricultural waste in Nigeria

The information on the types and availability of different organic wastes that might be utilized in fish culture are lacking in Nigeria. The increasing cost of fish feeds and competing demand for conventional feed compounding ingredients by both humans and livestock make this information imperative. One problem associated with organic waste utilization is inability of generators to sort them. Great effort and education would be needed to prevail on generators of waste to sort them or

categorize them. However, Nigeria produces large quantities of organic wastes in the form of agricultural and agro-industrial by products (Oladeji, 2011), which could serve as alternatives sources of conventional feeds. About 60 percent of wastes collected in Nigeria are organic waste (Ogwueleka, 2009). An estimated 0.34Kg of waste per person is generated daily in Nigeria (Shridar, 2007). A city with an estimated one million inhabitants produces 50,000 tonnes of effluent water and 2,000 tonnes of waste material daily (Deelstra, 1989). However, differences in waste production between the industrialised and developing countries have been observed. Kano, a cosmopolitan city in Nigeria has on the average; 1.4 million persons generate about 450 tonnes of wastes per day (Lewcock, 1994), São Paulo (13 million) approximately 10,000t per day. Therefore, for Nigeria with a population of about 170,000,000 people, about 3 million tonnes of waste generated daily is a huge resource of enormous economic importance. According to Parr *et al.* (1986), organic wastes can be grouped into 7; namely, (a) animal manures, (b) crop residues, (c) sewage sludge, (d) food processing wastes, (e) industrial organic wastes, (f) logging and wood manufacturing wastes, and (g) municipal refuse. Of these animal manure is of greatest importance in fish culture in Nigeria. Animal wastes include cow dung, poultry droppings, pig excreta and human excreta. Poultry and livestock industry in Nigeria generates about 932.5 metric tonnes of wastes produced annually (Adewumi *et al.*, 2011). The use of animal manure in feeding fish is widely reported in literature including Tilapias (*Sarotherodon mossambica*) (Stickney and Simmons, 1977), channel catfish (*Ictalurus punctatus*) (Fowler and Lock, 1974; Lu and Kevern, 1975), the African catfish (*Clarias gariepinus*) (Oladosu *et al.*, 1990) and gold fish (*Carassius auratus*) (Lu and Kevern, 1975). Generally, organic wastes can be categorized into crop residues, animal manure, agro food organic wastes and by-products, organic wastes produced by shops, restaurants and households and those from sewage. Organic wastes common in Nigeria include plant matter such as plantain leaves, unripe and ripe fruits, pawpaw leaves, wet chaff from fermented milled or ground maize, rice bran, fish waste such as fish offal meal, fish silage excreta and household waste among others (Oribhabor and Ansa, 2006).

According to Panda (2013) “Organic waste from food sources includes vegetables, fruits, grains, meat, fish, and dairy products and constitutes some 18 percent of the typical municipal organic waste stream. An average of 1 kg per person per day of organic waste is produced, originating from households, wholesalers and processors, restaurants, and institutions” Waste utilization denotes multiple use of a given waste matter or material. The use of various kinds of organic waste has been

integral part of sustainable agricultural practice in Nigeria (Ademoroti, 1996). Organic wastes are used as fertilizer and most times as composting substrates. According to Chopin *et al.* (2000), organic wastes have been used effectively as fertilizer for centuries for fish production in the far Eastern part of the world. Organic waste utilization is an ecologically safe and economically efficient method of waste management since it does not require spending money or disposal of waste in landfill that is likely to cause further pollution problems such as contaminating the ground water aquifer. Despite the substantial availability of organic wastes and potentials of utilizing them to produce other products, management of waste are not well developed or effectively organized in Nigeria. However, current approaches may offer practical and cost effective solution to the problems of waste disposal faced in developing countries (Oribhabor and Ansa, 2006). Improvement on organic waste management and utilization could enhance fish production, and reduce greenhouse gas emission.

Methods of utilization of organic waste

Organic wastes have many useful applications; however, current level of utilization in Nigeria is very low. Organic waste is used for feeding livestock and poultry, fish and composting. Food wastes from restaurants are fed to dogs and other pets. The plant matter is used to feed snails, livestock and as composting and mulching materials, while the livestock and poultry wastes are used as manure for crops and fertilization of fish ponds. The phytoplankton are consumed by zooplankton and ultimately fish (Aquaculture South Africa, 1999; Symoens, 1995). These organisms can supply 80 percent of nutrients required by fish for normal growth. Lack of proper food item mainly zooplankton causes poor survival of spawned fishes (fry) in nursery ponds. Some organic wastes are particularly used in making supplementary feeds including crab meal, blood meal and bone meal (Bekibele *et al.*, 1995). Livestock and poultry waste when appropriately treated represent valuable resource which can replace significant amount of inorganic fertilizer in fish production (Bowoan and Booji, 1998; Chan, 1998) and components of feed ingredients (Steffens, 1994). Organic waste is an asset in fish production. In China, about 40-50 kg of organic manure can produce 1 kg of fish (NACA, 1989) In developing countries such as Nigeria, organic wastes serve as both food and fertilizer in an integrated approach to fish farming. Organic wastes are also used in maggots' production which can be fed directly to fish or used in making supplementary feed. Indirectly, maggots can be used as rich source of animal protein to replace fishmeal. Livestock and human wastes can be harnessed for energy production. Methane gas captured from anaerobic digestion of organic waste generates electricity which could be used to power aquaculture facilities. It is a well-established fact that one of the

greatest challenges of successfully running and establishing re-circulatory aquaculture system in Nigeria like most developing nations where the energy supply is inefficient is limited or complete lack of adequate electricity to power such systems.

Fish waste utilization

Seafood industry wastes are a significant source of environmental contamination. Research has been carried out to convert these wastes into useful products (Kristinsson and Rasco 2000; Larsen *et al.*, 2000; Guerard *et al.*, 2001; Coello *et al.*, 2002). The most prominent current uses for fish and shrimp waste include: isolation of collagen and antioxidants for cosmetics, biogas, biodiesel, fertilizers, dietary applications (chitosan), food packaging (gelatine, chitosan), enzyme isolation (proteases), fish sauce, fishmeal and fish silage (Arvanitoyannis and Kassaveti, 2008). Fish waste- derived feed ingredients have good nutritive value and can be sufficient for animal feeding (Plascencia-Jatomea *et al.*, 2002; Arruda *et al.*, 2007; Al-Abri *et al.*, 2014; Goosen *et al.*, 2014).

Rice bran

Rice bran is the most important rice by-product. The bran fraction contains 14–18 percent oil. Rice bran that has not been defatted is a useful Binder for feed production. Defatted rice bran can be used at higher levels than ordinary rice bran. The oil has a marked softening effect on body fat and the butterfat in milk. With attention to the oil content, rice bran is a valuable feed for all classes of livestock. This is due to its particularly high lysine and methionine content Full-fat rice bran is often used as a basal diet for pigs. It is also fed directly to herbivorous fishes but in the case of catfish, it is better dried and grounded for inclusion in feed formulation (Osho, 2013).

Rice bran, which contributes about 10 percent of whole grain weight, is obtained during milling as a by- product. Every year production of rice bran is increasing as the production of paddy increases; the world rice bran production in 2014–2015 is about 23.80 million tonnes, and during 2015–2016, it is estimated to be 38.50 million tonnes (SEA, India). Interest in the field of rice bran is increasing due to its amazing nutrient content and its health benefits. Raw rice bran has characteristics of bland flavor, slightly bitter, and sweet in taste. Rice bran is nutritionally rich in protein, fiber, lipids, and antioxidants; it also contains anti-nutritional factors, such as trypsin inhibitor and lectins. Bran contains less soluble fiber and cholesterol-lowering and other health-enhancing properties. These include rice bran oil, plant sterols, tocopherols, oryzanol, and β -sitosterol (Sairam *et al.*, 2011). Although the nutritional and food potential of rice bran have been recognized, the consumption of

rice bran in human foods has been limited to a very small quantity due to quick rancidity of the bran. Stabilization process will inactivate the rancid -causing enzyme and anti-nutritional factors (Sharma *et al.*, 2004). As bran deteriorates due to the presence of lipase enzyme, the flavor of bran also will change to incipient rancid, musty, and sour. Physicochemical properties are very important to know how rice bran will behave during food processing. Physicochemical properties include physical properties (bulk density, color, particle size, water activity), functional properties (water absorption capacity, water solubility, and fat absorption), and chemical properties (nutritional content, antioxidant property). These properties will help to utilize maximum rice bran in food applications. In this chapter, the physicochemical properties of rice

Physical Properties

Raw rice bran has light tan or yellowish-brown color, and it varies according to the variety and the processing conditions. Most of the bran is stabilized before using commercially. In heat processing, the color of the bran changes to brown by losing its yellowish light color, and the bran stabilized by dry heat changes its color to brown and extruded bran dark brown (Garcia *et al.*, 2012). Upon heating, change in the color may be attributed to the formatting of Maillard reaction compounds and partly to the color of pigments of raw bran. Rice bran is composed of beta-carotene and lycopene, which is considered as carotenoid, which gave its reddish-brown appearance. Lycopene and beta-carotene are precursors of vitamin A, and both of them are antioxidants in food and biological system (Lamberts *et al.*, 2006). Carotenoids act as photoprotective agents by absorbing the potentially harmful light energy or by quenching singlet oxygen and trapping free peroxyl radicals.

Chemical Properties

Proximate and antioxidant properties of the bran. For any food material, we need to know the composition of what we are eating, and how much we are eating is very important for the betterment of health. As mentioned earlier bran is a rich source of protein, fiber, and fat and other nutrients, having unique antioxidants like oryzanol and tocopherol, which makes bran more interesting and passionate to incorporate into the foodstuff. The nutrients are distributed throughout the aleurone layer in varying quantity. The multibreak system will provide the resting time while milling, to avoid the reduction in the production of heat due to friction in polishing and also serve as a port to the separation of the bran which has been removed from the grain (Yilmaz, 2016).

The stabilization techniques change the properties of bran, and it retains the maximum amount of nutrients by inactivating the rancid-causing enzymes especially lipases. The proximate composition of different brans is given in Table 5.5. Oil quality will be improved by inactivating enzyme, increasing shelfstability of the oil by reducing FFA of the bran. The FFA of raw bran is more as compared to the stabilized one over the period of bran storage. The high amount of FFA indicates the bran rancid, and it is no longer able to add in the human diet. Rice bran contains 15–20 percent oil with three main fatty acids, i.e., palmitic acid (12–18 percent), oleic acid (40–50 percent), and linoleic acid (30–35 percent). The bran is a rich source of minerals also like iron, calcium, and phosphorus. As told earlier the bran has unique compounds like oryzanol and tocopherol (Orthoefer, 2005).

Uses of Rice

Bran Rice bran is finding enormous applications in food industries for increasing the nutritional quality of processed foods. Rice bran being high in dietary fiber and in view of its therapeutic potential, its addition can contribute to the development of value-added foods or functional foods that currently are in high demand. Supplementation of rice bran has been successfully carried in various foods like bread, cakes, noodles, pasta, and ice creams without significantly affecting the functional and textural properties. The primary use of rice bran as an additive in food is due to its high fiber content, which mildly promotes stool regularity. From a marketing point, the most commonly available rice bran-derived product is the oil (Prasad *et al.*, 2012). Rice bran oil has an impressive nutritional quality that makes it suitable for nutraceutical products. It also has the potential to be used as an additive to improve the storage stability in food due to its antioxidant properties. Rice bran oil has industrial potential, especially in the preparation of snack food due to the great stability of frying, whereas rice bran fiber can be used as both a nutritional and functional ingredient. Chicken coated with stabilized rice bran fiber tends to absorb less fat during frying, and the small amount of fat present naturally in rice bran fiber can act as a carrier of flavors (Mohd Esa *et al.*, 2013). The nutritional and functional properties of rice bran are suitable for baked products, namely, cookies, muffins, bread, crackers, pastries, and pancakes. The addition of rice bran into the wheat flour further increased the protein, lysine, and dietary fiber contents in bread and cookies. The color, flavor, protein extractability, and solubility of bran, as well as other properties, such as water and fat absorption and emulsifying and foaming capacity, have demonstrated improvements that further enlighten us on the potential use of bran in foods (Tuncel *et al.*, 2014). Due to its naturally occurring

enzymatic activity (lipases) and subsequent hydrolytic rancidity, rice bran needs to be stabilized to control these undesirable reactions. The antioxidants present in bran destroy the fungi, bacteria, and insect infestations, hence enhancing the shelf life of rice bran. The stabilized rice bran was successfully incorporated in up to 20 percent of the production of yeast bread because the hygroscopicity of the rice bran may improve its moisture retention in the baked products, while its ability to foam improved the air incorporation and leavening processes (Gul *et al.*, 2015). Defatted rice bran can be used to substitute for up to 10–20 percent of the wheat flour used for making cookies without adversely affecting the quality. Biscuits prepared with broken rice powder were highly acceptable in terms of taste and feel in the mouth. Besides oil, rice bran also has 10–15 percent protein content, consisting of 37 percent watersoluble, 31 percent salt-soluble, 2 percent alcohol-soluble, and 27 percent alkali-soluble storage proteins. Rice bran proteins have been found to be of high quality and application in food and pharmaceutical industries. Its unique properties, hypoallergenicity, and anticancer effects make it a superior cereal protein with a wide range of possible applications (Gul *et al.*, 2015; Tuncel *et al.*, 2014).

2.5.1 Nutrient content of rice bran (Batal and Dale, 2010)

- Dry matter: 91 percent
- Metabolizable energy: 2040 kcal/kg (1000 kcal/lb)
- Crude protein: 13.5 percent
 - Methionine: 0.17 percent
 - Cysteine: 0.10 percent
 - Lysine: 0.50 percent
 - Tryptophan: 0.10 percent
 - Threonine: 0.40 percent
- Crude fat: 5.9 percent
- Crude fiber: 13.0 percent
- Ash: 11.0 percent
 - Calcium: 0.10 percent
 - Total phosphorus: 1.70 percent
 - Non-phytate phosphorus: 0.24 percent

Rice Culture-Based Diet Ingredients

To reduce the dependency on fishmeal in the steadily increasing aquaculture sector and to provide affordable feeds for farmers, alternative plant-based feed ingredients have been a prioritized field of research for the last few decades. There have been evaluations of the value of “new” aquafeed ingredients mainly in terms of palatability, nutritional quality, digestibility, and their effects on growth performance and health of fish. The relatively slow aquaculture development in Ghana has been mainly attributed to a lack of nutritionally balanced, cost-effective feeds (especially for tilapia) using locally available, cheap, and unconventional resources (Agbo, 2008).

Criteria of Fish Species Selection for Integrated Fish Culture

Prominent features:

- i. Rapid growth potential
- ii. Having cellulose digesting enzymes
- iii. Ability to use natural food efficiently
- iv. Acceptance to artificial feed of low conversion value
- v. Hardy in nature
- vi. Accept all provided/available food
- vii. Enhances mineral bioavailability from food in the meal
- viii. High feed conversion ratio

The utilization of organic waste through direct supplementary feed

Fish farmers across Nigeria have access to different agricultural by – products depending on locality at little or no costs. These are used as feed supplements but do not provide complete fish nutrition. These wastes are always available in large quantities, to the point of constituting environmental nuisance. These feedstuffs can be used as direct supplementary feed. For example, a fish farmer in Nigeria has access to groundnut cake (byproduct of groundnut oil processing), palm kernel cake (by – product of oil processing), wheat bran, rice bran, maize bran, livestock blood, (blood meal), fish wastes like bones, heads and guts. These can be chopped up and fed as supplement to fish including livestock; moreover, they are inexpensive (David and Jonathan, 2007). Nonetheless, some of these materials is bagged and sold throughout the country for use as livestock feed.

Utilization of organic waste as a feed compounding ingredient

Some of the organic waste, for instance, groundnut cake, livestock blood, palm kernel cake, wheat bran, and maize bran can be utilized as feed compounding ingredient. The production of fish feed is one of the most profitable ways of utilizing these wastes. According to Adeniji *et al.* (2014). “The feed route represents the highest immediate cash return” because the demand for fish feed is high and stable and the technology involved is not sophisticated.

Significance of waste utilization in aquaculture

In the conventional fish culture system fish feed and fertilizer constitute major cost components of the total cost of producing either fish seeds or table size fishes for consumption. Consequently, high cost of feed in particular is a major constraint to intensive fish production in Nigeria and most developing nations of Africa where access to finance is not only difficult, but interest's rates on borrowed capital is very high. According to Falaye (1992), feed cost constitutes about 60 percent of production input. Olvera–Nova (1996) also reported that feed alone has been estimated to account for 40 – 70 percent cost of intensive aquaculture operations. Thus high operational input can be sharply reduced by judicious utilization of organic waste. It also reduces groundwater contamination and encourages integrated fish farming and upgrades the quality of fishery product through efficient resource utilization including labour, feed, land spaces, reduction in investment risk through diversification of income generation, family food source, conservation of the environment due to its waste management potentials.

Problems associated with organic waste utilization in fish culture One of the problems of organic waste; particularly livestock waste that have attracted attention is their potential as pollutants in water courses which results in the destruction of aquatic organisms, (University of Nevada, 2005). Organic wastes could also constitute nuisance through environmental pollution, principally the liquid component which seep into the aquifers (underground geological formation, which is the natural reservoir of portable groundwater that can supply wells or springs). According to Button and Tuner (2003), organic waste, like animal manure, is not only a source of valuable nutrients but can also a source of pollution and a threat to aquifers and surface water. Pollution of surface water may occur if poorly managed, especially by improper or inappropriate application of manure and receiving untreated effluent from ponds or streams, development of sludge banks in the ponds usually have high nutrient loading leading to deleterious effect of cyanobacterial bloom. According to Osuji *et al.*, (2003), cyanobacterial bloom is undesirable in aquatic food base, because they are poor producers of

oxygen in pond water with undesirable growth habit, some species produce unpleasant odour that impact undesirable flavour to the culture fish. Others produce compounds that are toxic to aquatic organisms. Eutrophication is a very critical phenomenon in surface waters that leads to depletion of dissolved oxygen in water. It arises as a result of excessive enrichment of water bodies from organic waste stream channeled into such eaters either on purpose or as a result of uncontrolled run offs from agricultural estates and effluent discharges. The putrefactive impacts generally associated with it are highly undesirable both in terms of distorted environmental aesthetics of the polluted water and poor organoleptic qualities of cultured fish species.

Management of problems associated with organic waste utilization in fish culture

One of the effects of heavy load of organic waste in fish culture facilities is the rapid depletion of dissolved oxygen. As a result, fish will swim to the surface to gulp air. When these signs are observed, fertilization must be immediately suspended and fresh water added to the pond to enhance the dissolved oxygen content of the water and by extension revive the fish. You may also drain water from the bottom of the pond where the oxygen levels are lowest. Another method is by keeping tracks of the phytoplankton, this can help in preventing oxygen depleted problems. There should be regular monitoring of the culture medium turbidity. Secchi – disc gives readings of the range of phytoplankton density that is present in a particular water body that is fertilized using organic wastes in particular. Reading from 20cm or below indicates that the phytoplankton or algal bloom content of the water is too high and would therefore be checked to avoid dissolved oxygen problems. The problems associated with poor dissolved oxygen in water occasioned by organic waste nutrient enrichment could be avoided by controlled and careful application of wastes into ponds, by filling porous bags with wastes and placing them in different points of the ponds (Oribhabor and Ansa, 2006) and routine secchi disc readings of such waters. Prompt application of such measures does not only ensure avoidance of fish mortality due to asphyxiation, but also ensures optimum growth and development of the cultured fish due to reduction of various diseases incidence burdens within the culture medium.

Waste management in integrated aquaculture

Integration of livestock and fish may have an important role under conditions of nutrient scarcity, such as most rural areas. Where nutrients are limited, re-use in fish culture could improve overall efficiency and support a more diversified food production system. In contrast, when nutrients are locally super-abundant, such as around livestock feedlots, integration can help treat the waste and

reduce their impact on the local environment. The increased risks of environmental pollution and spread of diseases makes waste management a very important concept in integrated aquaculture. In addition, integrated aquaculture is a practical way of turning waste to wealth in a sustainable and environmentally friendly manner. The principles of reduction, reuse and recycle must be adhered to in order to efficiently manage waste on an integrated fish farm. Appropriate management and technical details must be diligently put in place to reduce waste generation (Osho, 2013).

Digestibility in fish

Nutrient digestion

Digestion is the process by which food in the digestive tract is split into simpler compounds capable of passing through the intestinal wall to be absorbed in the blood stream. This task is performed primarily by the digestive enzymes. The digestive enzymes, which are secreted into the lumen of the alimentary canal, originate from the oesophageal, gastric, pyloric caecal and intestinal mucosa and from the pancreas (De Silva and Anderson, 1995).

Protein digestibility

The digestion coefficients for protein in protein-rich feedstuffs are usually in the range of 75 to 95 percent. Protein digestibility tends to be depressed as the concentration of dietary carbohydrates increases (NRC, 1993). Increased amounts of dietary lipids have produced increased protein digestibility (Takeuchi *et al.*, 1978). The negative effect of Crude Fibre has been reported for many fish species (Ferraris *et al.*, 1986; Wang *et al.*, 1985; Hilton *et al.*, 1983).

Lipid digestibility

Digestibility of lipid ranges from 85 to 95 percent in most fish species (NRC, 1993). Long-chain fatty acids exhibit a higher digestibility than short-chain fatty acids. Polyunsaturated fatty acids such as 20:5 or 22:6 acids are up to 100 percent digested by rainbow trout (Austreng *et al.*, 1980). The lipid digestibility coefficients of carp range between 53 and 90 percent (Kirchgessner *et al.*, 1986), and between 64 and 94 percent for channel catfish (Andrews *et al.*, 1978).

Carbohydrate digestibility

Warm-water fish are able to utilize much higher levels of dietary carbohydrates than coldwater or marine fish. This difference may be related to the relative amylase activity present in the digestive system of the various fish. Source, dietary level, and heat treatment affect the digestibility of carbohydrates in fish (Wilson, 1994). Channel catfish were found to digest over 70 percent of the

energy of raw corn starch. Cooked starch was 12.1 percent more digestible than raw starch when fed at 30 percent dietary level to channel catfish (Wilson, 1994).

Determination of digestibility

The nutritive value of a feedstuff is determined by its chemical composition and the availability of dietary components. The bioavailability of nutrients or energy in feedstuffs for fish may be defined mainly in terms of digestibility or in the case of energy, metabolizability. Digestibility describes the fraction of nutrient or energy in the ingested feedstuff that is not excreted in the faeces (NRC, 1993). Methods for determining digestibility involve either a direct or an indirect measurement of the amount of nutrient or energy ingested and subsequently excreted.

Indirect method

This method uses a non-digestible marker, such as chromic oxide (Cr_2O_3) included in the diet at a concentration of 0.5 to 1.0 percent. It is assumed that the amount of the marker in the feed and faeces remains constant throughout the experimental period and all ingested marker will appear in the faeces. The digestibility of the nutrient can be determined by assessing the difference between the feed and faecal concentration of the marker and the nutrient or energy. The indirect method has the advantages that it eliminates the need to quantitatively collect all of the excreta, and the test fish can eat voluntarily (NRC, 1993).

Direct method

The direct method involves measuring all the feed consumed by the fish and all of the fish excreta. The fish are force-fed a measured amount of feed and the excrements are subsequently collected and analyzed for their nutrient or energy content. The amounts of the nutrients or energy in the excrements are then subtracted from those in the feed to determine the amounts retained. This method allows for determining carbon and nitrogen balances as well as digestible energy and metabolizable energy values. Also, the problem of faecal leaching is eliminated because all of the water in the chamber is included in the analysis. However, this method is open to criticism because the fish are immobilized and so stressed that the utilization of the feed may be compromised (NRC, 1993).

Factors influencing digestibility

Digestion of food in fish depends on three main factors: (1) the ingested food and the extent to which it is susceptible to the effects of the digestive enzymes; (2) the activity of the digestive enzymes;

(3) the length of time the food is exposed to the action of the digestive enzymes. Each of these main factors is affected by a multitude of secondary factors, some of which are associated with the fish itself, such as fish species, age, size and physiological condition; some are associated with the environmental conditions, such as water temperature, and some are related to the food itself, i.e., its composition, particle size and amount eaten (Hepher, 1988).

CHAPTER THREE

3.0

MATERIALS AND METHODS

Study site

The study will be conducted in Kebbi State and Ebonyi State. Ebonyi State is located in South East Nigeria. The state lies in the humid tropical agroecological zone of Nigeria within Longitudes 7° 30' E and 8° 30' E and Latitudes 5° 40' N and 6° 45' N (Okereke 2012). It has a land area of 5,935 km² (ebonyistate.gov.ng, accessed 17/04/2017) with a projected population of 2,253,140 persons in 2016 using a growth rate of 3.5 percent (National Population Commission, 2016). The State shares boundaries on the North by Benue State, to the West by Enugu State, to the East by Cross River State and to the South by Imo and Abia State (ebonyistate.gov.ng, accessed 17/04/17). The climate of Ebonyi State is that of a humid tropical climatic region. The mean annual temperature stands at 28°C with an average rainfall of 1200mm – 2500mm [Ebonyi Agricultural Development Programme (EBADep, 2005). It has a luxuriant vegetation of tropical rainforest. The soil of Ebonyi State is basically clayey and loamy soil. The clayey swampy soil is suitable for rice farming. The state has three senatorial zones, the Abakaliki division make up Ebonyi North and Ebonyi Central senatorial zones, while the Afikpo division make up the Ebonyi South senatorial zone. Ebonyi is primarily an agricultural region, it is a leading producer of rice in Nigeria. Ikwo, Izzi and Ohaozara will be used for the integrated rice cum fish farming.



Figure 1: Map of Ebonyi State showing location of study area.

Kebbi State was created in 1991. It lies in Northwestern Nigeria with its capital in Benin Kebbi. The state is bordered by Sokoto State to the north and east, Niger State to the south, Dosso Region in the Republic of Niger to the northwest and the Republic of Benin to the west. Kebbi State has a total land area of 37,698,685 square kilometers (KSG, 2017). Based on projections from the 2006 census figure, the state is estimated to have a population of 4,629,880 (NPC, 2006; 2017). The state is divided into 21 Local Government Areas (LGAs) and the local government to be used for this study is Argungu, Jega and Ngasi. The state, with a mean temperature of 23°C and a maximum of about 40°C, is divided into two ecological zones: the Sudan savanna zone and the Southern Guinea zone in the northern and southern parts respectively. This climate peculiarity supports the production of a wide range of arable crops, roots and tubers, agro forestry, fisheries and livestock. The total cultivable land in the state consists of 320,000 hectares (ha) upland and 170,000 ha of fadama land, with high potential of surface water and extractable shallow aquifer to support medium- and small-scale irrigation activities (KSG, 2017). The state is traversed by two major rivers, namely River Niger and River Rima, as well as minor rivers of Zamfara, Ka and their tributaries. The vastness of agricultural land comprising upland, fadama and several wetland areas creates an opportunity for all-year-round agricultural activities. The major crops produced in Kebbi

State are rice, millet, sorghum, maize, groundnut, cotton, wheat, sugar cane, sweet potatoes and cassava. Sesame, soya beans, bambara nuts and acha are grown as minor crops while vegetables such as tomato, onion, garlic, pepper, carrot and cabbage are also produced. It creates an opportunity for all-year-round agricultural activities. The major crops produced in Kebbi State are rice, millet, sorghum, maize, groundnut, cotton, wheat, sugar cane, sweet potatoes and cassava. Sesame, soya beans, bambara nuts and acha are grown as minor crops while vegetables such as tomato, onion, garlic, pepper, carrot and cabbage are also produced.



Figure 2: Map of Kebbi showing the three locations

Data Collection

The study will be conducted in all the three senatorial districts in each of the two states. The survey on the agricultural wastes' resources will be conducted from the total samples of all the rice and fish processing factories/groups/households in each senatorial districts. Data will be collected on the rice bran and fish offal resources using a structured questionnaire, which will be completed through face-to-face interviews with the managers/heads of these facilities. All agricultural byproducts that are available from rice and fish processing will be captured and recorded and a literature review on their nutritive value shall be documented

The structured questionnaire will be administered keeping the objectives of the study in view. The questionnaire will be used to obtain primary data on the; agricultural waste utilization pattern, major feed resource, production of fish and crop residues; seasonality of feed resources in Ebonyi and Kebbi state, Nigeria.

Estimation of feed resources requirement

The quantity of feed dry matter (DM) will be obtained from crop residues per household farm/processing group/factories using the estimate from crop yield to crop residue ratio using conversion factors of FAO (1987).

Determination of proximate composition of rice bran and fish offal meal

The Association of Official Analytical Chemist (AOAC, 2006) methods of analyses will be used to analyze the following parameters: moisture content, crude protein content, crude fibre content, fat content, ash content and free nitrogen extract for the experimental diets.

Dry matter determination

Remove the free water from the sample to perform the procedure, the original sample is weighed, the weighed sample is placed in a 105⁰C oven for 12–17hours, the sample is reweighed. The dry matter and the moisture content will be calculated:

Percent Dry matter = Initial weight of the sample – final weight (after dried in 105⁰C oven for 12–17 hours)

Moisture Content Determination

A clean crucible will be dried to a constant weight in an air oven at 110 °C, cooled in a desiccators and weighed (W1). Two grams of finely pulverized sample was weighed into the crucible and then re-weighed (W2). The crucible and its content were dried in an oven to a constant weight (W3). The percentage moisture will be calculated thus:

$$\% \text{ Moisture} = \frac{W2 - W3}{W2 - W1} \times 100$$

Ash Content Determination

A porcelain crucible will be dried in an oven at 100 °C for 10 minutes, cooled in a desiccator and weighed (W1). Two grams of finely milled sample will be weighed (W2) into the previously weighed clean crucible which will be ignited in the muffle furnace at 550°C for 1 hour and cooled in a desiccator. The crucible and its content will then be transferred into the muffle furnace and the temperature will be gradually increased until it reached 550°C, the sample will be left in the furnace for 8 hours. The crucible containing the ash will be allowed to cool to 200 °C, the crucible will then be removed and cooled in a desiccator until constant weight is obtained (W3) (AOAC, 2006).

The ash content will be calculated as:

$$\% \text{ Ash} = \frac{W2 - W3}{W2 - W1} \times 100$$

Determination of Crude fibre

Two grams of the defatted sample will be weighed (W) into a dry 600cm³ round bottom flask. 100cm³ of (0.023M) sulphuric acid will be added and the mixture boiled under reflux for 30 minutes. The hot solution will quickly filter under suction. The insoluble matter will be washed several times with hot water until it will be acid free. This will be quantitatively transferred into the flask and 100cm³ of hot (0.312) sodium hydroxide solution will be added and the mixture boiled under reflux for 30 minutes and quickly filtered under suction. The insoluble residue will be washed with boiling water until it will be base free. It will be dried to constant weight in the oven set at 100 °C. This will then cool in a desiccator and be weighed. The weight residue will be incinerating in a muffle furnace at 550 °C for 2 hours, cooled in a desiccator and reweighed (AOAC, 2006).

The loss in weight will be (incineration) = W1-W2

Weight of original sample = W

$$\% \text{ Crude Fibre} = \frac{W_1 - W_2}{W} \times 100$$

Determination of crude lipid content

Four grams of sample will be weighed (W1) into an already weighed clean, dried 500ml round bottom flask containing few anti-bumping granules (W2), and 300ml of petroleum ether (40-60 °C) for the extraction will be poured into the flask fitted with soxhlet extraction unit. The round bottom flask and a condenser will be connected to the soxhlet extractor, and cold water circulation will be turned on. The heating mantle will be switched on and the heating rate adjusted until the solvent is refluxing at a steady rate. Extraction will be carried out for 6 hours. The solvent will recover and the oil will be dried in the oven at 70 °C for 1 hour. The round bottom flask and oil will be cooled and then weighed (W3) (AOAC, 2006). The fat content will then be expressed as follows:

$$\% \text{ Crude Lipid Content} = \frac{W2-W3}{W2-W1} \times 100$$

Determination of Crude Protein by Kjeldahl Method

Two grams of the sample will be weighed into 100 cm³ Kjeldahl digestion flask and about 1g of catalyst mixture (K₂SO₄ and CuSO₄) will be added to speed up the reaction. 25ml of concentrated sulphuric acid which will be added into the flask. The content in the Kjeldahl digestion flask will be heated slowly at first in Kjeldahl heating unit frothing subsides and then more vigorously with occasional rotation of the flask to ensure even digestion and avoid over heating of the content. The heating will continue until a clear solution is obtained. After cooling, the solution will be transferred into a 100 cm³ volumetric flask and diluted to mark with distilled water. Ten aliquot of the diluted solution or digest will be pipetted into Markham semi macro nitrogen steel and 10 cm³ of 4 percent sodium hydroxide solution will be added. The liberated ammonia will be trapped in a 100 cm³ conical flask containing 10 cm³ of 40 percent boric acid and 2 drops of methyl red indicator. Distillation will be done to allow continue, until pink colour of the indicator turned green. The

content of the conical flask will be titrated with 0.1M HCl, with the end point indicating by a change from green to pink colour. The volume of the acid used for the distillate as well as the blank will be noted (AOAC, 2006).

$$\% \text{ Nitrogen} = \frac{0.014 \times M \times (V_1 - V_0)}{\text{weight of test sample}} \times 100$$

Crude Protein = % Nitrogen (N₂) X 6.25

Where M= actual molarity of acid

V₁ = volume of HCl required for 10ml sample solution,

V₀ = volume of HCl required for the blank

Atomic weight of nitrogen = 0.014

Determination of Nitrogen free extracts (NFE)

The total carbohydrate content will be determined by different method. The sum of the percentage moisture, % ash, % crude lipid, % crude protein and % crude fibre was subtracted from 100.

NFE= 100- (crude protein + crude fibre + crude lipid + ash + moisture)

Determination of Gross energy

Gross energy was determined in an adiabatic bomb calorimeter (model PARR 1261). Faecal samples were burned in 100 mg pellets, and diets and test ingredients using pellets of about 700mg. The following caloric conversion factor was used: 1 cal= 4.184 joule.

Gross energy for feed, GE =(5.7× (g) protein + 9.4× (g) fat +4.1× (g) NFE + (g) fiber), The calculation for nitrogen free extract is: % NFE = 100 % – (% EE + % CP + % Ash + % CF).

CF= Crude Fiber, NFE- Nitrogen Free Energy

Experimental design and feeding trial

The experiment will be set up in the laboratory of the Department of Aquaculture and Fisheries Management, University of Ibadan.

Oreochromis niloticus ((n= 240; 15g) and *Clarias gariepinus* (n= 240; 8g) seeds to be used for the digestibility experiment will be sourced from fish breeding unit of Department of Aquaculture and Fisheries Management, University of Ibadan. The fishes will be acclimatized for 2 weeks in each of the two 5000-L outdoor tanks in the rearing facility of University of Ibadan fish farm. The level of dissolved oxygen was maintained by supplying air using air pump. During this time, they will be fed to apparent satiation on the basal diet to be used in subsequent digestibility twice daily. At the end of the second week, fish will be transferred from the outdoor tanks to the experimental tanks.

The experiment will be carried out at $25 \pm 1^{\circ}\text{C}$ in a constant temperature room under a 12 h light: 12 h dark regime. The experimental setup consisted of 12 glass aquaria, each of 70 L capacity. All aquaria were filled with 50 L dechlorinated water, and provided with continuous aeration.

Feed ingredients and Experimental Diets: The reference diet will be prepared to supply adequate levels of required nutrients for normal fish growth. Chromic oxide will be used as an inert marker and incorporated at 1 percent inclusion level in reference diet. The test diets will be composed of 70 percent reference diet and 30 percent of each of the respective feed ingredient (rice bran and fish offal) to be tested. The feed ingredients will be finely grounded to pass through 0.5 mm sieve size. All ingredients will be mixed in a mixer (laboratory blender) for 5-10 minutes and fish oil will be gradually added thereafter. Eighty-five (85 ml) of water will be slowly blended into the mix, resulting in suitably textured dough (Lovell, 1989). Pellets will be prepared using a hand pelleting machine and will be dried in an oven at 60°C . The dry product will be cut into pellets of 3 mm size.

Feeding Protocol and Sample Collection: The fingerlings of *C. gariepinus* and *O. niloticus* will be fed to apparent satiation on their prescribed diet twice daily (morning and afternoon). For each experimental diet three replicates will be assigned and, in each replicate, 20 fish each of *C. gariepinus* and *O. niloticus* (10 ± 0.01 ; 15 ± 0.01 g) will be randomly allocated to each of the aquaria

in 2 X 3 factorial arrangement in a completely randomized design. After the feeding session of three hours, the uneaten feed will be siphoned out from each tank (Falaye *et al.*, 2014). The tanks will be cleaned completely to remove the particles of diets and refilled with water. The feces will be collected twice a day. Care will be taken to avoid breaking the thin fecal strings in order to minimize nutrient leaching. Fecal material of each replicated treatment will be dried and stored for chemical analysis.

Table 1 - Percentage Ingredient Composition of the diet to be formulated for the digestibility experiment.

Ingredients	RFD (%)	RBMD (%)	FOMD (%)
Maize	20.0	14.0	14.0
Rice bran	0.0	30.0	0.0
GNC	15.0	10.5	10.5
Soya bean meal	34.5	24.15	24.15
Poultry Byproducts	5.00	3.5	3.5
Fish offal meal	0.00	0.0	30.0
Wheat Offal's	15.0	10.5	10.5
Starch	2.0	1.4	1.4
Chromic oxide	0.5	0.35	0.35
Fish oil	5.0	3.5	3.5
Salt	0.5	0.35	0.35
Pre-mix	0.5	0.35	0.35
Methionine	1.0	0.7	0.7
Lysine	1.0	0.7	0.7
TOTAL	100.00	100.00	100.00

RFD: Reference diet, RBM: Rice bran meal diet, FOMD Fish offal meal diet

The experiment will last for ten weeks for the collection of 4-5 g fecal material of each replicate. The feces will be dried in oven, ground and then analyze for the estimation of nutrient values.

Analytical procedure for determination of digestibility indices

Chromic oxide in the diets and faeces will be analysed (Furukawa and Tsukahara, 1966 as cited in Falaye, 2014). Chromic oxide levels, both in diets and faeces, will be determined by first digesting the organic matter with nitric acid and then oxidizing Cr₂O₃ to Cr₂O₇ with perchloric acid followed by the colorimetric analysis of the dichromate ion with diphenylcarbazide (Furukawa and Tsukahara, 1966).

Percentage chromic oxide content will be calculated as follows:

Weight of Chromic oxide in sample = Absorbance – 0.0032/0.2089

% Chromic oxide = weight of chromic oxide x 100

Weight of sample

Calculation of Apparent Digestibility Coefficient

The apparent digestibility coefficients (ADCs) of protein, lipid and energy for the test ingredients will be calculated as follows (Cho and Slinger, 1979 cited in Falaye *et al.*, 2014).

ADC_{nutrient} =

$$100 - 100 \left\{ \left(\frac{\text{CrO}_3 \text{ in diet (\%)}}{\text{CrO}_3 \text{ in faeces (\%)}} \right) \times \left(\frac{\text{Nutrient in faeces}}{\text{Nutrient in diet}} \right) \right\}$$

The ADC of the test ingredients will be calculated according to the following equation (De Silva and Aderson 1995):

$$\text{ADCn} = \frac{\{\text{ADCTD} - (\text{Y} \times \text{ADCRD})\}}{\text{Z}}$$

Where

ADCn = Apparent digestibility coefficient of nutrient in test ingredient,

ADCTD = Apparent digestibility coefficient in test diet

ADCRD = Apparent digestibility coefficient in reference diet,

Y = the reference diet proportion;

Z = the test diet proportion.

Statistical analysis

Data to be collected will be analyzed using Analysis of Variance (ANOVA) with significant differences between means separated by Tukey test using the SAS Version 9.3.

Materials Needed for the experiment

a) Materials

The following materials will be required to carry out the experiment as per schedule:

- 12 glass aquaria of $0.8 \times 0.4 \times 0.4$ m each;
- a total of 240 seeds each of *Clarias gariepinus* and *Oreochromis niloticus* of about 10 and 15 g each, respectively.
- Water quality test kits

b) Equipment

- Electrical balance;
- Thermostatically controlled oven;
- Kjeldahl apparatus;
- Muffle furnace;
- Porcelain crucibles;
- Desiccator;
- Soxhelt apparatus;
- Heating units for fibre determinations;

- Glassware (volumetric flask, Erlenmeyer, beakers, burettes, pipettes);
- Homogenizer.

c) Chemicals

Different kinds of chemicals will be required to carry out the proposed experiment for complete proximate analysis, such as H₂SO₄, HCl, Na₂S₂O₃, NaOH, isopropanol, boric acid, mercury oxide, potassium sulphate, Ba(OH)₂, and some others.

d) Personnel requirement

- 10 Enumerators -
- Technician/laboratory attendant: 2 man/months;

These personnel will work under the direct supervision of the project co-investigator throughout the study period. Their availability should be ascertained to the project investigator as per work schedule.

Plan activities

	Activities	Year 1 (Quarterly)				Year 2 (Quarterly)			
		1	2	3	4	1	2	3	4
1	Resources survey Objective 1								
i	Baseline survey of project communities and sites								
ii	Reliability test and validation of questionnaires								
iii	Training of Enumerators and Field survey								
iv	Feed resources sampling and feed chemical analysis								
v	Data analysis and result development								
2.	Digestibility study (Rice Bran and fish offal) Objective 2 and 3								
i	Fish procurement and acclimatization								
ii	Diet formulation and Experimental setup								
iii	Water quality tests and chemical analysis of the feed and fish								
iv	Nutritional data collection (weight measurement, feed intake etc)								
v	Data analysis and Result development								

	Activities	Year 1 (Quarterly)				Year 2 (Quarterly)			
vi	Draft Dissertation Preparation and Presentation								
vii	Oral examination								
viii	Submission of thesis and development of finding for dissemination								

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Appendix 1

QUESTIONNAIRE ON ASSESSMENT OF AGRICULTURAL WASTE PRODUCTS (RICE BRAN AND FISH OFFAL MEALS) RESOURCES SURVEY

Questionnaire ID:	STATE	LGA	Town/Village	Date: dd/mm/yyyy
Section A: LOCATION GENERAL INFORMATION				
Location Name:				
Latitude:		Longitude:		
Time Interview Starts:		Time Interview Ends:		

Section A: General Information

S/N	Item	Options	Response
1	Name of the factory/ Processing group/Communities		
2	Staff strength or members (no.) in the factory/ Processing group/Communities		
3	Gender of the respondent	[1] = Male [0] = Female	
4	Product Processed	[0]= Rice and Fish [1] = Rice [2] = Fish	
5	Production Capacity	[1] ----- kg per Annum -Rice [2] -----kg per Annum- Fish	
6	Seasonal Production	Dry season [1] ----- kg per Annum -Rice [2] -----kg per Annum- Fish Wet season [1] ----- kg per Annum -Rice [2] -----kg per Annum- Fish	
7	Total Years of Experience in Processing		

8	Did you receive any formal agricultural training in product processing?	[1] = Yes [0] = No	
9	If yes to Q. 8, where did you obtain the training?	[1] = Extension agents [2] = Technical school [3] = School of agriculture [4] = Others (please specify)	
10	Primary occupation (for processing group/Communities/household only)	[1]= Fish Farming [2] = Civil Servants [3] = Artisans [4] = Farming [5] = Others (please specify)	
11	Sources of raw material for processing	[1]= Directly from farmers [2] = Personal farm produce [3] = Produce marketers [4] = Suppliers from neighboring communities [5] = Others (please specify)	
12	Distance to Input Market (km)		

WASTE PRODUCTS FROM RICE AND FISH PROCESSING

13. Kindly list five wastes products from rice processing

- i. _____
- ii. _____
- iii. _____
- iv. _____
- v. _____

14. Kindly list five wastes products from fish processing

- i. _____
- ii. _____
- iii. _____
- iv. _____
- v. _____

15. When are the rice processed by-products most available?

- i. _____ wet season [] dry season [] all round season []
- ii. _____ wet season [] dry season [] all round season []
- iii. _____ wet season [] dry season [] all round season []
- iv. _____ wet season [] dry season [] all round season []
- v. _____ wet season [] dry season [] all round season []

16. When are the rice processed by-products most available?

- i. ----- wet season [] dry season [] all round season []
- ii. ----- wet season [] dry season [] all round season []
- iii. ----- wet season [] dry season [] all round season []
- iv. ----- wet season [] dry season [] all round season []
- v. ----- wet season [] dry season [] all round season []

17. What are the five listed rice processed by-products used for?

- i. -----
- ii. -----
- iii. -----
- iv. -----
- v. -----

18. What are the five listed raw fish processed by-products used for?

- i. -----
- ii. -----
- iii. -----
- iv. -----
- v. -----

19. What is the preferred fish Species for processing? *Clarias gariepinus* [] *Oreochromis niloticus* [] others []

20. What is the most used rice residue?

21. What is the most used fish residues

22. What is the quantity of five listed raw rice processed by-products produced (Kg)?

- i ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- ii ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- iii----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- iv ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- v ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000

23. What is the quantity of five listed raw rice processed by-products produced (Kg)?

- i ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- ii ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- iii----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- iv ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000
- v ----- <1000 [] 1000-10000 [] 10000- 100000 [] >100000

24. What are the management strategies for these agricultural wastes generated during processing?

24. What are the challenges faced in production of processed fish or rice production?

Annex 5: Integrated rice-fish study proposal (Performance evaluation, and the biological and technical efficiency of integrated rice-fish farming in Kebbi and Ebonyi states, Nigeria)

Introduction

Rice production is central to the Nigeria's agricultural sector. Majority of farmers depend both directly and indirectly on the success of the rice crop each year. As a staple food, rice production is a big factor in the national effort to promote food and nutritional security. Kebbi and Ebonyi are two frontline states in rice production in Nigeria, however, these two states despite increase productivity in recent times are still grappling with problem of low yield per hectare in line with global standards. This is coupled with the high rate of food and nutrition insecurity in these states. Hence, there is a need to develop innovation that will address the issues of food and nutritional insecurity in these states while further intensifying, enhancing and optimizing the productivity of farmers in these states.

Rice-fish farming could play an important role in the fight against hunger, malnutrition and food insecurity due to the rich source of essential macro and micronutrients (protein, fat (poly-unsaturated fatty acids), vitamin (including, vitamin A, vitamin B2, vitamin B6 and others), minerals (iron, calcium, iodine, potassium and other minerals) that could be derived and utilized by human body from the food products harvested from the farming system Integrated rice-fish farming is a unique system that not only offers intensification and diversification but also increase the system productivity and profitability in a sustainable way (Freed *et al.*, 2020). Integrated rice and fish farming has also been identified as means of diversifying the food productivity and smallholder farmer profitability; and improved resilience from having an alternative source of livelihood.

For sustainable development of this new innovative approach toward raising the productivity of rice and fish production in Ebonyi and Kebbi, Nigeria, it is important to document the performance of the two different integrated farming systems examined by analyzing the comparative biological productivity and nutrient cycling in rice-fish farming (African catfish) under the two different ecological arrangements in Nigeria. In addition, there is need to identify the core factors influencing rice and fish production in these two states.

In this study, the basic biological production processes related to the alternative food chains created through various nutrient flow in the integrated fish and rice farming will be examined. Hence, primary production, planktonic, benthic bacterial production, fish production and bioenergetics efficiencies will be study. In addition, this study will try to identify core influencing factors of technical efficiency in order to explain the possibilities of increasing productivity and profitability of rice and fish by increasing efficiency at the selected sites in the two states. This is expected to lead to identification of

various technical progress policy that would be recommended to help decision makers increase the rice and fish productivity in Nigeria.

Objectives

1. To examine the physico-chemical environment and natural food resources variability in integrated rice and fish farming under different ecological zones in Ebonyi and Kebbi states
2. To carry out comparative analysis of the basic biological production processes, primary production, planktonic and benthic bacterial production of integrated rice and fish farming under different ecological zones in Ebonyi and Kebbi states
3. To assess the fish production and bioenergetic efficiencies of the two integrated rice and fish farming systems in Ebonyi and Kebbi states
4. To measure the technical efficiency and establish core factors affecting integrated rice and fish production in Ebonyi and Kebbi states

Proposed study methods

The study areas will be three selected adaptive research sites in each of the three communities selected in the two project states (Ebonyi and Kebbi states).

After stocking the adaptive research plots with rice seedling and fish seeds in each of the project states, data shall be collected biweekly on the biological parameters during the production span of rice and fish system in each of the adaptive research plots. These production cycle shall be replicated thrice during which, data shall be collected on the following biological and technical indices from the adaptive research plots established in these six sites:

Biological indices

Growth parameters of rice like plant height and total tillers hill^{-1} and yield parameters such as, number of effective tillers hill^{-1} , number of grains/panicle, number of sterile spikelets/panicle, 1000-grain weight and grain, straw and biological yields and harvest index will be recorded. Fish growth shall be recorded in terms of initial individual fingerling length, initial individual fingerling weight, final individual fingerling length, final individual fingerling weight, length gain (percent), weight gain (percent), length gain/day, weight gain/day and survival rate (percent).

Water quality parameters such as the temperature, pH, dissolved oxygen and free ammonia in each of the six rice and fish production systems will be monitored and measured. The basic biological production processes, primary production, planktonic and benthic bacterial production shall be measured simultaneously in each of the six adaptive research plots. Gross primary production will be estimated by the direct measurement of diurnal changes of oxygen concentrations with three measuring points and the McConnell (1962) equation will be used to calculate primary production. Planktonic

and benthic bacterial production will be measured by the ^3H -thymidine (Moriarty, 1986) and the dark ^{14}C -bicarbonate incorporation method (Overbeck, 1979), and occasionally by the ^{35}S -sulphate uptake method (Jordan and Likens, 1980).

Fish production and bioenergetic efficiencies shall be calculated using the approach of Pekar and Olah (1992).

Technical efficiency

The Cobb-Douglas functional form of the stochastic frontier will be used to determine the technical efficiency of rice and fish farmers in study areas. This will be used to measure the technical efficiency and the relationship between factor-product in rice -fish value chain in these areas. Therefore, the stochastic frontier model to be adopted will be the one used by Battese and Coelli (1995).

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Aquatic biodiversity under integrated rice and fish culture system and their food provision contribution in Kebbi states

Assessment of aquatic flora and fauna diversity under integrated rice and fish culture system and their food production services in Ebonyi states

Introduction

Part of the major action areas of sustainable development challenges are food and nutrition security and biodiversity conservation. However, there are reversible relationship between aforementioned objectives of sustainable development goals as the sustainable management of biodiversity can support food and nutrition security (Johns *et al.*, 2013}. A good narration could be obtained from rice and fish production system with focus on helping poor rural communities achieving profitable intensification of their production systems while also meeting their food and nutrition needs.

Various studies have shown that despite the increase productivity and improve nutrition and food security that come with practice of integrated rice and fish brings, many rural rice and fish producing families in developing countries cannot obtain a sufficient variety of nutritious food in their local markets or are simply too poor to purchase it. The traditional systems of meeting these need is by exploring aquatic biodiversity present in the rice field ecosystem as support base for local and/or domestic food security by supplying essential nutrients that are not adequately found in the diet (Wittman *et al.*, 2017). In this landscape, wild aquatic species not only contribute to biodiversity, but are collected and consumed, thereby contributing to local food and nutrition security.

Ebonyi and Kebbi states, Nigeria are blessed necessary natural structures for promotion of rice and fish farming. These states are currently major traditional rice producers in Nigeria however with increasing growth and high poverty landscape in these regions, innovative process such as rice and fish farming is regarded as some of the process of intensification of productivity, nutrition and food security; and increase income level. The impact of this innovative on the equally important aquatic flora and fauna diversity in the wetland suitable for rice and fish production needs to be properly documented and well understood should they could be properly integrated into national agricultural systems that embrace the concepts of an ecosystem approach and the important role of agro-biodiversity for people and the environment (Halwart, 2006).

This study will therefore look at status and seasonal dynamics of aquatic biodiversity in rice ecosystems in the Ebonyi and Kebbi state

Objectives

1. Identify major planktons, flora and fauna species in the rice and fish fields of Ebonyi and Kebbi states

2. Determine the diversity and interrelation among aquatic species in the rice and fish fields of Ebonyi and Kebbi states
3. Assess the seasonal variation in aquatic biodiversity in relation to location, water quality, soil nutrients and fish/rice stocking density

Methods

The study areas will be three selected adaptive research sites in each of the three communities selected in the two project states (Ebonyi and Kebbi states).

This study shall be carried out for 18 months covering dry and wet seasons. These periods shall cover all the phases of rice cropping seasons. The series of activities to be included are a preliminary participatory rural appraisal, participatory rural appraisal, data collection, data verification and analysis and reporting.

The preliminary participatory rural appraisal and participatory rural appraisal shall follow the methods of Nawawi *et al.* (2014) to obtain preliminary information and get some insight on present knowledge about the aquatic organisms in rice-fish based ecosystem, including the way they are collected, specific sites in the paddy field ecosystem where they are commonly found, and in the way they are used by the people

Field study

The field study shall cover two dry and two wet seasons where all the rice- fish growing phases will be captured. Sampling shall be done bimonthly. During these periods, fields near the trial farms will be selected to sample the aquatic fauna. Biophysical field variables such as the mean water depth in the field, the average soil pH, soil organic carbon, soil (total) nitrogen content, the average rice height, and rice densities, mean weight gain of fish and stocking density will be measured and these will be evaluated in statistical models as predictors of faunal variables following the procedures of Cochard *et al.* (2014). Also plankton samples of 0.5 l of water will be collected at a depth of ~3 cm from 8 random locations in each field using a plankton net. The plankton shall be identified to species level following the approach of Chittipun *et al.* (2007). Also fish and invertebrates' samples shall be collected following method as described by Cochard *et al.* (2014) while aquatic flora collection and identification will follow the methods of British Columbia Ministry of Forests (1996). In addition, taxonomy-related work, particularly verification of scientific name of aquatic organisms will be based on the manual on taxonomy and fish identification (Olasebikan and Raji, 1998), online resources such as fishbase, reptile database amphibian web, Wikipedia, etc.,

Aquatic biodiversity shall be measured using the following indices (Magurran 2003):

1. Shannon–Wiener index ($A2e/A3e$) = $-\sum [n_i/N * \ln(n_i/N)]$
2. Shannon evenness index ($A2h/A3h$) = Shannon–Wiener index/ S

where n_i denotes the organism counts of species i in the sample, N the total count of arthropods sampled, and S the number of species in the sample.

Statistical analyses will be carried out using IBM SPSS Statistics (version 25). To present the changing effect of total water quality and nutrients inputs on rice and fish yields second order polynomial curves were fitted

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Performance evaluation of integrated fish rice farming system in Kebbi and Ebonyi state

Introduction

The rice – fish integration system is a means of intensification of crop and fish production with concomitant effects enhancing of principles of water conservation, soil improvement and biological control and plays an important role in sustainable production. Fish culture in paddy fields can turn and recycle the available material and energy into fish production, accelerate the productivity of paddy fields and enhance the production potential of traditional farming practice (Caguan *et al.*, 2000) with increased net income (Halwart, 1998).

Farm diversification and efficient market access system of the diversified farm produce from integrated rice –fish system in Nigeria, have been reported as means of increasing the food and nutrition security in the target communities, and provide economic opportunities for youths and women in Nigeria (Ajani *et al.* 2020). However, to ensure these benefits, this farming system need to be implemented and sustained through efficient management systems in major states (Ebonyi and Kebbi) in Nigeria, that are highly ecologically suitable for rice culture. However, despite these multiple benefits of rice-fish integration, adoption and application of this innovation may be challenged and slow down. These are due to the facts that several technical and production constraints need to be resolved and documented, these include yield gap between experimental and field models; and development of suitable design. Study of the mechanism of rice – fish culture and the relationship among rice, fish and other factors such as soil, water and fertilization in the rice field will give a critical information needed in development of operational manuals for rice –fish culture.

This study will therefore attempt to evaluate rice – fish integration system in two different rice farming ecological landscapes (Ebonyi and Kebbi) in Nigeria with special reference to stocking density, water use efficiency and growth performance of cultured species and system's rice equivalent yield.

Objectives

1. To evaluate the production efficiency of combining rice and fish culture in these two different ecological systems in relation to fish and crop growth performance,
2. To assess the water use efficiency, water quality and soil chemistry of rice and fish field under these different ecological systems in Ebonyi and Kebbi.

Methods

The study areas will be three selected adaptive research sites in each of the three communities selected in the two project states (Ebonyi and Kebbi states) representing upland and lowland rice farming systems.

After stocking the adaptive research plots with rice seedling and fish seeds in each of the project states, data shall be collected biweekly on the biological parameters during the production span of rice and

fish system in each of the adaptive research plots. These production cycle shall be replicated thrice during which, data shall be collected on the following biological:

Phyto- and zooplankton estimation, biweekly observations on water quality (temperature, pH, DO, total alkalinity, transparency, total suspended solids, dissolved organic matter, nitrite, nitrate, ammonia, phosphate, etc.) and monthly observations on soil quality (pH, available N,P and organic carbon) will be recorded using standard methods (APHA, 1989). Field test instruments will be used to analyze in situ water pH meter, soil pH and dissolved oxygen (YSI-55, USA). The sediment, nitrogen and potassium losses through runoff from rice field will be estimated as per guidelines given by Mishra *et al.* (1997).

Growth parameters of rice like plant height and total tillers hill⁻¹ and yield parameters such as, number of effective tillers hill⁻¹, number of grains/panicle, number of sterile spikelets/panicle, 1000-grain weight and grain, straw and biological yields and harvest index will be recorded.

Fish growth will be recorded in terms of initial individual fingerling length, initial individual fingerling weight, final individual fingerling length, final individual fingerling weight, length gain (percent), weight gain (percent), length gain/day, weight gain/day Specific growth rate, Feed Conversion Ratio, Protein efficiency ratio and survival rate (percent). After harvesting, fish yield will be recorded and expressed as kg ha⁻¹. These shall be evaluated following the approach of Njoti *et al.* (2020).

The water use efficiency and water productivity will be calculated using methods of Abdul-Rahman *et al.* (2011). Consumptive water use (CWU) from the integrated system will be due mainly to rice irrigation, which will be calculated as m³/m². Water use efficiency will be calculated as: WUE kg/m³=total yield/CWU, and will be used to evaluate efficiency for fish and rice integration. Finally, water productivity WP \$/m³=WUE kg/m³×price\$/kg, will be calculated for fish and rice using an estimated fair market value for fish and rice

Statistical Analysis

Statistical analysis will be carried out through one-way ANOVA. Means will be compared using Duncan's Multiple Range Test to find the difference at 5 percent ($p < 0.05$) levels (Duncan, 1955).

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Assessment of the agricultural waste products (rice bran and fish offal meals) availability from integrated fish and rice culture in Ebonyi and Kebbi states, Nigeria and their apparent digestibility study in the diets of *Clarias gariepinus*

Assessment of the agricultural waste products (rice bran and fish offal meals) availability from integrated fish and rice culture in Ebonyi and Kebbi states, Nigeria and their apparent digestibility study in the diets of *Oreochromis niloticus*

Introduction

Rice bran and fish offal are two major agricultural by-products produced from integrated rice and fish farming system. Many tonnage of these produced without any clear measure of sustainable utilization of these products. For instance, rice brans are generally taking a low value something used without any refinement in livestock feed or at best in pond water fertilization. Fish offal meal (FOM) is a by-product from the fish processing industry, consisting of discarded parts (head, bones and internal organs) generally regarded as unfit for human consumption (Farahiyah *et al.*, 2015). These by-products are being wasted and dumped, at most are used in an unrefined manner for feeding fish something lead to water pollution and disease infestation. These by-products can be however be utilized to produce fish feed and indirectly helps towards a greener environment (Thongprajukaew *et al.*, 2015).

Fish feed production relies on the use of many imported feedstuffs and hence subject to global price fluctuations and availability. The consequent high cost of these imported fish feed make production of fish from integrated fish farming unsustainable. The way out is to explore cheap, largely unutilized locally available agro-byproducts as fish feed thus enhance food security. Presently, there is very little information which asses the availability and utilization of these feed resources in rural and peri-urban areas of Nigeria (Falaye, 1993). Feed resource assessment is important to diagnose the problems and suggest intervention measures to be taken by farmers and policy makers. In addition measurement of their digestibility is important in order to evaluate the nutritive value of these feed ingredients for formulating the diets.

This study will therefore assess the bioavailability and evaluate nutritive value of agro-byproducts from integrated rice -fish farming in Nigeria

Objectives

1. To assess the two major available feed resources from agro-byproducts of integrated rice -fish farming system in Ebonyi and Kebbi state, Nigeria
2. To evaluate nutritive value of these feed resources in the diets of *Oreochromis nilotcus* and *Clarias gariepinus*

Methods

Primary data (household size, land utilization pattern, major feed resource, production of grain and crop residues, household herd size; seasonality of feed resources) will be obtained from the questionnaire survey during the course of the study. The primary data will be collected using semi-structured questionnaire.

The quantity of feed dry matter (DM) obtained from crop residues per household farm will be estimated from crop yield to crop residue ratio using conversion factors of FAO (1987).

Samples will be analysed for proximate composition (dry matter, crude protein, crude fibre, ash, gross energy and lipid) following the method of AOAC (AOAC, 2002). Crude protein will be analysed for its N content (as g N x 6.25) using the Kjeldahl and amino acids concentration will be determined using Amino Acid Analyzer. The reference diet will be formulated to meet the nutrient requirement of tilapia and *C. gariepinus* (NRC, 1993) where fishmeal will be used as the sole protein supply. The experimental diet will consist of 70 percent of the reference diet and 30 percent of the test ingredient (Rice bran and Fish offal meals FOM) by weight (Lim *et al.*, 2005). Digestibility of Rice bran and FOM will be performed using an indirect method where chromic oxide will be used as an inert marker and will be incorporated at 0.5 percent in the experimental diet. Ten each of tilapia fish and African catfish (mean weight of 20 g) will be placed in each in 70-L aquarium glass tank. The experiment will consist of two treatments (reference diet and experimental diet) each, with 3 replicates of each treatment conducted using 6 tanks each for the two studied ingredients. These experimental arrangements will be repeated twice representing each of the test fishes.

The fishes will be fed once a day till satiation in the morning at 0900. All uneaten feeds will be collected an hour after feeding. After 4-5 h feeding, fresh feces will be collected. Feces will be also collected every morning before feeding time. The collection of feces will be done through siphoning the feces into a plankton net and samples will be collected gently to avoid any damage or break off of the fecal strand which could cause leaching of nutrients. Samples of the feces will be pooled for the 10 days of the fecal collection and dried in the oven. Analyses of chromium, protein, amino acids and energy content of the feed and feces will be performed to determine the digestibility values. The digestibility calculation of dry matter, protein, carbohydrate and lipid will follow the formulae of Lim *et al.*, (2005):

ADC of nutrient (%) = $100 - 100 \times [(\% \text{ Cr diet} / \text{Cr feces}) \times (\% \text{ fecal nutrient} / \% \text{ diet nutrient})]$

ADC of test ingredient (%) = $\text{ADC of test diet} + [(0.7/0.3) \times (\% \text{ nutrient in reference diet} / \% \text{ nutrient in test ingredient}) \times (\text{ADC of test diet} - \text{ADC of reference diet})]$

Where ADC: Apparent Digestibility Coefficient

Data to be collected will be analysed using Analysis of Variance (ANOVA) with significant differences between means separated by Tukey test using the SAS Version 9.3.

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Growth performance, Immunological Responses, the Antioxidant Status and gene expression of *Clarias gariepinus* to varying inclusion levels of agro-industrial waste products (fish offal meals) from integrated fish and rice culture based diets

Growth performance, Immunological Responses, the Antioxidant Status and gene expression of *Oreochromis niloticus* to varying inclusion levels of agro-industrial waste products (fish offal meals FOM) from integrated fish and rice culture based diets

Introduction

Nigeria as one of the leading players in African aquaculture has been tapping the opportunities provided from aquaculture in meeting her food and nutrition security needs (Ajani, 2019). In addition, aquaculture have serves as a veritable source of employment and livelihood enhancement in Nigeria. With current efforts at intensifying the food production systems in Nigeria for improved livelihood and food and nutrition security, constraints to aquaculture production especially in area of fish feed development need to be well addressed. It worthy to note that achieving the highest profit percentage with the lowest cost percentage is critical to the growth of any industry. In the aquaculture industry, the prices of certain feed ingredients are among the major challenges affecting the industry's success or failure (Omitoyin *et al.*, 2019; Falaye, 2013).

A critical ingredient in aquafeed is Fishmeal (FM) as its the costliest and imported in Nigeria. This is due to its highly palatable dietary protein source in aquafeed as it contains balanced amino acids, essential n-3 fatty acids, vitamins, and minerals. Efforts is now tailored towards finding a cost effective and cheaper local alternative to the FM. The FOM, a byproduct of fish processing activities could be a good alternative to fish meal (Farahiyah, *et al.*, 2015). Therefore, there is need to develop knowledge base on the best ways of utilizing FOM as replacement for FM in diets of two most commonly cultured fish species (*Oreochromis niloticus* and *Clarias gariepinus*) in Nigeria.

Objectives

1. To determine the growth performance and nutrient utilization of *O. niloticus* and *C. gariepinus* fed varying inclusion levels of FOM as replacement for FM
2. Assessing its effects on immune status, antioxidant activity, pituitary adenylate cyclase-activating polypeptide (*PACAP*) gene expression, and disease resistance of of *O. niloticus* and *C. gariepinus*

Fish

A total of 150 each of *C. gariepinus* (mean weight 50g) and *O. niloticus* (mean weight 25.00g) will be procured from fish hatchery of University of Ibadan, Nigeria. To allow acclimation to the laboratory conditions, the two fish species will be randomly distributed in each of the two glass aquaria

(80 × 40 × 30 cm, water capacity 60 L) for 14 days and will be fed twice daily with a basal diet (to satiation).

Experimental Diet and Design

Five isocaloric and isonitrogenous each (32 percent crude protein for African catfish and 25 percent for Nile tilapia) diets will be formulated to replace 0 (control), 30, 50, 70 and 100 percent FM with FOM in the diets of African catfish and Nile Tilapia, respectively. These will form the experimental diets (AC0, AC30, AC50, AC70 and AC100 - African catfish and NT0, NT30, NT50, NT70 and NT100 - Nile Tilapia, respectively). The experimental diets will be supplemented with methionine and lysine (as synthetic amino acids) and dicalcium phosphate to maintain the dietary requirements. The proximate amino acid and chemical analyses will be performed according to the Association of Official Agricultural Chemists.

The fishes will be randomly distributed into 5 groups each, and each group will be in triplicate (30 fish/group with 10 fish/replicate each). The fish will be fed manually to satiation twice daily (08:00 and 15:00. Water parameters will be kept at standard values throughout the experimental period. One-fourth of the volume of aquarium water will be exchanged daily.

Blood Sample Collection

Blood samples will be collected for serum separation after 15 and 30 days each for the two experiments. At each point in time, 9 fish/group each will be collected and anesthetized with 100 mg/l of benzocaine. Blood samples will be collected from caudal vessels without anticoagulant for the separation of serum (centrifugation at 3000 rpm/15 min at 4 °C). The serum samples will be held at -20 °C until analysis. For the analysis of total and differential leukocyte counts, the blood samples (9 fish/group each) will be collected after 30 days using EDTA-rinsed 1-mL syringes. After completing the blood sampling collection, the 9 fish each will be dissected to obtain samples for gene expression analysis.

Leukogram, Serum Total Protein, and Electrophoretic Fraction Analysis

Total and differential leukocyte counts will be examined by using Automated Hematology Analyzer. Serum total protein (g/dL) and albumin (g/dL) will be estimated using standard procedure and total globulin will be calculated by subtracting albumin from total protein. Serum protein will be analyzed according to Laemmli (1970).

Serum Oxidant/Antioxidant Status

Serum levels of total antioxidant capacity (TAC) (mM/L), superoxide dismutase (SOD) (U/mL), catalase activity (CAT) (U/L), and reduced glutathione (GPx) (mmol/L) will be estimated using commercial ELISA test kits.

Nonspecific Immune Analysis

Nonspecific immune parameters such as serum alternative complement pathway C3 activity will be examined using a C3 kit. A C3 standard curve will be created using the same process. C3 levels will be determined according to Thomas (1998). For serum nitric oxide (NO) ($\mu\text{mol/L}$), will be measured using a spectrophotometric method (Rajaraman *et al.*, 1998).

Expression of Pituitary Adenylate Cyclase-Activating Polypeptide Gene

The same 9 fish each for each of the two studied fish species will be used for the collection of blood samples at the end of the experiment (30 days) will be euthanized using a benzocaine solution overdose (250 mg/L) and used for gene expression analysis to collect spleen samples. The total RNA will be extracted using the QIAamp RNeasy Mini Kit according to the manufacturer's protocol. Complementary DNA will be synthesized following the manufacturer's instructions. Quantitative real-time polymerase chain reaction (PCR) analysis will be performed with the SYBR green PCR master mix (Step One Plus, Applied Biosystem, Waltham, MA, USA). The amplification efficiency of the used primer will be determined by standard curve assay.

Challenge Test

Seven fish/replicate each for the two experimental fish species (21 fish/group) will be challenged by intraperitoneal injection with pathogenic [*Aeromonas aeruginosa*](#). The fish will be observed for 15 days, and their clinical signs, postmortem lesions, and daily mortality will be recorded. For confirmation, the pathogenic bacterial strain will be re-isolated from the liver, kidney, and intestine of dead fish.

Statistical Analysis

One-way ANOVA (SPSS version 61.0) will be performed to detect the difference among experimental groups within the same period. The group means will be analyzed with Duncan's multiple range tests and presented as the mean $\pm$ SE. Two-way ANOVA (Statistica software, version 8) will be used to determine the interaction between the levels of FM substitution with FOM and the feeding duration.

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Annex 6: Socio-economics study proposal (integrated rice-fish culture technology adoption, profitability and food security in Nigeria)

Background

1.0.Introduction

Integrated farming involves a dynamic system of fish poly-culture (a systematic way of rearing fish), production of poultry, livestock, and crops, and the “integration” (combination) use of manure, grass and other crops as feeds and fertilizers (Ujoh, Ujoh and Kile, 2016). It is a system of producing fish in combination with other agricultural/livestock farming operations centered on the fish pond. Integrated Agriculture Aquaculture (IAA) systems are characterized by low dependence on external inputs, and a strong focus on recycling resources within the farm, to preserve the availability of nutrients inside the farm through recycling while improving production to increase incomes and sustain the livelihoods of the farming households (Mutiaka, Dochain, Rollin, Mafwila, Bindelle, Unit and Tech, 2019). The systems culture is based on the rice-fish Symbiosis system, where both rice and fish are grown in the same ecosystem and both are benefitted by creating a beneficial relationship. The principle has evolved through the years and major technological advances have allowed for the commercialization of the practice (Lu and Li, 2016). The integrated agriculture-aquaculture (IAA) is a simultaneously synchronized linkage between two or more human activity systems, one or more of which is aquaculture, directly on-site, or indirectly through off-site needs and opportunities, or both (Phong, Udo, van Mensvoort, Bosma, QuangTri, Nhan, and van der, 2003).

The integrated rice-fish culture system is old age, an ancient practice employed by numerous farmers in Asia, (Food and Agricultural Organization, FAO, 2019), first described by Liu Xun in China, and practiced in Thailand more than 200 years ago and in Japan and Indonesia. By the mid-1900s, rice-fish culture has been in 28 countries on six continents of Africa, Asia, Australia, Europe, North America, and South America. Common carp was then the most popular fish species, followed by the Mozambique tilapia *Oreochromis mossambicus* (Halwart and Gupta, 2004). The system has recorded numerous successes in all the continents where it has been successfully adopted (FAO, 2019 and Halwart, Bartley, Bueno, Innes-Taylor, 2014)

In Nigeria, rice is cultivated in nearly all the agro-ecological zones, the yield and share of cultivated farmland have been historically very low (Onyekwena, 2016). Nigeria is the biggest producer of rice in Africa, with production progressively growing at 4 million tonnes per year in 2019 (FAO, 2020). It is the fourth largest cereal crop grown in the country behind sorghum, millet, and maize. Fish constitutes about 41 percent of the total animal protein intake by the average Nigerian hence; its great demand in Nigeria is inevitable. At present, Nigeria requires about 2.66 million metric tonnes of fish

annually to satisfy the dietary requirement of its citizens of about (200million) population, regrettably, the total aggregate domestic fish supply from all sources (capture and culture fisheries) is less than 0.7 million metric tonnes per annum (Aquaculture in Nigeria Factsheet, 2019). The Rice-fish culture was introduced in eight states in the Federal Republic of Nigeria and this has helped to double rice and tilapia production at some of the demonstration sites (FAO, 2019). It is estimated that about 4-6 million hectares of land areas would be cultivated under rice-fish culture technology, these covered over 1.5 million hectares of swamp areas in Niger Delta as well as in the Niger flood plain between Yauri in Kebbi state and Lokoja, Kogi States as well as the Benue flood plains suitable for rice-fish culture (Osuji, 2010).

The rice-fish culture system has been found to be helpful in increase the productivity of water, land, and associated resources while contributing to increased food fish production (food security) and expanding of aquaculture value chain (Halwart, *et al.*, 2014) with little impact on the environment. The system provides nutrients for rice and the added cultures of planktons that are used to feed the fish (Lu and Li, 2016), and has led to a decrease in manual labour since fish act as weed and pest controllers as well as fertilizers. Although the net return percentages vary between countries and within countries, integrated Rice-Fish fields do have a positive impact on net returns. The net returns are over 50 percent greater than normal rice monocultures in Bangladesh and China, a testimony on the profitability of the system (Halwart and Gupta, 2004). This has led to increases in farmers' income by 23 percent, and contributes largely to better nutrition and supply of essential nutrients through fish protein (Koseki, 2014). In addition, the use of Rice-Fish systems has increased rice yields and in turn in productivity. Studies have shown that it allowed an increase in productivity from 6.7 tonnes to 7.5 tonnes of rice and simultaneously also from 0.75 tonnes to 2.25 tonnes of fish, through nutrient recycling created by the fish (FAO, 2019). Aside increase in profitability and productivity of the farmers, rice-fish farming culture has been identified to play an important role in the fight against hunger, malnutrition and food insecurity. Essential macro and micronutrients (protein, fat (poly-unsaturated fatty acids), vitamin (including, vitamin A, vitamin B2, vitamin B6, and others), minerals (iron, calcium, iodine, potassium, and other minerals) that could be derived and utilized by the human body from the food products harvested from the rice-fish culture farming system (FAO, 2018; FAO, 2017b; Thilsted *et al.*, 2014).

1.2. Statement of Research Problem

Food insecurity remains a great challenge in Nigeria, with the country having a 38kcal/person/day food energy deficit and an indication of a critical shortage of nutrient-rich foods (Federal Ministry of Agriculture and Rural Development, FMARD, 2016). The country has been consistently bedeviling with myriads of problems such as the dual problem of undernourishment and undernutrition (FAO,

2019), coupled with various degrees of social unrest, youth unemployment, and vulnerability of women of children to various degrees of challenges. Nigeria has been facing a food crisis problem with a majority of the poor population having limited access to adequate quantity and quality of food. Since food security reflects the stability of the food supply and availability of and access to food, these in turn, affect the amount of food consumed and have implications on the health of the entire population (Fasoyiro and Taiwo, 2010). In such a situation many rural households continue to face serious food and nutrition security challenges, thus, there is an urgent need for safe, healthy, and sustainable agriculture practices which can be adopted to ensure more food production. Recently, Nigeria overtook India as the country with the highest number of people living in extreme poverty globally, with about 102.4 million Nigerians living in extreme poverty (World Data Lab, 2018; 2020). The precarious state of acute food insecurity in Nigeria is an occasion by chronic and hidden hunger, extreme poverty, corruption, conflict events (insurgency in the North East), and unfavorable climate change. These reflected in various communities in the forms of stunting, wasting, and underweight in children, and under-employment for youths, gender disparity in resource use and allocation, and limited access to food (USAID, 2018). In addition, the Global Hunger Index in Nigeria falls into the *serious category* of 27.9 scores (Global Hunger Index (GHI), 2019), an indication of acute hunger in the country.

The poverty scenario in the country is a pointer or an indication that the country might not attain the Sustainable Development Goals (SDG) 2 target of ending all forms of hunger, achieve food security and improved nutrition, and promote sustainable agriculture by 2030 is a call for concern. The proportion of undernourished increased from 9.3 percent in 2000 to 13.4 percent while a slight decrease was reported in stunting from 39.7 percent in 2000 to 37 percent in 2019 (Ayinde, Akinbode and Otekunrin, 2020). Chronic and seasonal food insecurity has been continuous in every part of Nigeria, these have been exacerbated by persistent high food prices, the impact of conflict related to insurgency (especially in the Northeast), armed banditry, communal, pastoralist/farmer crisis, kidnapping, cattle rustling, and climate change (FEWS NET, 2020).

In Nigeria, rice is cultivated in nearly all the agro-ecological zones, but the yield and share of cultivated farmland have been historically very low (Onyekwena, 2016). Despite Nigeria being the current largest rice-producing and consuming country in Africa, nevertheless, its rice consumption demand still exceeds its local production supply (Erhie *et al.*, 2018; Kubo and Purevdorj, 2004; Imolehin and Wada, 2000), the problem of demand-gap of rice production has been persistence. KPMG (2019) reported that just 57 percent of the rice consumed in Nigeria annually is locally produced, leading to a supply deficit of about 43 percent. The report further shows that while the annual rice production trends in Nigeria increased from 4.7million MT in 2017 to 4.9million MT in 2019, the consumption trends

increased from 6.7million MT in 2017 to almost 8million MT in 2019. Also, the (Aquaculture in Nigeria Fact Sheet, 2019), reported that the country still requires about 2.66 million metric tonnes of fish annually to satisfy the dietary requirement of its citizens of about a 200million population. Unfortunately, the total aggregate domestic fish supply from all sources (capture and culture fisheries) is less than 0.7 million metric tonnes per annum despite fish constitutes about 41 percent of the total animal protein intake by the average Nigerian hence; its great demand in Nigeria is inevitable.

Exploring the nexus between food production and consumption through an integrated agriculture-aquaculture program can lead to more production and sustained farming system. The farming system has the potential to support the nutritional needs of vulnerable communities in a sustainable way when properly managed. Explicitly, the system is a form mutual symbiosis, where both benefit from growing in the same ecosystem. The rice provides the fish with a shelter as well as providing shade and, in turn, reducing water temperature, which creates a more suitable environment. Rice plantations decrease the concentrations of ammonia in the water as well as the total of Nitrogen present in the soil, contributing also to the improvement of environmental conditions. Fish also benefit from the herbivorous insects that can be found on the rice by having a supplementary food source (Xie, Hu, Tang, Wu, Li, Yuan and Chen, 2011). Also, the farmer's income is improved by the integrated rice cultures with an estimated increase of over 23 percent, and it also benefits the farmer's nutrition requirement and diet by integrating fish protein (Koseki, 2014). Following from the above the following research questions will guide this study

1.3. Research Questions

1. What is the food security and profitability level of the adopters and non-adopters of integrated Rice-Fish technology in the study area?
2. What are the determinants of participation and extent of adoption of integrated Rice-Fish technology among farmers in Nigeria?
3. What are the effects of integrated Rice-Fish culture technology on the profitability and food security status of the farmers?
4. What is the impact of the adoption of integrated Rice-Fish culture technology on profitability and food security status of the farmers?

1.4. Research Objectives

The general objective of this study is to examine the impact of integrated Rice-Fish technology adoption, profitability, and food security in Nigeria. The following are the specific objectives:

1. Determine the food security and profitability level of the adopters and non-adopters of integrated Rice-Fish culture technology.

2. Examine the determinants of participation and extent of adoption of integrated Rice-Fish culture technology among the farmers in Nigeria.
3. Isolate the effect of integrated Rice-Fish culture technology on profitability and food security status of the farmers in Nigeria.
4. Estimate the impact of adoption of integrated Rice-Fish culture technology on profitability and food security status of the farmers

1.5. Justification for the Study

More empirical information are still needed in order tackle the menace of food and nutrition insecurity in Nigeria. Although there are dearth of information on the state of the debilitating food insecurity in the country. Numerous factors ranging from poverty, lack of nutrition education, knowledge gap in agriculture/aquaculture practices and inefficient market system among others are justification for widespread of food insecurity and nutrition challenges across Nigerian states (FMARD, 2016). These challenges are manifest in the rural communities in the forms of stunting, wasting and underweight in children, under-employment for youths, gender disparity in resource use and allocation, and limited access to food (USAID, 2018). The Rice-Fish culture system has the potential to support the nutritional needs of vulnerable communities sustainably if properly managed. FAO, (2017c) reported that the introduction of fish into a rice-farming system will not only result in a shift from a cropping system, but will also be a shift to a more balanced diet consumption for the farming communities. Hence, this study will add to body of literatures on the rice-fish technology in Nigeria, though there are few studies on the effects of the technology on the profitability and food security of the farmers.

On methodology, the proposed study area Kebbi and Ebonyi represents two different rice-producing agro-ecological zones in the country, and are ranked very high among Nigerian states that are food and nutrition insecure (USAID, 2018). Poverty rate in the two states stands at 50.2 percent and 79.76 percent for Kebbi and Ebonyi States respectively (Statista, 2019). Consequently, the two states could benefit immensely from the introduction of fish to their rice fields, and they will eventually contribute to food security through increased yield and profitability, increased access to food through own consumption and open up market for sales. Furthermore, most of empirical studies on Integrated Aquaculture Agriculture (IAA) does not focus on examining the extent and intensity of adoption of Rich-Fish culture technology their profitability, yield or food security of the farmers (Ujoh, *et al.*, 2016, Lu and Li, 2016, Koseki, 2014, Thilsted, 2014 and Halwart *et al.*, 2014). In technology adoption, the use of standard regression analysis will provide a misleading and inconsistent estimates due to presence of zero observation in the intensity of adoption. The application of double-hurdle model originally proposed by Cragg (1971) will take care of the inherent limitations associated with standard regression. The double-hurdle model has been widely applied in the study of technology adoption

(Akinola, .Ayendun, Abubakar, Shehu, Abdoulaye, 2015, Damisa, Saleh, Lyocks, 2011; Aristei and Pieroni 2011, Asfaw, Shiferaw, Simtowe 2011; Damisa, Abdulsalam, Ugbabe, 2007). Hence, this study will adopt the double hurdle regression model in examine the determinants of participation and extent of adoption of integrated Rice-Fish culture technology among the farmers in Nigeria. Also, large percentage of empirical studies on impact evaluation have employed the Average Treatment Effects to estimate the causal treatment effect of the technologies adopted among the target population. Nevertheless, the Average Treatment Effect is at the population level, with a major assumption of homogenous treatment within a population (Moffitt, 2014). But this is not plausibly true in reality as the probability of a subject taking part in a treatment might be influenced by the unobservable which most times are heterogeneous in nature and the treated might not attain the same level of gain. This gain is otherwise called marginal gain (Heckman and Vytlacil, 2005, 2007). In a bid to overcome this weakness, this study will adopt the Marginal Treatment Effect (MTE). The approach accommodates the self-selection and heterogeneity in evaluating treatment effect and permits direct access to treatment effect heterogeneity among individuals (Zhou and Xie, 2015; Cornelissen *et al.*, 2016). Also, it can gives estimates on the average population and marginal gains within the population of interest and can produce estimates for both average and marginal effects, correct for unobservable bias unlike the endogenous switching regression (Brave and Walstrum, 2014). Thus, this study will make use of MTE approach due to the potential presence of heterogeneity in response to treatment and its ability to estimate marginal gain due to treatment. Lastly on methodology, the Foster Greer and Thorbeck (FGT) measure of food poverty will help in assessing food security from food consumption expenditure of the households perspective i.e. food poverty. Ranking the study population as either food non-poor (secure), moderately food poor and core food poor (insecure), this measure takes into account the extent of severity (deviation from minimum requirement). The FGT is the most appropriate model to determine the food security status of households because the introduction of a new class of poverty (severity, gap and incidence) measures that is understandable theoretically, robust in application and it gives a concrete illustration of the new technology, like the integrated rice-fish technology (Obike *et al.*, 2019).

In the area of policy, this study is necessary when considering various advantages of integrating rice and fish production together, both in the area of profitability and food and nutrition security status of the farmers. Following the theory that a strong relationship exists between food production and consumption, this study will help in policy formulation on integration of aquaculture into agricultural production in the area of increase yield, profitability and a nutritionally food secure households among the farmers. A better understanding of the profitability and nutritional (food) security of the farmers is very necessary in order to make relevance policy on the food security status of the farmers. Interactions

between the socio-economic, profitability and food security of the rice-fish culture system will be the driving forces in the relationship that will enhance the understanding the cause and effects of food insecurity as it affects the health and general well-being of their household. In addition, the study will provides a useful baseline and policy analysis tool to inform, target and rank households and, thus, it is a good base for policy decisions for both government and civil societies. As a ranking tool, Rice-fish culture system can help inform policy by identifying the types of fish technology that is more profitable (monoculture, poly-culture) and having noticeable impacts on the food security of the farmers.

Table of analysis of objectives

Objectives	Data required	Proposed analytical methods
Determine the food security and profitability level of the adopters and non-adopters of integrated Rice-Fish culture technology.	Variable inputs, fixed inputs, cost of inputs used, rice yield, fish yield, Household size, total food expenditure	Foster Greer and Thorbeck (FGT) and Gross Margin analysis
Examine the determinants of participation and extent of adoption of integrated Rice-Fish culture technology among the farmers in Nigeria.	Socioeconomic, farm and institutional variables, quantity of rice paddy produced, quantity of fish produced	Double Hurdle Regression
Isolate the effect of integrated Rice-Fish culture technology on profitability and food security status of the farmers in Nigeria.	Socioeconomic, farm and institutional variables, quantity of rice paddy produced, quantity of fish produced, Price per bag, quantity of paddy produced,	Tobit regression
Estimate the impact of adoption of integrated Rice-Fish culture technology on profitability and food security status of the farmers	Participation in Integrated Rice-Fish technology, Socioeconomic, farm and institutional variables, quantity of rice paddy produced, quantity of fish produced, Price per bag, quantity of paddy produced, income	Marginal Treatment Effect (MTE)

CHAPTER TWO

Theoretical, Methodological, Empirical and Conceptual Review

2.1.0. Theoretical Framework

A theory is a set of organized concepts, definitions, and propositions that present a systematic view of events or situations by specifying the relationship among variables in order to explain and predict events or situations. Theory also explains how some aspect of human behaviour or performance enables us to make predictions about their behaviour (Glanz *et al.*, 2008).

2.1.1 Rational Choice Theory (RCT)

This is otherwise called the choice theory or rational action theory. It is a theory for understanding the social and economic behaviour of individuals (Levin and Milgrom, 2004; Lawrence and Easley, 2008). It has wide application in enterprise decisions about production, output, investment, and technological change, personal and household choices about consumption and savings, public policy (Burns and Roszkowska, 2016). Levin and Milgrom (2004) explain choice theory as the individual decision-making framework which forms the basis for nearly the microeconomic analyses. The rational choice theory uses a specific and narrow definition of *rationality* simply to mean that an individual such as a farmer acts to balance costs against benefits to arrive at action that maximizes personal advantage (Milton, 1953; Burns and Roszkowska, 2016).

The RCT is a process of determining what options are available and then choosing the most preferred one according to some consistent criterion (Sato, 2013, Levin and Milgrom, 2004). In the face of a decision-making situation, an actor i.e. the farmer considers a finite set of alternatives (in this case, the adoption or non-adoption of Rice-Fish culture technology. Sato (2013) identified two types of rationality: forward-looking and backward-looking rationalities. The former means that actors (rice-fish farmers in this case) choose alternatives by predicting the social outcome of their choices. The actual outcome may be different from the predicted one due to factors such as the choices of others, unpredicted events and uncertainty. However, they are assumed to try to choose the alternatives that produce the best outcome for them. In backward-looking rationality, an actor relies his/her decisions on the past outcomes. Farmers choose the alternative that is likely to give them the greatest satisfaction in terms of technological adoption (Heath, 1976; Carling, 1992).

2.1.2 Technology Adoption Concept (TA)

Technology is any substance that is intended at improving a given situation or changing the statusquo to a more desirable level (Bonabana-Wabbi 2002). It is also the knowledge or information which

permits some tasks to be accomplished more conveniently or new way or method of producing goods and services within a particular place or amongst a group of farmers (Lavison 2013). Technology adoption is the incorporation of new technology into existing practice in order to complement it, or the use or non-use of new or improved technology by an individual or farmer at a given point in time (Kaba, 2016 and Loevinsohn *et al.*, 2013), and is usually preceded by a period of 'trying' and some degree of adaptation. TA can be divided into two; the rate of adoption and the intensity of adoption. The rate of adoption is the relative speed at which farmers adopt an innovation or ideas and has "time" as one of its pillars. The intensity of adoption means the level of use of a given innovation or technology in any time period (BonabanaWabbi, 2002). A farmer is expected to choose whether or not to adopt a technology based on the match between her assets, the technology's requirements, and her perception of that technology's suitability for her needs. In other words, diffusion of innovations depends on the characteristics, preferences, and environment of individual adopters (Rogers, 2003).

2.1.3 Theory of Diffusion of Innovations (DIT)

This theory originated in communication to explain how an idea or product gains momentum and diffuses (or spreads) through a specific population or social system over time. The end result of the theory is that people, as part of a social system adopt a new idea, behavior, or product. Adoption means that a person does something differently than what they had previously (i.e., purchase or use a new technology and perform a new behavior, etc.) (Rogers 1962). The key to adoption is that the person must perceive the idea, behavior, or product as new or innovative. It is through this that diffusion is possible. The adoption of a new idea, behavior, or product (i.e., "rice-fish culture technology") does not happen simultaneously in a social system; rather it is a process whereby some people are more suitable to adopt the innovation than others. Researchers have found that people who adopt an innovation or technology early have different characteristics than people who adopt it later. When promoting an innovation to a target population, it is important to understand the characteristics of the target population that will help or hinder adoption of the innovation. There are five established adopter categories, innovators, early adopters, early majority, late majority and the laggards. Majority of the general population tends to fall in the middle categories (early majority), it is still necessary to understand the characteristics of the target population.

Technology divisibility and indivisibility as opined by Abera, (2008) is a measure of share of farm area under the new technology or quantity of input used per hectare, this measure the intensity of adoption of the technology. The extent of adoption for indivisible agricultural technologies such as rice-fish technology at the farm level at a given period of time is dichotomous (use or no use), and the aggregate measure becomes continuous. Thus, the adoption rate can be obtained by calculating the

percentage of farmers using the new technology within a given area/region. This study follows the indivisible form of technology as it involves the use and extent of use of integrated rice-fish technology among rice farmers in the study area.

2.2.0 Methodological Reviews

2.2.1. Food Security Concept and Measurement

Food Security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996).

2.2.2. Household Dietary Diversity Score (HDDS)

The HDDS is one of the direct outcome indicators which is related to food and nutrition security and widely used in developing countries for computing the food security status (Antwi and Lyford, 2018), it is based on food groups according to Swindale and Bilinsky (2013). In determining the household dietary diversity score and following Ruel (2002), the food items that households responded to have eaten over a reference period; usually, the last 24 hours, is stated in the survey questionnaire and grouped into food categories such as cereals and grains; white roots and tubers; vitamin A rich vegetables and tubers; dark green leafy vegetables and other vegetables; vitamin A rich fruits and other fruits; organ meat and flesh meat; eggs, fish and seafood; legumes, nuts and seeds; milk and milk products; and oils and fats. A household is scored based on if a household member had consumed any food item belonging to that particular food category in the past 24 hours. A household is classified as food insecure if its diversity score is less than six various food and vice versa irrespective of geographical location of the household.

2.2.3. Food Consumption Score (FCS)

This is an index of food security that was developed by the World Food Programme (WFP). The FCS totals or combines household-level data on the diversity and frequency of food groups consumed over the previous seven days, which is then weighted according to the relative nutritional value of the consumed food groups. The FCS captures information about usual household diet, since it asks respondents to recall what they consumed over the past seven days. The FCS can be used in numerous ways, including a program monitoring and evaluation and population-level targeting. Since it is a standardized measure and it can also be useful in comparing households in different locations, as well as tracking cyclical changes in household diet if collected repeatedly across seasons or years. It has been used by the WFP as the part of its Comprehensive Food Security and Vulnerability Analysis (CFSVA) tool to assess food security and vulnerability in crisis-prone populations (International

Dietary Data Expansion Project INNDEX 2019). In computing the FCS, food groups containing nutritionally dense foods, such as animal products, are given greater weight than those containing less nutritionally dense foods, such as tubers. Using this score, a household's food consumption can be either classified into one of three categories of poor, borderline, or acceptable. The food consumption score is a proxy indicator of household caloric availability and validation studies have demonstrated that the FCS and the Household Dietary Diversity Score (HDDS) are both associated with caloric intake, as well as with each other. The strength of the FCS indicator lies in capturing information on household diet, as it incorporates consumption frequency over a seven-day period unlike HDDS (Coates *et al.*, 2007 and Weismann *et al.*, 2006).

2.2.4. Foster Greer Thorbercke (FGT) Class of Poverty Measure

This measure is applicable when food security is assessed from food consumption expenditure i.e. food poverty. This measure uses a similar approach to the one traditionally used to assess poverty (Burchi and De Muro, 2012). While poverty was conceived as a lack of enough income necessary to buy a bundle of goods to guarantee the survival (or minimum standard of living) of a person, food insecurity is implicitly assumed as a sub-category of poverty (often referred to as “food poverty”); that is, lack of enough income necessary to buy at the given conditions the amount of food required (Sibrian *et al.*, 2007; Sibrian, 2008). Ranking the study population as either food non-poor (secure), moderately food poor and core food poor (insecure), this measure takes into account the extent of severity (deviation from minimum requirement). The FGT is the most appropriate model to determine the food security status of household (Obike *et al.*, 2019), it has contributed to the literature on food poverty in several ways:

- It introduced a new class of poverty measures that is understandable, theoretically sound, and applicable;
- It helped justify the measures using new and practical axioms; and
- It provided a concrete illustration of the new technology

FGT consists of three axioms groups as invariance, dominance and other subgroup axioms, the invariance category; P_α measures satisfy the invariance axioms, with the exception of P_0 which has a discontinuity at the food poverty line. The dominance category includes various versions of monotonicity, the transfer axiom, and transfer sensitivity. A higher α reflects greater aversion to food poverty. This signals the versatility of the FGT class in that one can select a specific measure with a desired degree of sensitivity to each of the underlying forms of transformation, namely, increased individual poverty, increased inequality among the poor, or increased inequality among the poor

matched by decreased inequality at higher poor incomes. The final category of axioms draws on the intuition that subgroups of populations can also be viewed as populations having their own levels of poverty—and that these levels should bear some relationship to the poverty level of the overall population.

Mathematically, the FGT class of poverty measures has some desirable properties (such as additive decomposability), and they include some widely used poverty measures (such as the head-count and the poverty gap measures).

$$P = \sum_{i=1}^q \frac{(z - Y_i)\alpha}{z} \quad (1)$$

Where:

P = Foster, Greer, and Thorbercke index ($0 \leq P \leq 2$)

N = total number of respondents i.e. farm household sample

q= number of respondents below the poverty line i.e. poor people

z= the poverty line

Y_i = per capital household expenditure of the ith respondent.

α = non negative poverty aversion parameter (0, 1 or 2).

This study will employ the FGT poverty measurement indicators in computing the food security status of rice-fish farming households.

2.2.5. Gross Margin Analysis

Farm profit is measured in terms of Gross Margin (GM) which equals the difference between the Total Revenue (TR) and Total Variable Cost (TVC), but not fixed costs as they remain fixed whether or not production has taken place, and to what scale production has been.

The gross profit of a business is estimated as the difference in between the total sales and the variables cost incurred.

$$GM = TR - TVC \quad (2)$$

Where;

GM = Gross Margin

TR = Total Revenue

TVC = Total Variable Cost

TR= Value of output (amount realized from the sales of rice and fish).

This was obtained by multiplying the quantity of pepper sold by the unit selling price.

2.2.2. Measurement of Intensity of Technology Adoption

2.2.2.1 Poisson Regression

Poisson regression is a generalized linear model form of regression analysis used to model count data and contingency tables. When the dependent variable is a count variable i.e. it takes on nonnegative, integer values, a Poisson regression model is appropriate. Poisson regression assumes the response variable Y has a Poisson distribution, and assumes the logarithm of its expected value can be modeled by a linear combination of unknown parameters. A Poisson regression model is sometimes known as a log-linear model, especially when used to model contingency tables. The parameters can be estimated by Maximum Likelihood Estimation (MLE), however, because the Poisson distribution imposes equality of the variance and mean, it is often necessary to compute standard errors and test statistics that allow for over- or under dispersion (Woodridge, 2012).

2.2.2.2 Tobit Regression

Tobit models are models with either censored or truncated dependent variables and it incorporates features of microeconomic data with zero values (Lung-Fei, 1993). Tobit regression models are required when the dependent variable is censored i.e. when there is an accumulation of observations at the limits of the range of the variable. The lower limit of the range is usually zero, and censoring is usually zero censoring, although sometimes, we are required to deal with upper censoring, where there is an accumulation of observations at the maximum. In other contexts, there is censoring from below but at a cutoff point different from zero. A major drawback of the Tobit model is the assumption that the decisions on whether or not to adopt and how much to adopt are jointly made and hence, the factors affecting the two decisions are assumed to be same (Cragg, 1971). The model has been used in adoption of improved agricultural technologies by authors such as Owusu and Donkor (2012), Adesina and Forson (1995). The standard Tobit regression model is defined as

$$\begin{aligned} y_i^* &= X_i\beta + \varepsilon_i \\ y_i &= y_1^* \text{ if } y_i > 0 \\ y_i &= 0 \text{ if } y_i \leq 0 \end{aligned} \tag{4}$$

Where y_i^* is the latent dependent variable, y_i is the observed dependent variable, x_i is the vector of the independent variables, β is the vector of coefficients, and the ε_i 's are assumed to be independently normally distributed: $\varepsilon_i \sim N(0, \sigma^2)$ (and therefore $y_i \sim N(X_i\beta, \sigma^2)$)¹. It should be noted that observed 0's on the dependent variable could mean either a "true" 0 or censored data. At least some of the observations must be censored data, or y_i would always equal y_1^* and the true model would be linear regression, not Tobit. The Maximum-likelihood estimation of the Tobit model is straightforward. Thus, the Tobit regression model will be used to determine the effect of Rice-Fish culture technology on profitability and food security level of the farmers.

2.2.2.3 Double Hurdle Model

A hurdle regression model is a class of statistical models where a random variable is modeled using two parts, the first which is the probability of attaining value 0, and the second part models the probability of the non-zero values. Hurdle models were introduced by John G. Gragg in 1971, where the non-zero values of x were modelled using a normal model, and a probit model was used to model the zeros. It consists of two separate stochastic processes which determine the decision to adopt and the extent of use of a technology. The dependent variable in the first stage is dummy, taking the value of 1 or 0 while the dependent variable in the second stage is continuous. According to Gragg, (1971), it is expressed thus:

$$D_i = 1 \text{ if } D_i^* > 0 \quad (5)$$

$$D_i = 0 \text{ if } D_i^* \leq 0$$

$$D_i = \alpha Z_i + \vartheta_i \quad (6)$$

In this study, D_i^* is a latent variable which takes the value of 1 if a farmer adopts or practices Rice-Fish culture technology and zero otherwise. Z is a vector of household and farm characteristics and α is a vector of parameters. The level or extent of adoption of Rice-Fish culture technology for individual farmers (Y_i) is represented by:

$$Y_i = Y_i^* \dots \text{if } Y_i^* > 0 \dots \text{and } D_i^* > 0 \quad (7)$$

$$Y_i = 0 \dots \text{otherwise}$$

$$Y_i^* = \beta' X_i + \varepsilon_i \quad (8)$$

Where Y_i , is the extent of use of Rice-Fish culture technology, X_i is a vector of household socioeconomic and farm characteristics and β is a vector of parameters. This model will be employed in this study due to its superior advantage over Poisson or Tobit regression model to independently reveal factors influencing the two processes. Various authors such as (Eakins, 2014; Akinbode and Dipeolu, 2012; Akpan *et al.*, 2012), has used it in technology adoption studies. This will be used to examine the determinants of participation and extent of adoption of integrated Rice-Fish culture technology by the farmers.

2.2.2.4. Marginal Treatment Effect (MTE): This is an approach used in empirical research when the impact of a treatment is thought to vary within a population in correlation with unobserved characteristics. Zhou and Xie (2015) added that individuals differ not only in background characteristics and outcomes of interest, but also in their responses to a particular treatment,

intervention, or stimulation. The selection of MTE approach in this study was based on the need to evaluate the marginal gain due to adoption of integrated Rice-Fish technology which is quite difficult for ATE to perform. In addition, average treatment effect is at the population level whereas the treatment at the individual level might not be homogenous. Moffitt (2014), Brave and Walstrum (2014) specified MTE model as follow:

$$YD = (1 - D)Y_0 + DY_1 \quad (9)$$

$$Y_1 = \alpha_1 + X\beta_1 + U_1$$

$$Y_0 = \alpha_0 + X\beta_0 + U_0$$

$$I = Z\gamma - V \quad (9)$$

$$D = \begin{cases} 1 & \text{if } I > 0 \\ 0 & \text{if } I \leq 0 \end{cases} \quad (10)$$

Where YD represents the binary outcome of food security status among the rice farmers, Y_1 is the outcome of the food secure rice farmers while Y_0 is for food insecure rice farmers, is the binary choice variable (food security status), which depends on observable covariates, X , and unobservable, $[U_1, U_0]$. Hence, the decision process to adopt is a function of both $Z\gamma$ (observables) and unobservables. These are linked to the observed outcome, YD , through the latent variable,

$$MTE \equiv (Y_1 - Y_0|X = x, UD = uD) \quad (11)$$

The MTE represents the marginal benefit associated with treatment ($D = 1$) conditional on a level of the observed covariates in the outcome equation (X) and the propensity not to be treated (UD). The estimated propensity score $\hat{p}(z) = pr(Z\gamma > V|Z = z)$ allows us to define the range of UD over which MTE is identified. Given $\hat{p}(z)$, the following conditional expectations of Y by observed treatment status form the basis of the parametric estimation procedure

$$\{Y|X = x, (Z) = p, D = 1\} = \alpha_1 + XB_1 + \{U_1|X = x, (Z) = p, D = 1\} \quad (12)$$

$$\{Y|X = x, (Z) = p, D = 0\} = \alpha_0 + XB_0 + \{U_0|X = x, (Z) = p, D = 0\} \quad (13)$$

The equations above form the basis of the parametric estimation of MTE.

Following Heckman and Vytlacil (2001a), the equations 12-13 can be re-written as:

$$\{Y|X = x, P(Z) = p\} = \alpha_0 + XB_0 + (\alpha_1 - \alpha_0) + \{(B_1 - B_0)\} + (p) \quad (14)$$

$$(p) = \{U_0|(Z) = p\} + E\{U_1 - U_0|P(Z) = p\}p \quad (15)$$

(Z) is the propensity score generated from the probit model.

Using the basis of MTE equation: $MTE \equiv (Y1 - Y0|X = x, UD = uD)$, the following equation can be derived:

$$\{X = x, UD = uD\} = (\alpha_1 - \alpha_0) + (B_1 - B_0) + (\rho_1 - \rho_0)\Phi^{-1}(uD) \quad (16)$$

Estimation of the parameters of the MTE then follows from the linear regressions implied by equations (12 and 13) using the fact that:

$$E(U_1|X = x, P(Z) = p, D = 1) = -\rho_1 \frac{\phi(p)}{\Phi(p)p} \quad (17)$$

$$E(U_0|X = x, P(Z) = p, D = 0) = \rho_0 \frac{\phi(p)}{\Phi(p)(1-p)} \quad (18)$$

Where Φ represents cumulative normal distribution, $-\rho_1 \frac{\phi(p)}{\Phi(p)p}$ and $\rho_0 \frac{\phi(p)}{\Phi(p)(1-p)}$ are the inverse Mills ratios to correct for any form bias in the selection of the respondents and in the distribution of the technology.

$$MTE\{X = x, U_D = u_D\} = (\alpha_1 - \alpha_0) + X(B_1 - B_0) + \sum_{i=1}^{\theta} i \phi_i p^{i-1} \quad (19)$$

According to Brave and Walstrum (2014), MTE can be related to ATE through this expression:

$$MTE = ATE + (u_1 - u_0) \quad (20)$$

And by integrating the MTE over p, we can arrive again at the ATE.

$$ATE = \int_p^{p'} MTE dp \quad (21)$$

2.2.2.5. Propensity Scores Matching (PSM): This is a non-parametric estimation technique that does not depend on functional forms and distributional assumptions. It is useful in the absence of an experiment as there is no need to have a baseline and panel data (Caliendo and Kopeinig, 2008). It has been used in wide varieties of studies and fields such as economics, agriculture, sociology, political science, medical science and financial scholars since its introduction by Rosenbaum and Rubin (1983). The first step in the PSM is the estimation of propensity scores (i.e. the farmers' probability of participation) based on similar characteristics using Logit model. The second step involved choosing a matching algorithm which includes the Nearest Neighbor Matching (NNM), Caliper or Radius Matching (RMM) and Kernel-Based Matching (KBM) methods. The NNM method is the most straight forward matching method where non-treated individuals that are very close to the propensity score of treated individuals are chosen as partners. The kernel matching and radius matching methods are complementary, KBM uses information from all control group households and a weighting function to construct the counterfactual outcome and reduces variance while the RMM uses information only from the nearest neighbors within the caliper distance and reduces bias. After matching, the most

prominent evaluation parameter known as Average treatment effect on the treated (ATT), which focuses explicitly on the effects on those for whom the programme is actually intended will be calculated. ATT is the difference between expected outcome values with and without treatment for those who actually participated in treatment (ibid). It is given by

$$\tau_{ATT} = E(\tau/D_i = 1) = E[Y_i(1)/D_i = 1] - E[Y_i(0)/D_i = 1] \quad (22)$$

Where

$Y_i(1)$ = the potential outcomes when the i^{th} farmer participates in agricultural program $Y_i(0)$ = the potential outcomes of the i^{th} farmer when he does not participate in the program

2.2.2.6 Endogenous Switching Regression is a natural extension of classical experimental design, which allows tests of assumptions about the exogeneity of treatment effects from survey data. The model is a regression-based method, which models two outcome equations (two regimes), one for treatment and one for comparison, allowing for endogeneity of selection into treatment (Maddala and Nelson, 1975), and it is a special case of the Heckman model, where the second stage (outcome) equation is a switching regression. The major advantages of the approach is that it allows for interaction effects between treatment and the variables affecting outcomes.

2.2.2.7. Inverse-probability-weighted regression adjustment (IPWRA) serves as a credible remedy for potentially biased estimates (ATT) that might emanate from propensity score models in the presence of misspecification (Vansteelandt *et al.*, 2007; Wooldridge, 2007). As posited by Wooldridge (2003), the IPWRA estimates would be consistent even if the treatment/outcome was miss-specified, but not if both were. The IPWRA therefore can ensure consistent results, as it allows for the treatment and the outcome model to account for misspecification due to its double-robust property. Conceptually, IP weighting estimates selection to treatment (treatment model), predicts treatment for all observations, assigns the inverse of probability of treatment for treated individuals and the inverse probability of not being treated for control individuals and re-estimates the outcome model using these new weights. The IP weights magnify treatment individuals who otherwise look like they would not have selected treatment and magnify control individuals who otherwise look like they would have selected treatment. Counterfactuals are created where they are not observed in the data. One important feature of IPWRA is double robustness. Even if one of the models (treatment or outcome) is mis-specified, the estimator is still consistent.

If Z represents an indicator variable denoting whether or not the i^{th} subject was treated and denotes the propensity score for the i^{th} subject, then weights can be defined as

$$W_i = \frac{Z_i}{e_i} + \frac{(1-Z_i)}{(1-e_i)} \quad (23)$$

A subject's weight is equal to the inverse of the probability of receiving the treatment that the subject actually received. Furthermore, the average treatment effect (ATE) using inverse propensity score matching is estimated as:

$$\sum_{i=1}^n 1 - Z_i Y_i \frac{1}{e_i n} \sum_{i=1}^n = 1 \frac{(1-Z_i) Y_i}{1-e_i} \quad (24)$$

Where Y_i , denotes the outcome variable measured on the i th subject and n denotes the number of subjects. In estimating the ATT, the IPW is given as:

$$ATT = \frac{\sum_{i=1}^n Z_i Y_i}{\sum_{i=1}^n Z_i} - \frac{\sum_{i=1}^n (1-Z_i) Y_i e(x_i) / (1-e(x_i))}{\sum_{i=1}^n (1-Z_i) e(x_i) / (1-e(x_i))} \quad (25)$$

2.3.0. Empirical Framework

2.3.1. Empirical Review on Agriculture Technologies Adoptions and Food Security

Ahmed, Echekwu, Mohammed, Ojiewo, Ajeigbe, Vabi, Affognon, Lokossou, and Nwahia, (2020) examined the adoption of improved groundnut varieties in the Tropical Legume (TL III) States of Nigeria using Average Treatment Effect method. The results showed that the breeding and promotion of improved groundnut varieties in Nigeria under the Tropical Legume Project and with the synergy of United State Agency for International Development (USAID) Groundnut up-scaling Project in Nigeria resulted in very high level of awareness of improved varieties, more than average level of access to the improved variety seeds, moderate level of utilization of the improved varieties among the groundnut farmers and the adoption rate of improved varieties increased from 8 percent at based line to 57 percent at the end of the project.

Onya, Okezie, and Ejiba, (2019) analyzed the preference and expenditure decision on local rice of rural households in Area of Abia State, Nigeria, using double hurdle modeling approach for data analysis. The result of the double hurdle model showed that marital status, age of the household head, education of the household head, household size, price of rice, and the quality of rice significantly influenced the preference decision of the household while marital status, age, household size, monthly income, and quality of rice significantly influenced the expenditure decision of the household in the study area. The major reasons for rice preference by the respondents were absence of foreign matter (impurities such as stones), shape of grain, stickiness after cooking, rate of breakage and cleanliness of the rice.

Adewole, Popoola, Obasoro and Adeoti (2019) examined the impact of adoption of improved cassava variety (TMS 01/1412) on household food security in Oyo state, Nigeria, using primary data. The Alkire and Foster approach was used to estimate multidimensional food insecurity index while the propensity score matching was used to estimate the impact of adoption of improved cassava variety on household food insecurity. Findings show that the Multidimensional Food insecurity index at $k=2$ was 0.465 with about 55.7 percent being multidimensionally food insecure. Food insecurity estimates show that 36.8 percent of the adopters were food insecure as compared to over 60 percent of the non-adopters who were food insecure and that the food insecure non-adopters suffer twice the level of deprivation suffered by adopters. The impact assessment shows that adoption of improved cassava variety positively and significantly reduces the food insecurity status of the farm households as shown by the ATT value of -0.367 implying that it reduces the food insecurity status of the adopters by an average of 36.7 percent.

Bayan *et al.*, (2019) examined what influences adoption and use intensity of artificial insemination technology among smallholder dairy farmers using double hurdle regression. The study identify various factors influencing adoption decision of artificial insemination (AI) technology and extent of adoption at farm level. Various farm, farmer, physical, environmental and perception factors such as education and experience of the household head, awareness about AI technology, government support, distance to AI centre, all-weather road and market and herd-size are found to significantly influence the decision to adopt AI technology; while, factors such as experience of the farmer, access to credit and local breeding bull, herd size and perceived risk associated with AI adoption are found to have significant influence on intensity of adoption of AI technology.

Using a quantitative data and logistic regression model, Ntshangase, Muroyiwa, and Sibanda, (2018) examined the factors that influence the adoption of no-till conservation agriculture (CA), farmers' perceptions of no-till CA and the impact of no-till CA on maize yield in Zashuke, KwaZulu-Natal Province of South Africa. Findings show that farmers' positive perceptions were positively correlated with higher maize yields. While an increase in extension visits, age, education and farmers' positive perceptions significantly increased the likelihood of a farmer adopting no-till CA, an increase in land size was negatively related to no-till CA adoption.

Udimal, Jincai, Mensah and Caesar, (2017) analyses the factors that influence the adoption of (Nerica) rice technology in the Northern Region of Ghana using both logit and probit models. The results from the two models were consistent with each other; as they have similar signs for each variable but slight difference in the magnitude of the coefficients. The study further find out that factors such as farm

size, credit access, on-farm demonstration, tractor ownership, age, profit orientation and family labor were the variables influencing the adoption of (Nerica) rice technology in the study area.

Emmanuel, Victor, and Enoch, (2014) examined the adoption of improved cassava varieties among cassava farmers in the Sekyere South District of Ashanti region, Ghana. The determinants of adoption were estimated with probit model. The results of the probit model showed that extension services, credit access, education, marital status, farmer based organization, and household size have significant positive effect on the probability of farmers to adopt improved cassava varieties.

Awotide *et al.*, (2014) assessed the extent and determinants of adoption of improved cassava varieties in south-western Nigeria, using double hurdle regression. Empirical estimates of the study revealed that adoption increases with the age of the household head and is influenced by the gender of the household head, hired labour, cultivated land, and access to credit. The results further showed that the intensity of adoption is influenced by hired labour and farm size; access to information about the improved cassava varieties is determined by the age, gender, and level of education of the household head, and by off-farm income.

Asfaw, Battista, and Lipper, (2014) examined the food security impact of agricultural technology adoption in Niger, using multivariate probit and instrumental variable techniques to model the selection decisions and its impact. The study found that modern inputs and organic fertilizers significantly improved crop productivity. However, the impact of crop residue approach was not clear, and the impact of agricultural technology could depend on the nature of technology being considered.

Nyyssölä, Pirttilä and Sandström. (2014) worked on the impact of an intervention to improve farming techniques and food security in the Gaza area of rural Mozambique using panel data. Using difference in difference and Local Average Treatment Effect (LATE). The findings showed that the impacts on farming techniques, such as fertilizer use, are significant in the first treatment year. The impact on food security is mixed across indicators but similar in both treatment years but the impact cannot strictly be attributed to adoption of new technologies by the households.

2.3.2. Empirical Reviews on Rice and Fish Profitability

Kulyakwave, Xu, Yu, Sary, and Muyobozi, (2020), examined the profitability of rice production, its key factors, and the consumption shares at household level in Tanzania. Data analysis was performed by descriptive statistics and Farm Budgetary Techniques was used to calculate farm economic viability variables including profitability index, return on investment, capital turn over and benefit cost ratio. The budgetary farm technique revealed that average total cost, gross margin, and net farm income was 846450 (~ US \$ 368.08), 1484175 (~US \$ 645.41) and 1357975 (~US \$ 590.73) Tanzania Shillings

respectively. The profitability index, return on investment, capital turn over and benefit cost ratio for producers were 9.5 percent, 160, 2.6 and 3.1 respectively. According to Kendall's coefficient of concordance, the identified main constraints for economic viability of rice production were weather variability, lack of access to irrigation services, rice price instability, lack of access to agricultural information and technology, and poor access to the key production inputs.

Chidiebere-mark, Ohajianya, Obasi, and Onyeagocha, (2019) examine the profitability of rice production in different production systems in Ebonyi State, Nigeria using Gross Margin analysis. Findings shows that rice farmers in swamp, lowland and upland rice production systems showed variability in profit. Swamp production systems had the highest return per hectare (29.37 percent) followed by lowland production systems (20.10 percent) and upland production systems (13.03 percent). Poor access to production credit and climate change were constraints to rice production in the area. Rice production using the swamp production system is profitable and would ensure increased production and higher returns to the farmers.

Olajide and Omonona, (2019) examined the Productivity of catfish production in Osun State Nigeria, using profitability analysis, Total Factor Productivity (TFP) and a multiple regression model. Results showed that the average Gross Margin of ₦788,823.54 and average profit of ₦413,012.27 per production season (5–6 months) and Benefit-Cost Ratio of 1.06 indicate that catfish farming is profitable, worth investing on and feasible. TFP of 11.32 indicates that the more the amount of variable input used the more the output.

Bwala and John, (2018) estimated the profitability of rice production among small scale farmers in Bida agricultural zone of Niger state. The finding revealed that variable cost per hectare for rice production to be \$126,100 per production cycle, while total revenue of \$227,500 was realized by the respondents. The results also revealed cost of labour to account for the largest portion (54.0 percent) of the total variable cost. This is followed by the cost of seed, fertilizer, transportation, herbicide, pesticide and bagging. The farm budgeting analysis revealed the costs and returns of rice production to be profitable with a gross margin of \$101,400 and net farm profit of \$98,546.4. The gross profit ratio was calculated to be 0.45 which implies that farmers are selling their rice produce at a relatively high profit percentage.

Using OLS and Gross Margin analysis Okam, Yusuf, Abdulrahman, and Suleiman, (2016) estimate comparative analysis of profitability of rice production and its determinants in Ebonyi State, Nigeria. Findings shows that farming experience, cost of labour and cost of seed were found to significantly influence rice profitability among male farmers while farming experience, cost of labour, cost of agrochemical and cost of seed) of the variables were significant at influencing rice profitability among

female farmers. The Total Variable Cost (TVC) incurred by the male and female farmers averaged N 73, 435.00/ha and N 60, 906.80/ha, with a Gross Margin (GM) of N 86, 328.00/ha and N 62, 035.20/ha respectively. Gross Margin/Naira invested was 1.18 and 1.02 for the male and female farmers respectively.

Olasunkanmi and Yusuf (2014) used Gross Margin and Stochastic Frontier Analysis to analyzed resource used efficiency among Catfish farmers in Osun State. The study find out that increasing the usage of fingerlings and fertilizer would improve the efficiency fish farmer's inputs. The major constraints identified are lack of extension officer's service, insufficient capital, high cost of feed/other input, lack of government assistance, market price fluctuation, preservation/storage/processing problem, flooding during the raining season and land acquisition problem among others.

2.4.0. Conceptual Framework

There are several potential pathways in which Rice-Fish culture technology adoption can influence farmer's profitability and food security. Following the World Food Programme (WFP) (2014) reports, food security depends on four factors (1) availability of food i.e. the extent to which sufficient quantity and quality of food is physically available or present in a household, (2) accessibility to food i.e. the extent to which households and individuals have enough economic resources to obtain sufficient quantity and quality of food for a nutritious diet, (3) utilization of food i.e. the dietary diversity and body utilization of food and its inadequate could lead to malnutrition; measured through anthropometrics), and sustainability i.e. The FAO further added a fourth pillar: the stability of the first three dimensions of food security over time, hence in 2009, the World Summit on Food Security unanimously agreed that the four components or pillars of food security are availability, access, utilization and stability. These four pillars are practically the core pillars or dimension on which any measurement of food security should focus on (Thomas *et al.*, 2017, WFP, 2014).

Thus, judging from the motivation above, the framework for this study as indicated in Fig (1) below indicates that adoption or participation in Rice-Fish culture technology can leads to attainment of outputs such as reduction in rice and fish loss, reduction in labour usage, reduction in production time, reduction in farm drudgery and provision of quality rice and fish for the farmers, profitability in rich-fish production and increase food security. The judicious combination of these outputs leads to attainment of outcomes such as increased in rice-fish production, improvement in market competitiveness, reduction in rice and fish packaging time, better and faster postharvest operation. These outcomes are culminated in increased or higher yields, leading to profitability among the farmers. A profitable enterprise will have a positive impact on the households, hence this leads to increase in nutrition and

food security of the farmers. The main component of food security; availability, accessibility, utilization and stability are achieved. Following various literatures such as (Phong, Mensvoort, and Bosma, 2003), (Dey, Paraguas, Kambewa, and Pems, 2010) and (Ujoh, Ujoh, and Kile, 2016), the effect of Rice-Fish culture technology on profitability and food security of the farmers is illustrated in Figure 1.

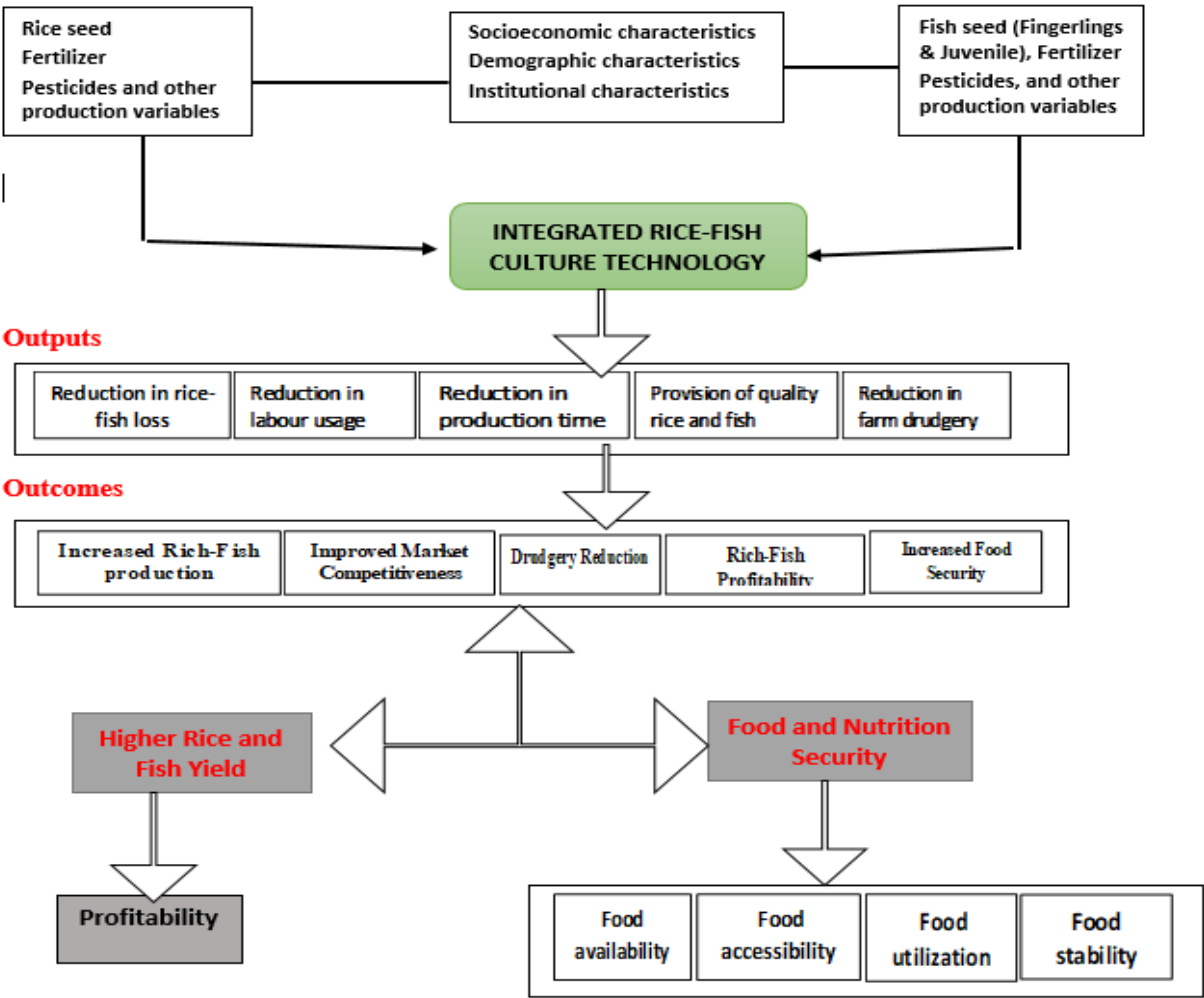


Fig 1. Conceptual Framework
Source: Authour’s Conceptualization

CHAPTER THREE

Methodology

3.1. Study Area

The study area for this study is Nigeria, two States Ebonyi (South-East) and Kebbi (North West) States was selected from the list of the main rice producing states in Nigeria.

Ebonyi state is one of the states in South East region of Nigeria, it lies within latitude 7°31'N and 8°30'N of the Equator and Longitude of 5°40'E and 6°45'E of Greenwich meridian. The State occupies 5,533 km² (2,136 sq mi), and based on 2016 figures 3, 49 million people (NBS, 2017). Agriculture is the major occupation of the inhabitants, and the state is popularly renowned in producing *Ebonyi or Abakaliki rice* with estimated production of 6 million tonnes per hectare. The vegetation in the state is rain forest and derived savannah that are suitable for rice production (Anorue *et al.*, 2017).

Kebbi State is a state in North West Nigeria, and it lies between latitudes 10° N and 30° N of the Equator and Longitude of 3°30' and 6° E, with a mean annual rain fall of 733 mm-1045 mm (Kebbi State Government, 2018). The State occupies 36800 km². Based on 2016 figures 4.4 million people and an annual growth rate of 3.2 percent (Wali *et al.*, 2018), the State's population for 2020 is estimated to be 5 million people. The vegetation in the states is savannah that are suitable for rice production. Farming is the major activities of residents of the state. The state is popularly known for the production of *Lake rice*; a joint and partnership initiative between Kebbi and Lagos state government. The rice production capacity in the state is estimated at 8 million tonnes per years. The two states are also part of the staple crops processing zones (SCPZ) according to agricultural transformation agenda (FMARD, 2016).

3.2. Data Source and Methods of Data Collection

Primary data will be used for this study. The data will be collected from participating and non-participating farmers in Rice-fish technology programme under the United State Agency for International Development (USAID)/FAO Feed the Future project. Three demonstrated plots located in the three senatorial district of the two states will be using for this study. Well-structured questionnaire will be used in collecting information on the variable of interest. Information to be collected from the farmers includes socio-economic characteristics (income from rice, income from fish, membership of cooperative association, education level, and access to extension agent etc.), demographic variables (age, sex, marital status, household size, income etc.), participation in rice-fish culture technology, distance to market(km) farming experience, farm size, land ownership, production

inputs used, assets owned by the farmers, farmer's total agriculture income (n), total rice output in (kg), total agricultural expenditure (N), transport costs (Naira) etc.



Fig 1: Map of Nigeria Showing the Two States for the Study

3.2. Sampling techniques

The study will adopt a multistage sampling technique. The first stage is the purposive selection of Ebonyi (South-east Nigeria) and Kebbi (North-west Nigeria) among the rice producing states due to their participation in the Feed the Future integrated Rice-Fish culture technology. The second stage is the selection of three (3) senatorial zones of each state, Ebonyi South, Ebonyi East and Ebonyi Central in Ebonyi state while Kebbi South, Kebbi North and Kebbi central will be selected in Kebbi state. One LGA each will be selected from each of the senatorial districts, making a total of six (6) local government areas, comprising of Izzi, Ohaozara and Ikwo LGAs from Ebonyi state, Argungu, Kimba and Ngaski LGAs from Kebbi state, where six (6) demonstration ponds has been located already. Finally, two hundred (200) farmers involving 100 participants in the rice-fish culture technology and 100 non-participants will be selected from the LGAs from the two states. In all, a total of four hundred (400) farmers including 200 participating farmers in rice-fish technology and 200 non-participating farmer will be selected for this study.

3.4. Methods of Data Analysis

3.4.1 Objective one: Profile Rice-Fish farmers by their profitability and Food security status of the farmers.

This will be achieved by using Gross Margin analysis and Foster Greer and Thorbeck (FGT) poverty measurement. Gross Margin Analysis will be used to determine the profitability level of the farmers. Following (Adepoju, 2017 and FAO, 2008), the Gross Margin is defined as the difference between the Total Revenue (TR) and Total Variables Cost (TVC).

It is expressed mathematically thus:

$$GM = TR - TVC \quad (26)$$

In order to determine the food security level of the households, the FGT index will be used to determine the threshold which will be used to categorize the level of food security among farm households in the study area. Following Foster Greer and Thorbeck (1984) as used by Ibitola *et al.*, (2019), this index is computed with the mathematical formula stated below:

$$p_{\alpha} = \frac{1}{n} \sum_{i=1}^{\alpha} \left[\left(z - \frac{y}{z} \right) \right]^{\alpha} \quad (27)$$

Where n = total number of households

Y = total Household monthly expenditure of the i^{th} household

Z = poverty line (the poverty line was arrived at by calculating the 2/3 of the mean per capita monthly household expenditure.)

α = is a measure of the sensitivity of the index to poverty or the degree of severity of poverty (food security index which takes value of 0, 1 and 2)

3.4.2 Objective 2: Examine the determinant of participation and intensity of adoption of integrated rice-fish technology among farmers in Nigeria

Double Hurdle Regression (DHR) Model: In this study, a rice-fish farmer is defined as an adopter if he has used this technology at least once and 1 is assigned to his adoption status but if otherwise, it is 0. On the other hand, the intensity in this study shows the level of use of Rice-Fish culture technology by individual farmers. This is measured by calculating the quantity of harvested from Rice-Fish culture technology out of the total produced by individual farmers. This makes it to have a range value of 0 to 1. The closer the value to 1, the higher the use of the Rice-Fish culture technology among the farmers and vice versa.

Thus, following Eakins, (2014) and Akinbode and Dipeolu, (2012); the two parts of double hurdle model are functionally independent and it is expressed as:

$$-d_i^* = Z_i'\alpha + ui \quad (28)$$

$$y_i^* = X_i'\beta + Vi \quad (29)$$

The first and second equations represent the adoption (probit) and intensity of use of Rice-Fish culture technology respectively. Where d_i^* is a latent variable that takes the value of 1 if the farmer adopts Rice-Fish culture technology and 0 otherwise, Z_i' is a vector of explanatory variables and α is a vector of parameters. Similarly, y_i^* represents the index obtained from the ratio of quantity of harvested by Rice-Fish culture technology to the total quantity produced, while X_i' is a vector of independent variables and β is a vector of parameters for intensity of use. The ui and Vi are independent error terms.

The y_i^* is calculated as:

$$y_i^* = \frac{\text{quantity of rice and fish produced from rice-fish culture}}{\text{Area of farm cultivated}} \quad (30)$$

The log-likelihood function for the double hurdle model is expressed below:

$$\text{Log } L = \sum \ln [1 - \Phi(Z_i'\alpha) \Phi(\frac{X_i'\beta}{\sigma})] + \sum \ln [\Phi(Z_i'\alpha) \frac{1}{\sigma} \phi(\frac{y_i - X_i'\beta}{\sigma})] \quad (31)$$

The independent double hurdle model assumes that the two error terms from the two hurdles are normally distributed and uncorrelated. This suggests that the two stage Rice-Fish culture technology adoption intensity decisions are done independently by the farmers. The determinants of adoption intensity of Rice-Fish culture technology will be modeled on the household, farming and institutional characteristics.

X_1 =Age of household head (years)

X_2 =Household size (number)

X_3 =Sex (Male=1, Female=0)

X_4 =Educational level (years)

X_5 =Experience in rice farming (years)

X_6 =Farm size (hectare)

X_7 =Credit access (Yes=1, No=0)

X_8 =Membership of cooperative (Yes=1, No=0)

X_9 =Livestock ownership (Yes=1, No=0)

X_{10} =Distance to input supply (Metres)

X_{11} =Quantity of paddy produced (Kg)

X_{12} =Quantity of paddy produced (Kg)

X_{13} =Cost of transportation (produce) (Naira)

X_{14} =Rice-Fish production modality ()

X_{15} =Extension visit (Yes=1, No=0)

X_{16} =Own mobile phone (Yes=1, No=0)

X_{17} =Agricultural income (Naira)

X_{18} =Food expenditure (Naira)

3.4.3. Objective 3: Examine the effect of integrated Rice-Fish culture on profitability and food security status of the farmers (Tobit Regression Model)

Tobit Regression Model will be used to examine the effect of integrated Rice-Fish culture on profitability and food security status of the farmers.

Following Adebosin *et al* (2013), Sanzidur Rahman, (2014), the model is expressed below;

$$\gamma_i^* = \beta'x_i + \varepsilon_i \quad (32)$$

$$\gamma_i = 0, \text{ if } \gamma_i \leq 0.3$$

$$\gamma_i^* = \gamma_i, \text{ if } 0.3 < \gamma_i \leq 1 \quad (33)$$

Where γ_i^* is the dependent variable (quantity of rice-fish harvested)

γ_i = the observed dependent (censored) variable

X_i = is the vector of independent variables,

β = is a vector of unknown parameters,

ε_i is a disturbance term assumed to be independently and normally distributed with zero mean and constant variance σ ;

The following socio-economic variables will be included in the model.

Y = The dependent variable (quantity of rice-fish harvested)

X_1 =Age of household head (years)

X_2 =Household size (number)

X_3 =Sex (Male=1, Female=0)

X_4 =Educational level (years)

X_5 =Experience in rice farming (years)

X_6 =Farm size (hectare)

X_7 =Credit access (Yes=1, No=0)

X_8 =Membership of cooperative (Yes=1, No=0)

X_9 =Livestock ownership (Yes=1, No=0)

X_{10} =Distance to input supply (Meters)

X_{11} =Quantity of paddy produced (Kg)
 X_{12} =Quantity of paddy produced (Kg)
 X_{13} =Cost of transportation (produce) (Naira)
 X_{14} =Rice-Fish production modality ()
 X_{15} =access to extension visit (Yes=1, No=0)
 X_{16} =Own mobile phone (Yes=1, No=0)
 X_{17} =Agricultural income (Naira)
 X_{18} =Food expenditure (Naira)

3.4.4. Objective 4: Estimate the impact of adoption of integrated Rice-Fish culture technology on profitability and food security status of the farmers (Marginal Treatment Effects)

In this study, a farmer is considered an adopter if he/she is participating in the integrated Rich-Fish culture technology, and 1 is therefore assigned to participant while 0 is assigned to non-participants or non-adopters. The outcomes of interest as a result of the adoption of integrated Rich-Fish culture technology are both continuous and binary (profitability and food security status respectively). This study therefore adapts the methodological approach of Cornelissen *et al.* (2016); Kowalski (2015; 2016); Brave and Walstrum (2014); Moffitt (2014); Carneiro *et al.* (2000); and Lokshin and Sajaia (2011) to estimate the impact of adoption of integrated Rich-Fish culture technology on profitability and food security status.

Thus, the MTE is thus specified as follow:

$$Y = (1 - D)_0 + DY_1 \text{ (For profitability)} \quad (34)$$

$$Y_D = (1 - D)_0 + DY_1 \text{ (For binary outcome)} \quad (35)$$

$$Y_1 = \alpha_1 + X\beta_1 + U_1 \quad (36)$$

$$Y_0 = \alpha_0 + X\beta_0 + U_0 \quad (37)$$

Where Y represents continuous outcome of interest (rice and fish income), Y_D represents the binary outcome (food security status) among the rice farming households, Y_1 is the outcome of the food secure households while Y_0 is for food insecure households, D is the binary choice variable (food security status), which depends on observable covariates, X , and unobservable, $[U_1, U_0]$.

$$\{Y|X = x, (Z) = p, D = 1\} = \alpha_1 + XB_1 + \{U_1|X = x, (Z) = p, D = 1\} \quad (38)$$

$$\{Y|X = x, (Z) = p, D = 0\} = \alpha_0 + XB_0 + \{U_0|X = x, (Z) = p, D = 0\} \quad (39)$$

Using the basis of MTE equation: $MTE \equiv (Y_1 - Y_0|X = x, U_D = u_D)$, the following equation can be derived:

$$\{X = x, U_D = u_D\} = (\alpha_1 - \alpha_0) + (B_1 - B_0) + (\rho_1 - \rho_0)\Phi^{-1}(u_D) \quad (40)$$

Where (Z) is the propensity score generated from the probit model.

$Y_1 - Y_0$ represent outcomes of interest for adopters and non-adopters respectively.

X represents the explanatory variables, $\alpha_1 - \alpha_0$ represent constant values for the treated (integrated Rich-Fish culture technology) and untreated households respectively, $B_1 - B_0$ represent parameters to be estimated for treated (integrated Rich-Fish culture technology) and untreated households respectively.

The selection bias corrective factor is expressed as follow:

$$E(U_1|X = x, P(Z) = p, D = 1) = -\rho_1 \frac{\phi(p)}{\Phi(p)p} \quad (41)$$

$$E(U_0|X = x, P(Z) = p, D = 0) = \rho_0 \frac{\phi(p)}{\Phi(p)(1-p)} \quad (42)$$

Where Φ represents cumulative normal distribution, $-\rho_1 \frac{\phi(p)}{\Phi(p)p}$ and $\rho_0 \frac{\phi(p)}{\Phi(p)(1-p)}$ are the inverse

Mills ratios to correct for any form of bias in the selection of the respondents and distribution of the integrated Rich-Fish culture technology.

Expected Outcomes of the study

At the end of this research, it is expected to provide the following

1. The food security situation and profitability level of the adopters and non-adopters of integrated Rice-Fish culture technology.
2. The determinants of participation and extent of adoption of integrated Rice-Fish culture technology among the farmers in Nigeria.
3. The effect of integrated Rice-Fish culture technology on profitability and food security status of the farmers in Nigeria.
4. The impact of adoption of integrated Rice-Fish culture technology on profitability and food security status of the farmers

Table 2: Variable Definitions and A priori Expectations for explanatory Variables

Variables	Variable type	Description	Empirical Evidence
Dependent Di, and Yi	Dummy	Yield of rice and area cultivated	
Age of household head (years)	Continuous (+/-)	Age of household head	Awotide <i>et al.</i> , (2014) and Haliu <i>et al.</i> , (2014).
Household size (number)	Discrete (-)	Number of people in the household	Abegunde <i>et al.</i> , (2018) Asfaw <i>et al.</i> , (2011)
Sex	Dummy (+/-)	1 if household head is male, 0 otherwise	Onya <i>et al.</i> , (2019), Awotide <i>et al.</i> , (2014)
Educational level (years)	Continuous (+)	Number of years of formal education of household head	Abegunde <i>et al.</i> , (2018), Nyssölä <i>et al.</i> , (2014)
Farming Experience (years)	Continuous (+)	Number of experience in farming practice	Onya <i>et al.</i> , (2019), Emmanuel <i>et al.</i> , (2014)
Farm size (hectare)	Continuous (+/-)	Number of farm cultivated	Abegunde <i>et al.</i> , (2018), Awotide <i>et al.</i> , (2012)
Credit access	Dummy (+/-)	Yes (1) or no (0), credit obtained for farm operation	Onya <i>et al.</i> , (2019), Asfaw <i>et al.</i> , (2011)
Membership of cooperative	Dummy (+/-)	1 if farmer is a member, 0 otherwise	Awotide <i>et al.</i> , (2014) Emmanuel <i>et al.</i> , (2014)
Distance to input supply (M)	Continuous (+/-)	Distance from home to farm	Ghimire and Huang (2015), Asfaw <i>et al.</i> , (2011)
Quantity of paddy produced (Kg)	Continuous (+/-)	Total quantity of rice harvested	(+) Hypothetical
Quantity of fish produced (Kg)	Continuous (+/-)	Total quantity of fish harvested	(+) Hypothetical
Cost of transportation (Naira)	Continuous (+/-)	Cost of transporting produce home/to market from farm	Abegunde <i>et al.</i> , (2018), Awotide <i>et al.</i> , (2014)
Rice-Fish production modality	Continuous (Hypothetical)	Mode of production	Hypothetical
Extension visit	Dummy (+/-)	Yes (1) or No (0)	Awotide <i>et al.</i> , (2016) Nyssölä <i>et al.</i> , (2014)
Own mobile phone	Dummy (+/-)	Yes (1) or No (0)	Onya <i>et al.</i> , (2019) Emmanuel <i>et al.</i> , (2014)
Total income (Naira)	Continuous (+)	Total income from rice and fish production	Awotide <i>et al.</i> , (2014), Tufa and Tefera (2016)
Rice-fish production Experience	Continuous (+)	Total experience in rice/fish production	Olajide and Omonona, (2019), Akinbode <i>et al.</i> , (2012)

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Annex 7: Wetland mapping report (aquaculture and rice farming system in Ebonyi and Kebbi states using geographic information system)

Abstract

This study examines suitable areas for rice cultivation and aquaculture in Ebonyi and Kebbi States, Nigeria. The evaluation of land in terms of the suitability was based on the information of land qualities for which the suitability was based. The selected theme factors include terrain, soil texture, land cover (agriculture land), wetland, flood plain area, precipitation and temperature. The physical factors were produced using remote sensing data such as Landsat images and ASTERDEM from official website of USGS, while rainfall and temperature data were extracted from Climate Research Unit (CRU). Soil texture was formulated using soil maps from Nigeria soil survey. The flood plain area was determined using the digital elevation model. Multi-Criteria Decision Making (MCDM) method using Remote Sensing and GIS techniques was employed to model the suitability of rice cultivation and aquaculture in the study areas. Overlay operations were carried out on the layers (factors) using Boolean analyst to produce land suitability surfaces for the two States. Rice suitability model identified the different areas as highly suitable (center part of Kebbi and western part of Ebonyi), mid suitable (Northern part of Kebbi and central part of Ebonyi), less suitable (parts of the Kebbi central and northeastern part of Ebonyi) and non-suitable (pocket of areas at the northern parts of both states). Models for land suitability for aquaculture on the other hand, identified suitable (Southwestern part of Ebonyi and central part of Kebbi) and non-suitable areas (Northern and Eastern part of Kebbi and northeastern part of Ebonyi with pocket of suitable areas).

Key words: Wetland, geographic information systems, suitability, land cover, multi-criteria analysis

Introduction

In the world today, food production is far less compared with population increase as reflected in the increasing levels of food (especially rice) importation and under-nourishment in countries such as Nigeria (Federal Office of Statistics, 2009), Ethiopia (Ayehu *et al.*, 2015), Papua New Guinea (Samanta *et al.*, 2011), Pakistan (Naz *et al.*, 2017), and Kenya (Kihoro *et al.*, 2013). In Nigeria, rice is both a staple food and also a major source of livelihood for a larger farming population but its production is far less than the demand for local consumption. Hence, the importation of rice is a major factor in depleting Nigeria's foreign reserve. Currently, the Federal Government of Nigeria (FGN) through the Central Bank of Nigeria (CBN) is seeking to boost agricultural production with rice highly prioritized (Mohammed *et al.*, 2019). Several studies (Adejuwon 2006; Mahmood *et al.*, 2012; Adamgbe *et al.*, 2013; Ujoh 2013; Mohammed *et al.*, 2019) have suggested that the declining yield of

crops particularly rice in Nigeria is attributable to several factors such as fluctuating climatic parameters, pressure on land due to population growth and attendant declining size of farm holdings, instability, and migrations resulting from ethnic conflicts and farmer-herdsman crises, and inability of the peasant farmers to access fertilizers. These are in addition to conservative attitudes towards extension services, and market forces that are disincentives, soil quality and terrain/relief, low capital base of farmers, pests and diseases, field operations, timing of planting, and superimposed on these is a fluctuating climate regime and weather elements (Mahmood *et al.*, 2012; Adamgbe *et al.*, 2013; Mohammed *et al.*, 2019). Optimizing rice production can be achieved primarily through farming practices that are environmentally friendly and economically efficient. As population continues to increase with consequent per capita land allocation decrease, the critical need to optimally utilize available land resources for efficient agricultural production is becoming increasingly prominent and indeed unavoidable.

Many establishments have shown interest in the suitability area for rice so as to estimate the production and expand the extent of rice farming. It is therefore necessary to develop a systematic approach to facilitate the production of land suitability information. The information can be in form of map layers to determine area suitable for the crop production. Food and agriculture organization (FAO) guideline on the land evaluation system is widely used. The system is based on defined land qualities as related to landuse requirement. Land cover classification activities have been conducted in the past studies. Two land classification systems are used: land capability for field crops and land suitability for rice. Landuse planning requires dynamic land evaluation system. The conventional map production is not such a dynamic tool. Recently with the advent of satellite remote sensing and geographic information systems (GIS), a number of pilot projects have been undertaken to test the capability of this new technology. So far the spatial database of land resources is being established by digitally encoding the existing maps. In an effort to apply this technology, this research proposes to model land suitability for rice using GIS. This can provide the key in improving yield to feed an expanding nation population, West Africa sub-region and the world population at a time of increasing restraints on agriculture. The river provides a good platform for irrigation. Increased usage of land resources in terms of production has led to soil degradation through loss of plant nutrients and organic matter, erosion, buildup of salinity and damage to soil structure. There is an urgent need for the evaluation of land resources in the context of their usability as well as sustainability for a crop landuse in the light of the needs of that crop. This process is technically known as land suitability evaluation and a detailed methodology has been laid down by the Food and Agriculture Organization (FAO, 1978). Geographic Information System can help to improve the understanding of the processes of land evaluation and decision-making. It can improve the efficiency of data processing, help to solve data integration problems and

can support spatial analysis. It is also crucial in improving the description of land utilization types required for land evaluation. This research is therefore set to produce spatial land evaluation for rice growing using geographic information system and Remote Sensing techniques. To achieve this aim, the following objectives were carried out: to determine areas good for rice cultivation in the areas of study and to provide the areal extent of rice growing suitable areas in the areas.

Identifying suitable place for rice and aquaculture farming implies bringing together the criteria for locating the farming activities in order to define broad areas suitable for such activities or mixes of activities (José *et al.*, 2017). It is a process that countries can use to sustainably and responsibly identify and allocate areas that are biophysically and socio-economically suitable for rice and aquaculture. In broad terms, it can be used to identify potential areas for growth where aquaculture is new, for example, and help regulate the development of aquaculture where it is already established (FAO.2013). More specifically, land suitability classification according to GESAMP (2001) can be used to: prevent and control environmental deterioration at the farm and watershed scale; implement biosecurity measures and disaster risk management; reduce adverse social and environmental interactions; and serve as a focus for estimates of environmental capacity. Additionally, it can also be used to increase production and social development; serve as a platform for dialogue to reduce conflict among potential resource users; help potential developers identify prospective farm sites where long-term investments are possible; establish clear regulations for commercial behaviour within areas identified; and define the area over which planners and regulators set and monitor objectives (José *et al.*, 2017). In Nigeria, especially in Kebbi and Ebonyi States, there is dearth of information on land suitability for both rice cultivation and aquaculture production. Therefore this study aimed at assessing the areas in Ebonyi and Kebbi States that are suitable for the cultivation of rice aquaculture practice using geographic information system (GIS) and remote sensing (RS).

Methodology

Study area

The study was carried out in Ebonyi and Kebbi States. Ebonyi State is found in the eastern part of Nigeria and cover about 35969.30 km². The Kebbi State is located in the northern part of the country and cover about 6185.77 km². The states area characterized by physical features such as high and low relief, wetlands, unique drainage system, and vegetation cover. The expansive wetlands give the States great potential for rice farming. The wetlands also provide grazing area during the dry season. Figure 1 shows the States and the drainage network system. The areas are generally densely populated mainly due to the availability of suitable lands for agriculture and good climatic conditions like relatively high rainfall and temperatures. Population is about 120 and 508 person/km² for Kebbi and Ebonyi States

respectively. Rainfall is between 1025mm and 1050mm/annum in Kebbi State (Agan *et al.*, 2019) and between 1613.80mm to 2136.27mm/annum in Ebonyi State (Ogbuene, 2010; Diagi1 and Nwagbara, 2018). The annual temperature is between 31°C and 38°C for Kebbi State (Agan, *et al.*, 2019) and 29 °C and 26 °C for Ebonyi State (Diagi1 and Nwagbara, 2018).



Figure 1: The study areas (Ebonyi and Kebbi States)

Data Collection and Analysis

The Landsat images of Kebbi State (190/52, 191/51 and 191/52 paths and rows) and Ebonyi State (188/54 and 188/55 paths and rows) were obtained from USGS website. Climate data sets of 2020 were obtained and used to develop the climate maps of the two states while the elevation surfaces were created from the SRTM DEM map (90 m × 90 m). The Landsat images were processed and classified into vegetation, water/wetlands and bare surfaces using Maximum Likelihood Classifier-MLC (Foody, 2018; Agbor *et al.*, 2012; Alo *et al.*, 2020). Elevation surface, the DEM image was first processed to fill sinks in order to remove outliers. Multi-criteria analysis technique was adopted because of the multiple parameters involved in decision-making (Maddahi *et al.*, 2014) using Boolean evaluation process of input raster that utilizes logical expression. The approach was specified by structural query Language (SQL) expression which uses an SQL query. The query expression was used to select a subset of features and table records. It adheres to standard SQL expressions. The Boolean images created were that of temperature, precipitation, soil, agriculture land, elevation. The outputs of this process are the multi-criteria maps that show appropriate areas suitable for rice cultivation and aquiculture. This approach has been documented by many researchers (Kihoro, Bosco, and Murage 2013; Masoud *et al.*, 2013; Giri and Nejadhashemi 2014; Maddahi *et al.*, 2014; Ayehu and Besufekad 2015; Abach and Ngigi 2016; Naz and Rasheed 2017). This approach is one of the extensive methods widely employed to resolve Multi-Criteria Decision-Making (Giri and Nejadhashemi 2014), and has

been considered reliable methods (Ayehu and Besufekad 2015). It was adopted in the 1960s to assist decision making by accommodating several criteria, while also integrating the opinions of the population involved, into a potential framework (Singha and Swain 2016). In principle, the multi criteria approach allows analysis of alternatives on the basis of conflicting factors which may be quantitative and/ or qualitative (Elaalem 2010), relying of GIS tools which accurately evaluates each variable according to their relative importance on the conditions for rice cultivation and aquaculture (Perveen *et al.*, 2008). The relevance and strength of this approach are in its capacity to present a synoptic perspective by handling a wide range of criteria data at multi-spatial, multi-temporal and multi-scale levels, and from different sources for a time-efficient and cost-effective analysis. In addition, the adoption of this approach is based on its simplicity and applicability in terms of identification and selection of parameters required for locating best sites with GIS.

Results and Discussions

Three major land cover types; water body, vegetation cover/agriculture land, and bare surface, were identified from the land cover map (Figure 2). About 2.05 percent and 0.09 percent of total area was occupied by water/wetland in Kebbi and Ebonyi state respectively while vegetation covered about 40.74 percent (14,653.74 km²) and 38.39 percent (2,374.48 km²) in Kebbi and Ebonyi respectively (Table 1). The bare surfaces, which include built up, dry land, and other areas were grouped as non-vegetation cover made up 57,021 percent (20,577.20 km²) in Kebbi and 50 percent (3806.00 km²) in Ebonyi. The states are characterized by hills and large extent of lowlands in the southern parts of both States. The flood plain map showed area that are susceptible to flood. However, when other factors obtained from the field are incorporated the flood plain area in the map will be reduced and can then confirm specific areas where the flood will be restricted.

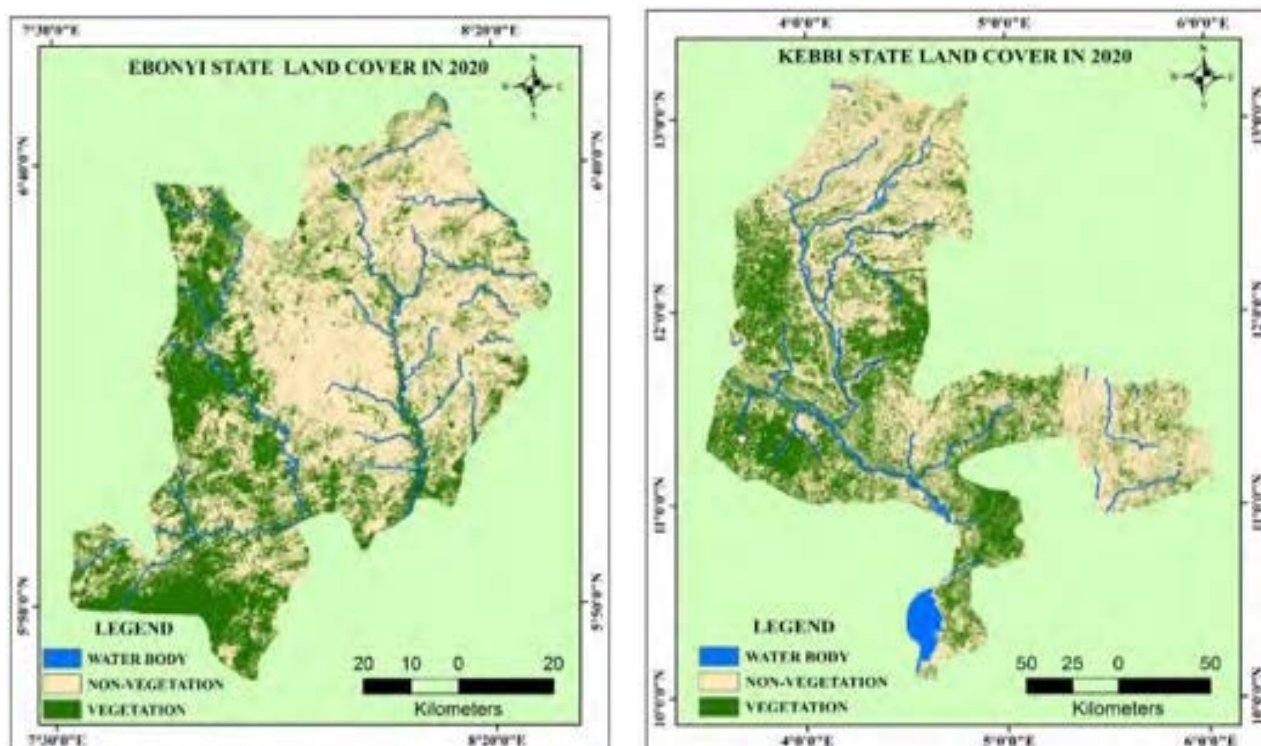


Figure 2: Land cover of Ebonyi and Kebbi States

Table 1: Land use land cover of Ebonyi and Kebbi States

	Kebbi State			Ebonyi State	
Class	Area	%		Area	%
Water Body	738.32	2.05		5.29	0.09
Non-Vegetation	20577.20	57.21		3806.00	61.53
Vegetation	14653.74	40.74		2374.48	38.39
Total	35969.26	100		6185.77	100

Figures 3 to 8 show the mean air temperature with high of 30°C and a low of about 25°C (Figure 4); mean precipitation (Figure 5); soil (Figure 6), wetland (Figure 7). Other maps include Digital Elevation Model (DEM), flood plain and wetland. Five of the variables analyzed in this study; DEM, temperature, precipitation, wetland and soil, are independently applied for suitability analysis of rice cultivation in Figure 8. Each combination of the parameters shows varying extent of suitability results for rice cultivation in the States. For instance, while high mean temperature, high rainfall, level land and wetland reflect a highest suitability for rice cultivation across the States, the overlay operation show non-suitability or least suitability for rice cultivation across the States if one or more input layers are missing (that is, with zero value). The land cover classification map (Figure 2) reveals the largest

area considered suitable for rice cultivation. The soil physical properties describe how much drained and suitable for rice cultivation in the States. All plants are affected by excessive drainage density which is dependent on soil structure. (Ambarwulan *et al.*, 2016). It is considered inappropriate for rice cultivation where the topography encourages high surface run-off during rainy season (Sonon, *et al.*, 2014).

Based on the multi-criteria analysis of Kebbi and Ebonyi States for rice cultivation (Figure 8), there are various degree of suitability from non-suitable, less suitable to moderately suitable and highly suitable. Izzi local government area of Ebonyi State is not suitable for rice cultivation. However, Abakaliki, Ivo, Ezza South, part of Ikwo and Ebonyi local government are moderately suitable and the highly suitable local government areas for rice cultivation include; Ishielu, Ohaozara, Onicha, Afikpo South, part of Ohaukwu and Afikpo North. In Kebbi State, Fakai, Shanga, northern part of Ngaski and part of Danko wasagu local government areas are less suitable for rice cultivation. Moderately suitable local government areas for rice cultivation are those at the northern part of the state, which include; Birninke, Gwandu, Augie, northern part of Arewa and little portion of southern Ngaski local government areas. For highly suitable area for rice cultivation, Maiyama, Suru, Jega, northern part of Dandi, southern part of both Arewa and Bagudo local government area are within the sphere of land. The result in this study is similar to that of the report of Dengiz (2013) when he used GIS to model land suitability for rice cultivation in Turkey. He combined the soil physical and chemical properties in his study but in this study only the physical properties of the soil, terrain, wetland, temperature and precipitation were considered to model the suitability of the states for rice cultivation. A number of authors (Adejuwon 2006; Mahmood *et al.*, 2012; Adamgbe *et al.*, 2013; Ujoh 2013; Mohammed *et al.*, 2019) reported that extreme climatic variation affect the cultivation of rice therefore making the temperature for the optimum yield of rice ranged from 25°C to 35°C, which was used in this study to model the land suitability for rice cultivation.

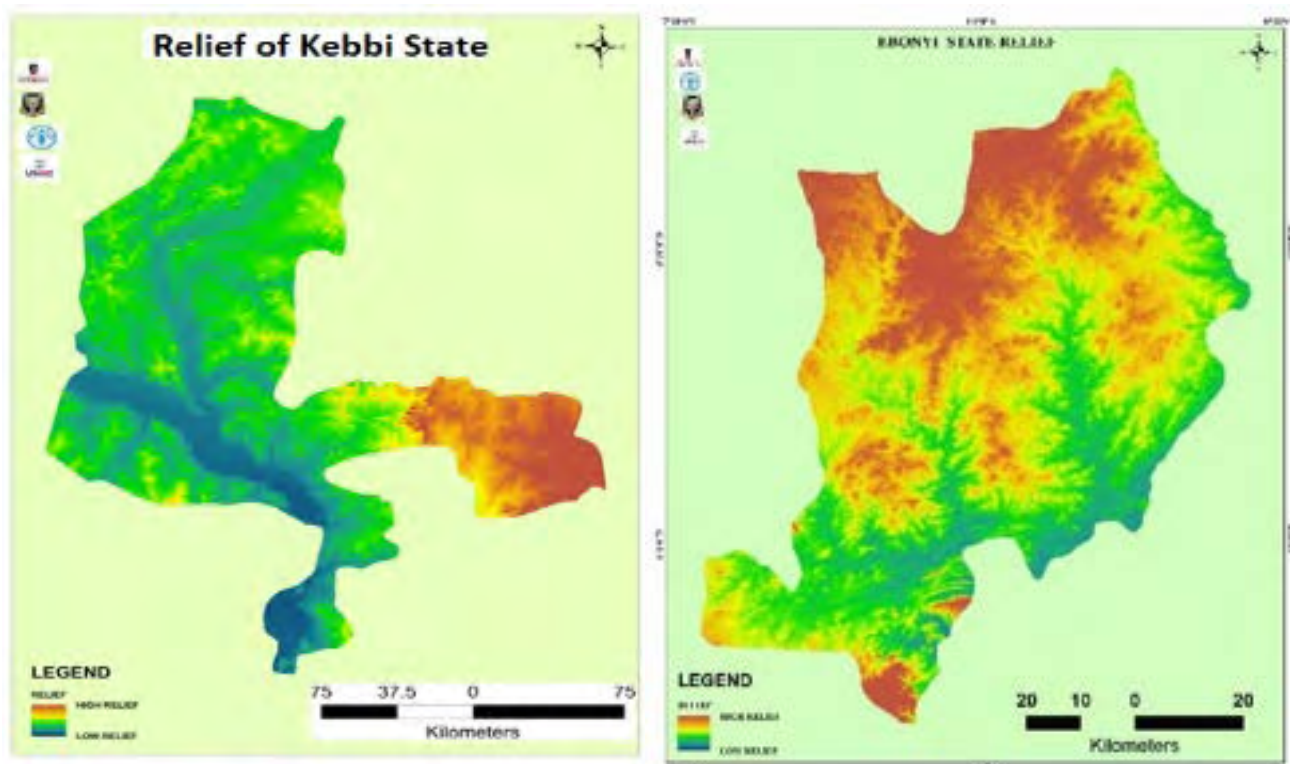


Figure 3: Relief of Kebbi and Ebonyi States

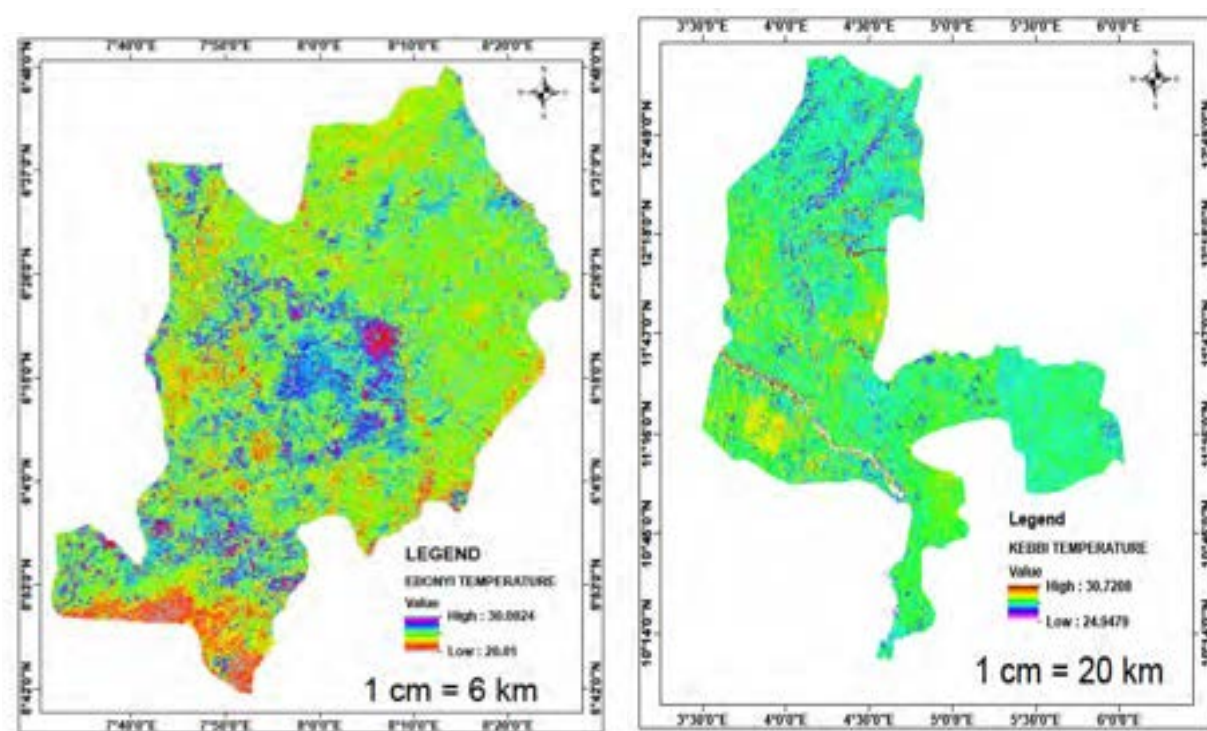


Figure 4: Mean temperature ($^{\circ}\text{C}$)

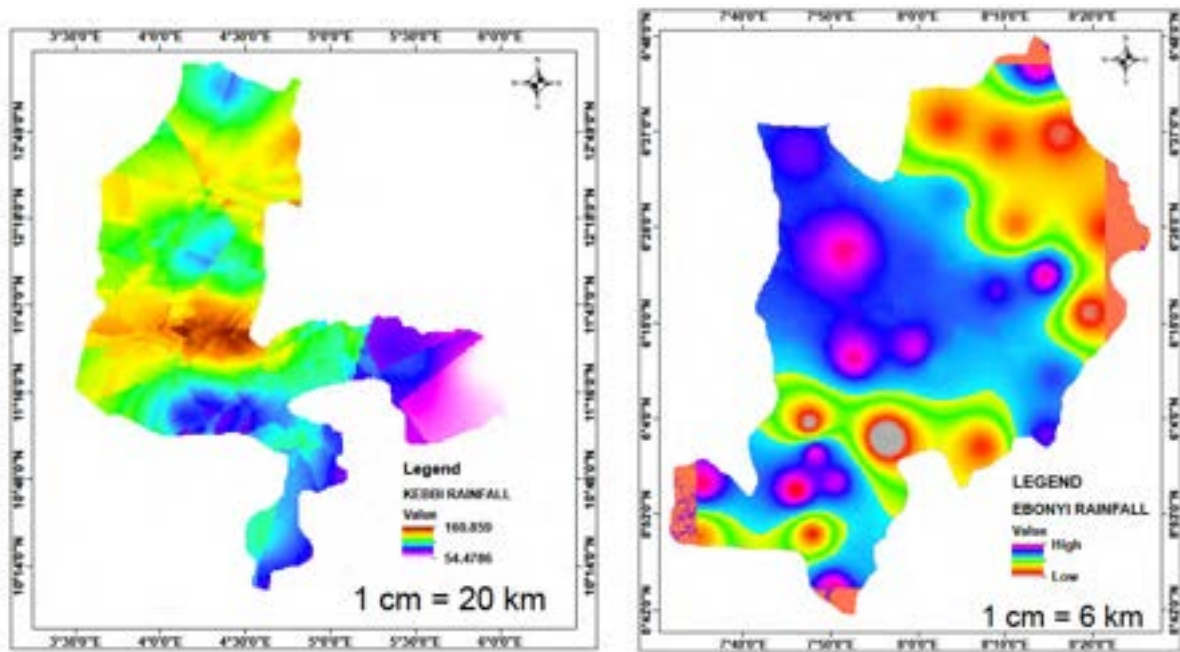


Figure 5: Mean precipitations in Kebbi and Ebonyi States

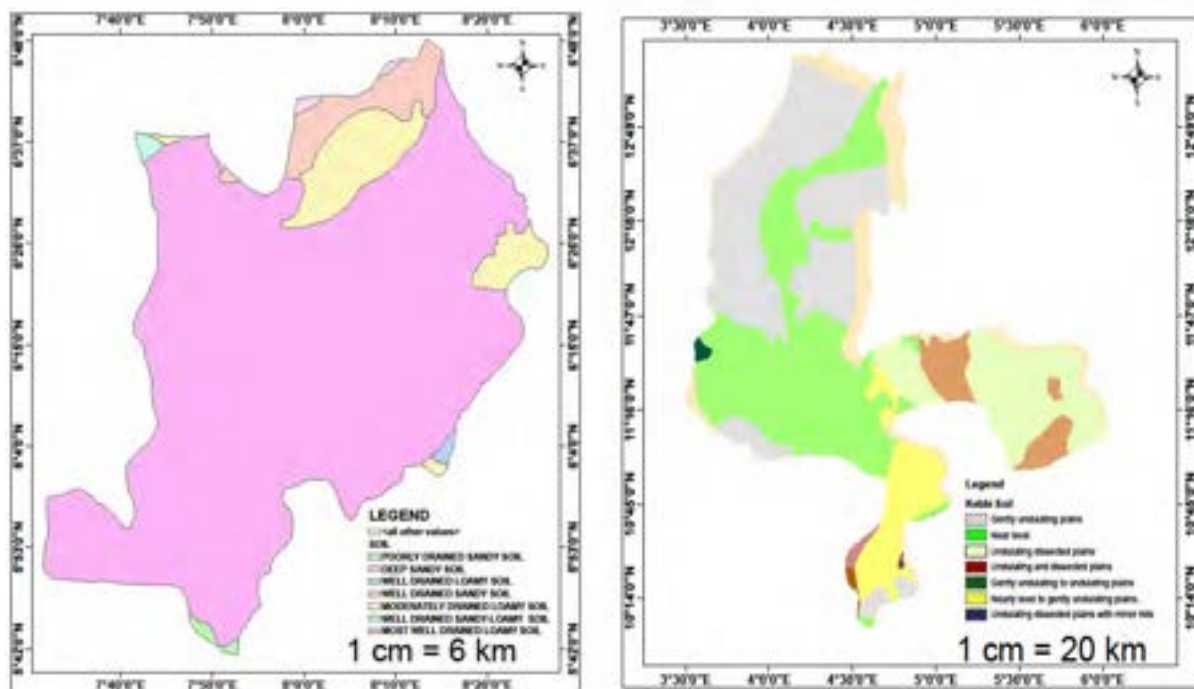


Figure 6: Soil Distribution in Kebbi and Ebonyi States

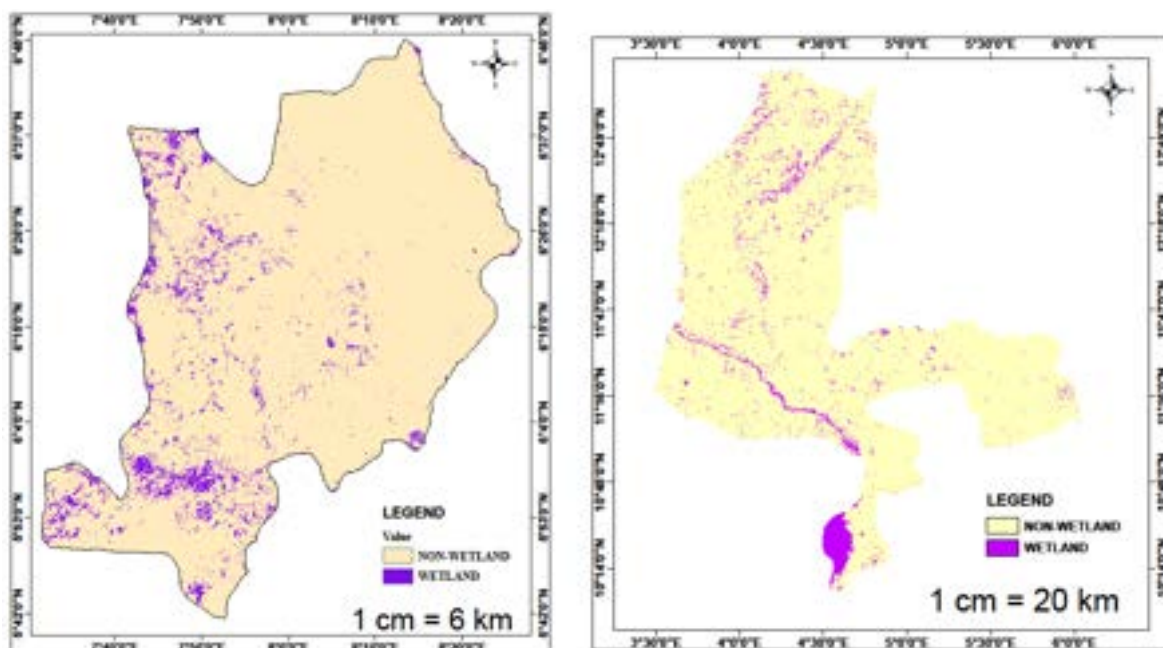


Figure 7: Wetland Distribution

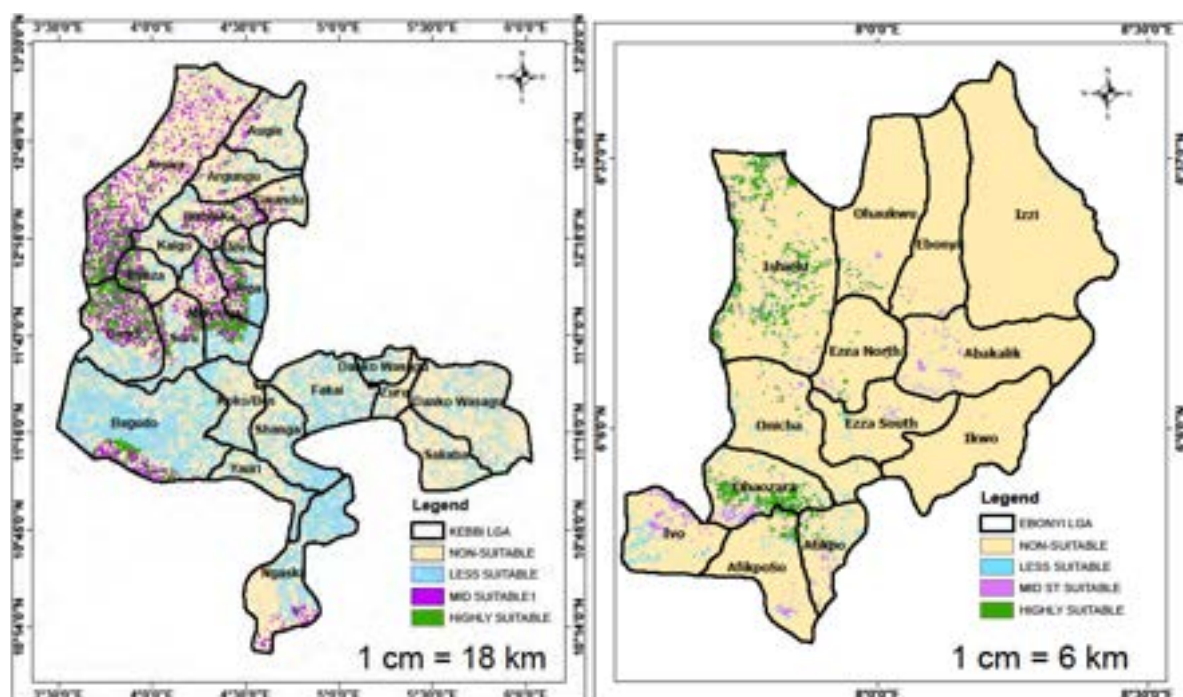


Figure 8: Suitability for rice cultivation

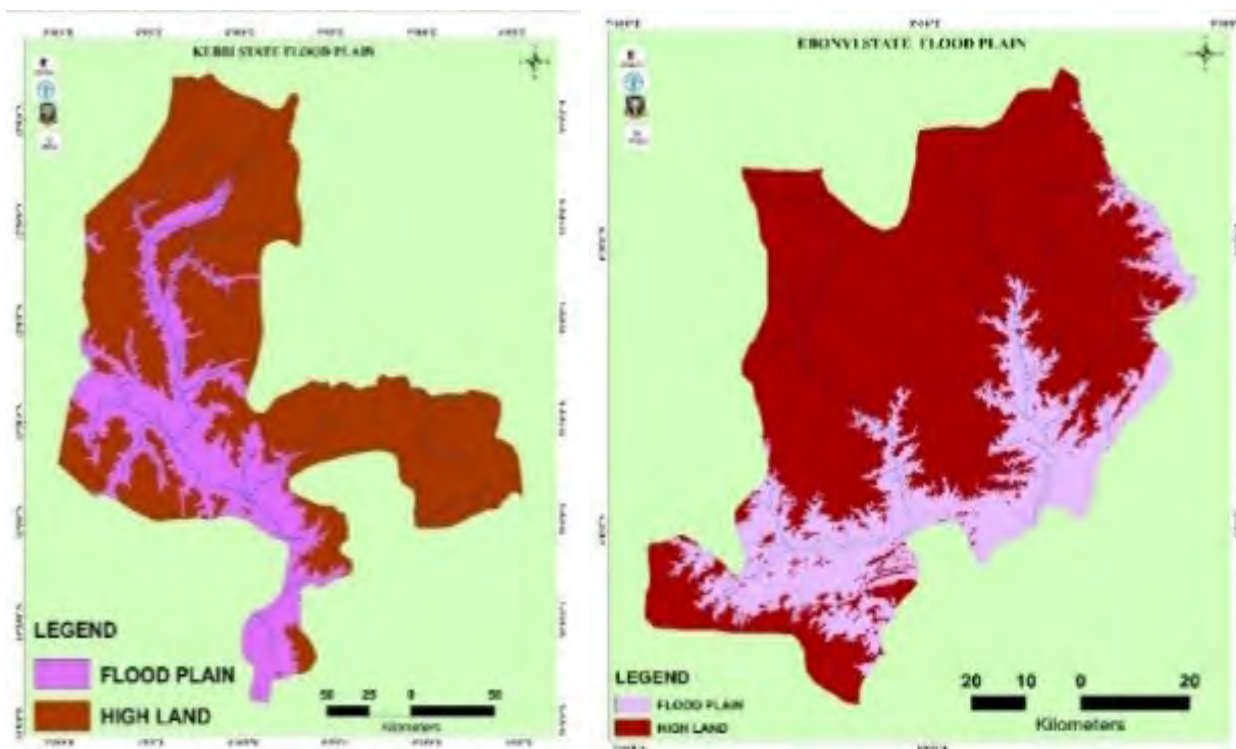


Figure 9: Flood plain area of Kebbi and Ebonyi States

Three of the variables analyzed in this study have been applied to identify areas suitable for aquaculture in Figure 9. The overlay analysis using temperature vegetation and wetland shows extent of suitability results for fish farming in the States. The combination of the parameters produced suitable and unsuitable maps. The areas of high mean temperature, wetland, and agriculture land (vegetation cover) reflect suitability for aquaculture across the States, the overlay operation show non-suitability across the States when one or more of the input parameters are missing. The suitability maps map (Figure 10) reveals the most areas considered suitable for fish farming are more in south-west parts of the two study areas. It is also a pointer to the fact that areas that are not considered suitable for rice cultivation are considered suitable for aquaculture, especially in Ebonyi State. The local governments considered very suitable for aquaculture include; Ishielu, Ezza north, Ezza South, Onicha, Ohaozara, Ivo Afikpo North and Afikpo South. However, some other areas have pocket of locations within the local governments where aquaculture practice is suitable; while there are pocket of areas suitable in Izzi, Ebonyi, Abakaliki and Ikwo lga. In Kebbi State, Ngaski, Yauri,, shanga, bogudo, Dandi, suru, Maiyama Jega, Bunza Arewa Birninke and partly Gwandu, Augie are suitable for aquaculture while there are also little portion of some local government areas where aquaculture can be practices; Argungu, Sakaba and Zuru and Danko Wasagu.

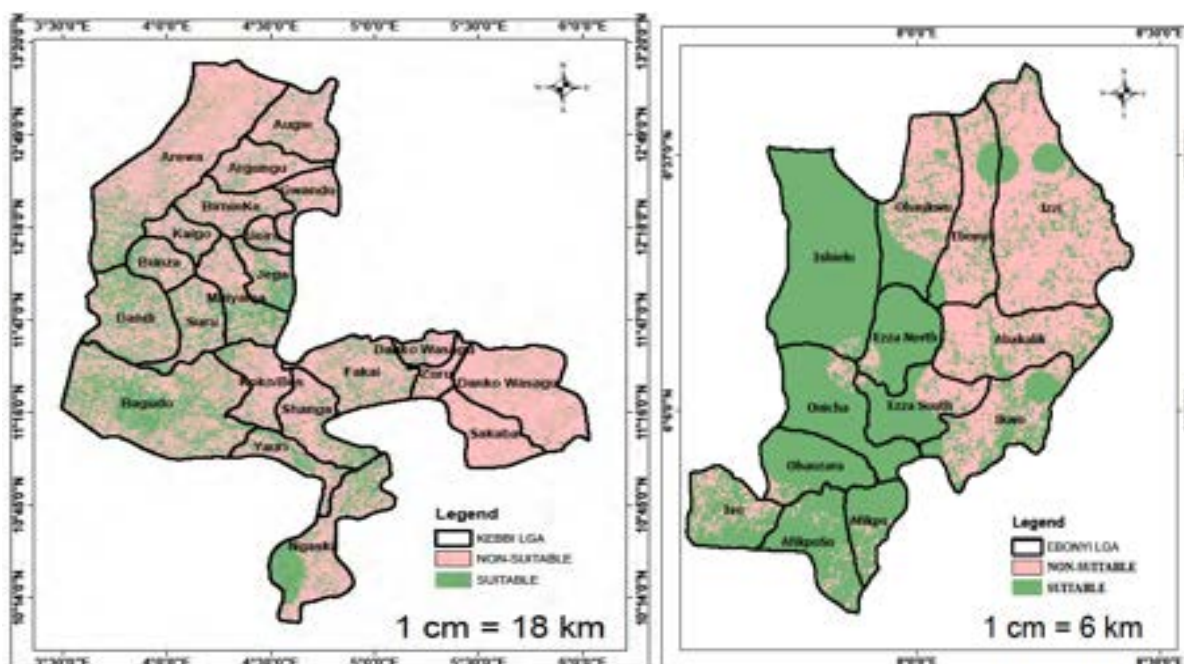


Figure 9: Suitability for Aquiculture

Conclusions

This study confirms the capability of GIS to integrate spatial and attribute data and to offer reliable method of land suitability assessment with high accuracy especially in a large are of land and where banditry and insurgency in imminent. It is a veritable tool for decision support system in rice cultivation and aquaculture production. In addition, the study's modeling component provided on the local government within states under investigation where cultivation of rice is suitable.

In the two States, areas suitable for aquiculture are more, compared to areas considered suitable for rice cultivation. The study also reveals that even in the areas with favourable rainfall within the States, rice cultivation may not be maximized. The same applies to areas considered with suitable temperature conditions, from 25°C to 30°C, given that rice is a tropical and sub-tropical crop. The practical relevance of this study is based on the need to improve food security as fish and rice importation accounts for billions of dollars. Therefore, it is important to assess land resources and maximal utilization in the face of rising food crisis in the country in order to move particularly the two States and Nigeria in general towards achieving food security. This study is one of the numerous ways needed to avert the dangers of food crisis at the local level. The study however did not include socio-economic criteria (population size and density, land tenure/ownership data, etc.) as well as the chemical characteristics of soil in the analysis. Going forward, this is are gaps that can be filled by further studies seeking additional accuracy in the suitability assessment of fish and rice cultivation within the study areas and the country at large.

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Annex 8: Fish feed study report I (apparent digestibility coefficients of by-products in integrated rice and fish farming (rice bran and fish offal meal) fed to the african catfish, *Clarias gariepinus* (burchell, 1822) and *Oreochromis niloticus* (linnaeus, 1758) juveniles)

Emmanuel K. Ajani,* Matthias Halwart, Bamidele Omitoyin, Amro Bart, Oluwafemi Ajayi, Xinhua Yuan, Austin Stankus, Gary Burtie, Kazeem Kareem, Ebenezer G. Funsah, Babatunde Oduntan, Lerana Georgina, Yahaya M. Abubakar, Johnpaul C. Ikokuemesi, Lawall A. Argungu

Emmanuel K. Ajani
Department of Aquaculture and Fisheries Management
University of Ibadan, Nigeria
ekajani@yahoo.co.uk

Farm diversification through the integration of aquaculture and agriculture (IAA) is a growing interest in the developing world. By-products generated from agriculture & aquaculture such as rice bran and fish offal may be a major environmental concern if not properly disposed of or utilized. Given the importance of feed in aquaculture development, exploring the opportunities of converting these by-products from IAA for the production of good quality and cost-effective feed for aquaculture development is important. This study, therefore, investigated the nutrient composition and apparent digestibility coefficient (ADC) of nutrients in rice bran and fish offal in diets fed to *Clarias gariepinus* and *Oreochromis niloticus*.

An 8-week feeding trial was conducted at the University of Ibadan, Aquaculture Nutrition Laboratory to determine the apparent digestibility of the test ingredients (TI) - rice bran feed (RBF) and fish offal meal feed (FOM) (procured from USAID/MSU IAA intervention project in Nigeria). These test ingredients were analyzed for their Amino Acid Profile and the amino acid contents. Samples were further evaluated using Provisional Amino Acid of Egg Scoring Pattern (PAAESP) to determine their Amino Acid Score (AAS) ingredients. In addition, the TIs were included in the diets of *Clarias gariepinus* and *Oreochromis niloticus* to formulate 40 % and 30% crude protein (CP) reference diets (RF), respectively. Test diets contained 70 % of reference diets and 30 % of test ingredients, with chromic oxide as the inert marker. Groups of *C. gariepinus* and *O. niloticus* (10±0.01; 15±0.01 g, respectively) were fed these diets for 8 weeks. Apparent digestibility coefficients for protein, ash and energy were determined. Data were analyzed using descriptive and quantitative statistics.

Crude protein for fish offal meal and rice bran meal was 65.83±0.21% and 10.59±0.11%, respectively (Table 1). These were similar to fish meal (75.4%) and maize (9.4%). Ash contents were 9.61±0.01 (%) in fish offal meal and 9.13±0.02 (%) in rice bran. The essential amino acid profile (Table 2) revealed that FOM contained arginine, lysine, methionine and Tryptophan with RB having methionine and Tryptophan at the concentration required for growth in *C. gariepinus*. The FOM contained histidine, isoleucine, methionine, Phenylalanine, Threonine, and Tryptophan with RB having (Histidine, methionine, Phenylalanine, and Tryptophan) for growth in *O. niloticus*. The limiting amino acid (LAA) for both the fish offal and rice bran was Met+Lys (TSAA). The ADC of nutrients (Tables 3 and 4) varied significantly across treatments ($p<0.05$) in *C. gariepinus* and *O. niloticus*. Apparent digestibility of Protein was significantly higher in FOM (77.77 ± 0.49 %) and least in RBF (64.17 ± 0.83 %) in *C. gariepinus* and FOM (78.61 ± 0.51 %) and least in RBF (63.11 ± 0.19 %) for *O. niloticus*.

The result of this study also indicate that nutrient digestibility by *C. gariepinus* and *O. niloticus* was adequate for both TI, FOM was more digestible.

Table 1: Proximate Analysis of the Test Ingredients *Rice Bran RBF and Fish Offal Meal FOM

Sample	Moisture content (%)	Crude protein (%)	Fat content (%)	Crude fiber (%)	Ash content (%)	Carbohydrate (%)
Rice bran	10.21±0.01	10.59±0.11	10.00±0.04	14.00±0.04	9.61±0.01	55.71±0.25
Fish offal meal	7.11±0.01	65.83±0.21	8.41±0.01	1.33±0.01	9.13±0.02	68.95±0.21

Table 2. Amino Acid Content(g/100g) and a Score of Fish Offal Meal and Rice Bran using Provisional Amino Acid of Egg Scoring Pattern

Parameter	PAAESP Protein (g/100g)	Protein (g/100g)	AAS	Essential AAS
Arginine	1	1.00	1.00	1.00
Lysine	0.5	0.02	1.34	0.35
Isoleucine	1	0.03	1.00	0.03
Tryptophan	1	1	1	0.00
Valine	2	0.77	0.80	0.27
Threonine	4	0.01	0.20	0.01
Phenylalanine + Tyrosine	4	0.00	0.20	0.02
Methionine + Cysteine	1.5	0.14	0.70	0.02
Total	30	20.79	7.36	00.02

Table 3: Apparent Nutrient Digestibility (%) for *Clarias gariepinus*

Parameter (%)	RF	RBF	FOM
ADC	72.51±1.12 ^a	64.17±0.83 ^c	77.77±0.49 ^a
Protein			
ADC	54.45±6.88 ^c	59.45±4.62 ^{ab}	65.14±6.23 ^a
Energy			
ADC	70.87±0.98 ^c	74.19±3.59 ^{ab}	77.24±1.88 ^a
Lipid			

Table 4: Apparent Nutrient Digestibility (%) for *Oreochromis niloticus*

Parameter (%)	RF	RBF	FOM
ADC	66.50±1.98 ^b	63.11±0.19 ^c	78.61±0.51 ^a
Protein			
ADC	60.77±0.58 ^c	64.30±2.16 ^{bc}	76.46±3.41 ^a
Energy			
ADC Lipid	71.21±5.67 ^a	73.95±1.07 ^a	75.13±5.61 ^a

Annex 9: Fish feed report II (Chemical Evaluations of Agricultural Wastes from Integrated Fish and Rice Farming and Their Potential as Fish Feed Ingredient)

FEED THE FUTURE INNOVATION LAB FOR FISH

Chemical Evaluations of Agricultural Wastes from Integrated Fish and Rice Farming and Their Potential as Fish Feed Ingredient

Georgina Fyinsohrwa Leramo, Halwari Mathias, Emmanuel Kolawole Ajami, Amrit Brat, Bamidele Oluwarotimi Omitoyin, Oluwafemi Ajayi, Gary Burtle, Stankus Austin, Yuan Xinlun, Oladeji Kareem kazeem, Babatunde Oluwafemi Oduniran

Department of Aquaculture and Fisheries Management, University of Ibadan, Nigeria

Introduction

- Rice bran and fish offal are two agricultural by-products from integrated rice and fish farming system.
- Rice bran comes from the outer layer of rice and waste from rice processing, its generally of low value used without any refinement in livestock feed or at best in pond water fertilization
- Fish offal is a by-product from fish processing, consisting of discarded parts (head, bones and internal organs) generally regarded as unfit for human consumption (Farahiyah *et al.*, 2015).
- They can be utilized to produce fish feed and indirectly help towards a greener environment (Thongrajukaew *et al.*, 2015).
- These two agricultural by-products could be solution to development of low cost and good quality fish feed for fish under IRF.
- However, to achieve this, there is need for proper evaluation of the chemical properties to ascertain their usefulness as alternative fish feed ingredients.

Objectives

- To evaluate the chemical properties of rice bran and fish offal produced at the research Integrated Fish and Rice plot in University of Ibadan.
- To assess the suitability of rice bran and fish offal as fish feed ingredient.

Materials and methods

- Collection of samples - 5kg of Rice bran and fish offal was collected as waste products from processing under the Integrated Fish and Rice (IFR) plot in the University of Ibadan.
- These were oven dried at 60°C for 2days.
- Dried samples were grinded to powder.
- These samples were analyzed for their proximate composition (dry matter, crude protein, crude fibre, ash, and lipid) following the method of AOAC (AOAC International, 2005).
- Also their Amino Acid Profile were determined (AOAC, 2005)
- The amino acid contents in each of the samples were further evaluated using Provisional Amino Acid of Egg Scoring Pattern (PAAESP) to determine their Amino Acid Score AAS following the method of Audu and Aremu (2011).

Statistical Analysis

- Mean, standard error of mean (SEM) were determined for all nutrients and statistical analysis was done by using Statistical Package for Social Sciences (SPSS/PC, Version 12.0; SPSS Inc., Chicago).

Table 1. Proximate Analysis of Rice bran and Fish offal meal

Samples	Moisture content (%)	Crude protein (%)	Fat content (%)	Crude fiber (%)	Ash content (%)	Carbohydrate (%)
Rice bran	10.21±0.01	10.59±0.11	16.08±0.04	14.06±0.04	9.61±0.01	35.71±0.25
Fish offal meal	7.11±0.01	65.83±0.21	9.41±0.01	1.93±0.01	9.13±0.02	6.60±0.21

Values are means ±SEM (Standard error of means) of duplicate samples.

Table 2. The amino acid profile of Rice bran and Fish offal meal

Amino acids	Ricebran (g/100g)	Fishoffal meal (g/100g)
Alanine	4.11±0.05	4.80±0.05
Arginine	4.33±0.3	6.28±0.05
Aspartic acid	8.67±0.05	9.92±0.05
Cystine	0.84±0.05	0.90±0.07
Glutamic acid	10.57±0.05	14.68±0.05
Glycine	2.2±0.3	5.3±0.3
Histidine	2.15±0.04	3.12±0.05
Isoleucine	2.88±0.03	4.08±0.05
Leucine	7.25±0.1	7.64±0.03
Lysine	4.34±0.01	6.77±0.05
Methionine	0.87±0.04	1.74±0.04
Phenylalanine	4.26±0.01	4.06±0.06
Proline	2.49±0.05	3.81±0.05
Serine	2.29±0.02	5.11±0.05
Threonine	3.19±0.03	3.89±0.05
Tryptophan	1.13±0.05	1.05±0.03
Tyrosine	2.43±0.02	3.93±0.04
Valine	3.17±0.05	4.82±0.05

Values are means ±SEM (Standard error of means) of duplicate samples.

Table 3: Amino acid content(g/100g) and score of Fishoffalmeal and Ricebran

Parameters	PAAESP Protein (g/100g)	Fishoffal EAAC	AAS	Ricebran EAAC	AAS
Leucine	7	7.66	1.09	7.24	1.03
Lysine	5.5	6.82	1.24	4.35	0.79
Isoleucine	4	4.03	1.01	2.85	0.71
Tryptophan	1	1	1	1.08	1.08
Valine	5	4.77	0.95	3.22	0.64
Threonine	4	3.81	0.95	3.16	0.79
Phenylalanine + Tyrosine	6	7.96	1.33	6.67	1.11
Methionine + Cystine	3.5	2.74	0.78	1.62	0.46
Total	36	38.79	7.36	30.19	6.63

Essential amino acid with the least score was considered limiting in the fishoffalmeal and ricebran
EAAC= Essential Amino Acid Content AAS= Amino Acid Score PAAESP= Provisional Amino Acid (Egg) Scoring Pattern




Photo 1: Rice bran Photo 2: Fish offal

- In this study, the crude protein (%) of 65.83±0.21 and 10.59±0.11 were recorded for fish offal meal and rice bran, respectively.
- These values compared favourably to fish meal (75.4%) and maize (9.4%) reported by AFZ (2011).
- Ash content 9.61±0.01(%) in fish offal meal and 9.13±0.02 (%) in rice bran were similar to the result of Nasim *et al* (2012) and Mohammad *et al* (2019).
- Fish offal meal recorded in this study were comparable to those recorded for proximate composition by Orisanola *et al* (2021).
- The amino acids content of fish meal offal and rice bran in this study is comparable to those reported by Abimorad *et al* (2008).
- The amino acid score showed that Methionine + cystine is the limiting amino acid in fish offal meal and rice bran.
- However, when rice bran and fish offal meal are combined with high methionine + cystine content of other ingredients it can support the requirements in fish diet.
- This statement is supported by (Robinson and Li, 2007) who claimed that a feed ingredient rich in a certain amino acid can be used to supplement a fish diet that lacks that particular amino acid.
- While choosing ingredients for the formulation of fish feed, rice bran and fish offal meal amino acid will serve as a guidance

Conclusion

- This study reveals that these by-products (rice bran and fish offal) have potentials to be used as ingredients in formulation of fish feed.

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Annex 10: Integrated rice-fish research result I (Evaluation of Water Quality and Soil Properties of Integrated Rice and Fish Farming IRF System Under Different Agro-ecological Zone in Nigeria)



FEED THE FUTURE INNOVATION LAB FOR FISH

Evaluation of Water Quality and Soil Properties of Integrated Rice and Fish Farming IRF System Under Different Agro-ecological Zone in Nigeria.
 Rosemary Okovido, Ogunkoya Temitope, Halwart Matthias, Emmanuel Kolawole Ajani, Amrit Brat, Bamidele Oluwarotimi Omitopin, Oluwafemi Ajayi, Gary Burtle, Greg Fonsah, Stankus Austin, Yuan Xinhua, KAREEM Kazeem Oladeji, Oduntan Oluwafemi Babatunde

INTRODUCTION

- Integrated Rice Fish (IRF) model is an innovative method that encapsulate all elements of sustainability.
- The IRFs can make efficient use of scarce water and land resources (Frei and Becker, 2005),
- maintain biodiversity (Freed *et al.*, 2020),
- regulate water flows and water quality (Zhang *et al.*, 2012), and
- reduce the need for agrochemicals for rice production (Xie *et al.*, 2011).
- Water used for aquaculture cannot give the desired production unless its quality parameters become optimal for the growth and survival of cultured organisms (Malik *et al.*, 2020).
- In addition, healthy soil supports and maintains better agricultural productivity with minimal environmental impact (Reynolds *et al.*, 2009).
- Soil quality indicates an inherent trait of soils that can be inferred from soil properties or long observation.
- Observations of water quality parameters and its monitoring in a fishpond would be necessary to ensure the supply of good quality water as well its appropriateness for fish culture (Malik *et al.*, 2018).
- The quantification of soil quality to estimate the soil productivity for long term purpose is crucial for the timely identification of adverse effects of management practices (Qi *et al.*, 2009; Barrios and Trejo 2003; Mairura *et al.*, 2007).

OBJECTIVES

- To provide understanding on how IRF fit into environmental sustainability concept under two distinct agro-ecological zones in Nigeria.
- To investigate the performance of IRF in relationship with water quality and soil properties.

MATERIALS AND METHODS

Bi-weekly field trip were taken to each of the USAID- FIL demonstration IRF plots in Nwanmu, Ebonyi State and University of Ibadan, Oyo State in a four months cycle to take water samples.

RESULTS AND DISCUSSIONS

- Sample collection procedure for water quality were carried out according to Bradley *et al.*, (2016).
- Water quality parameters such as pH, Dissolved oxygen, nitrate, nitrite, ammonia, were analyzed in-situ for each of the IRF plots using pondlab test-kit in accordance with APHA standards. (APHA, 1995)
- Soil Sample Collection were done monthly and collection Procedure were done according to Carter And Gregorich (2008).
- Available Nitrogen, Phosphorus and organic carbon were analysed and recorded using standard methods of APHA (1989) and Biswas, (1993).

Results in table 1 shows there is no significance difference in the DO, pH and Alkalinity while the Hardness and Ammonia has significant difference at T two - tail

The mean value of alkalinity for the two agro-ecological locations (UI is 83.18 and Nwanmu is 63.25mg/L, agrees with Kuya (2011), who reported that an alkalinity of 75–200 mg/L was suitable for production of tilapia and catfish in earthen ponds.

The mean values of dissolved oxygen (DO) is 5.34 and 5.82mg/L in UI and Nwanmu respectively and it falls within the standard range of 3.0-6 as suggested by Malik *et al.*, (2020), therefore favorable for the growth of fish

The desirable range of pH appropriate for fish culture is from 6.0 to 9.0, as described by Rahman *et al.* (2015) and Jassid *et al.* (2018). Hence, based on water quality standards for fish culture, the pH mean values of water in IRFs were found to be suitable for fish growth.

Nitrate and nitrite level in both locations was 0 mg/L and are desirable for aquaculture according to (Bhaskar and Davis 2013)

High nitrate causes value eutrophication leading to low oxygen levels that affect the aquatic organisms since they cannot tolerate anaerobic conditions.

Table 2 shows that all the soil parameters at T two - tail are no significantly difference except for phosphorus

Agronomically, the pH range of the soils is good for rice cultivation, as it can make room for the availability of both macro and micronutrient as well enhancing the activities of soil micro organisms in the soils (Ano and Oyeleware, 2008).

With exception of phosphorus that was low in Ebonyi, all other parameters examined fell within acceptable limits as stated by AONDOAKAA And AGBAKWURU(2012)

CONCLUSION AND RECOMMENDATIONS

It was revealed that IRF practices in these zones do not lead to any negative impact on water quality and soil properties

Table 1: Water Quality Results

Parameter	UI	Nwanmu	Significance
pH	7.5	7.2	ns
DO (mg/L)	5.34	5.82	ns
Alkalinity (mg/L)	83.18	63.25	ns
Hardness (mg/L)	120	150	**
Nitrate (mg/L)	0	0	ns
Nitrite (mg/L)	0	0	ns
Ammonia (mg/L)	0.5	0.2	**

Table 2: Soil Quality Results

Parameter	UI	Nwanmu	Significance
pH	6.5	6.8	ns
Available N (mg/kg)	15	12	ns
Available P (mg/kg)	10	8	**
Available K (mg/kg)	120	110	ns
Organic C (mg/kg)	150	140	ns

Table 3: Recommended soil quality parameters range for rice

Parameter	Range (kg/ha)
pH	5.5 - 7.5
Available N	10 - 20
Available P	10 - 20
Available K	100 - 150
Organic C	10 - 20
Water Soluble S	10 - 20
Water Soluble B	10 - 20
Water Soluble Cu	10 - 20
Water Soluble Zn	10 - 20
Water Soluble Mn	10 - 20
Water Soluble Fe	10 - 20

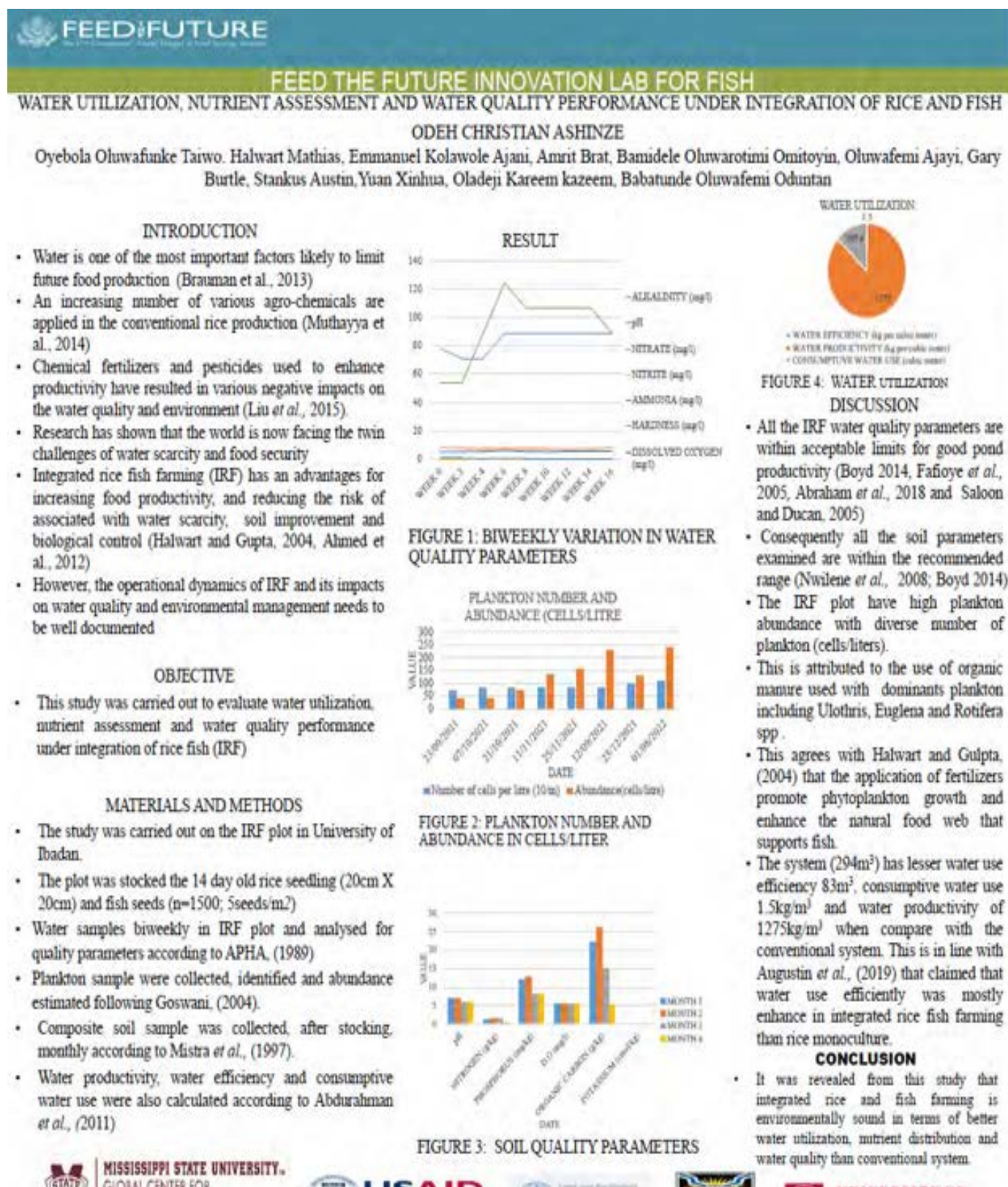
Acknowledgement



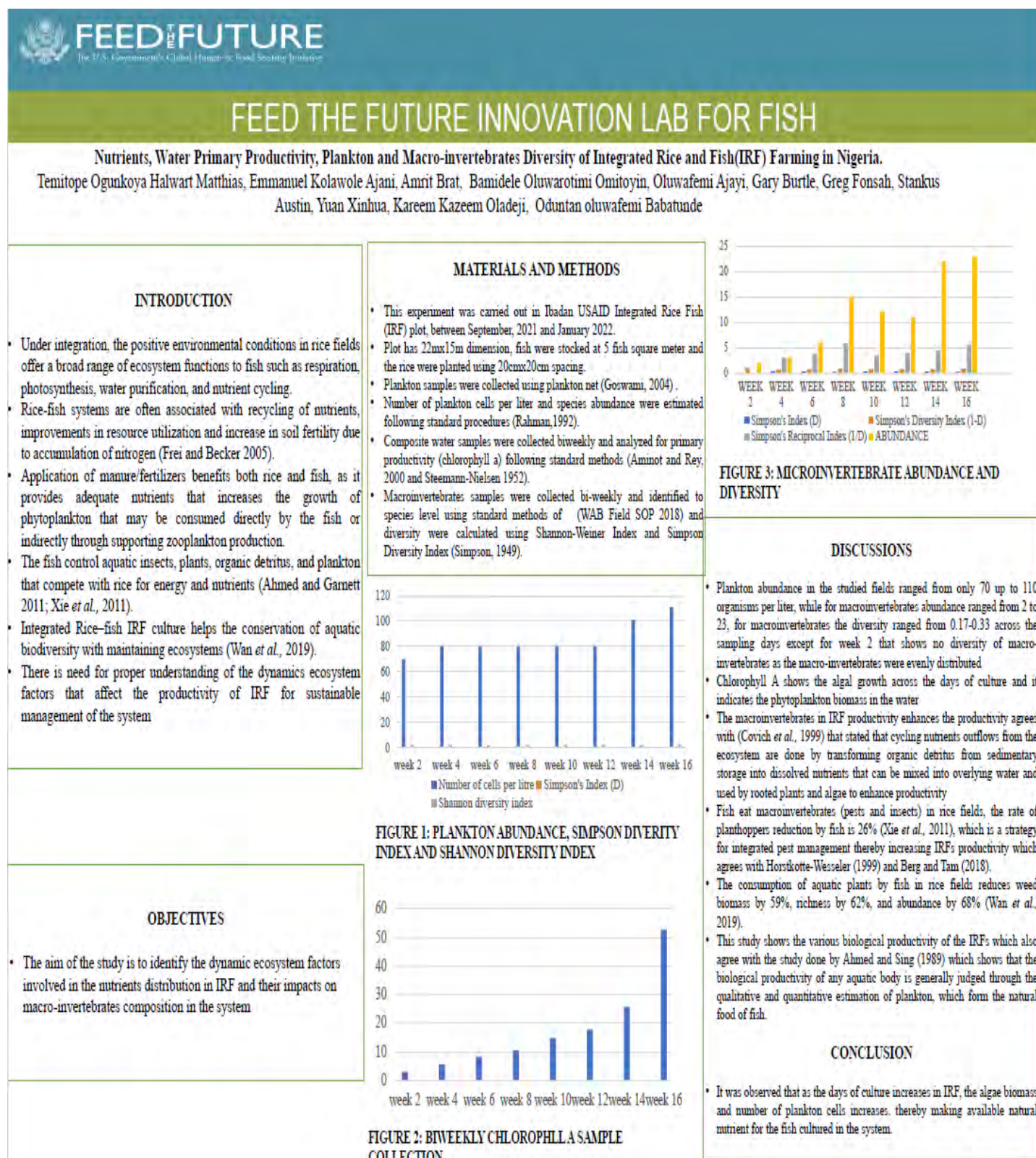




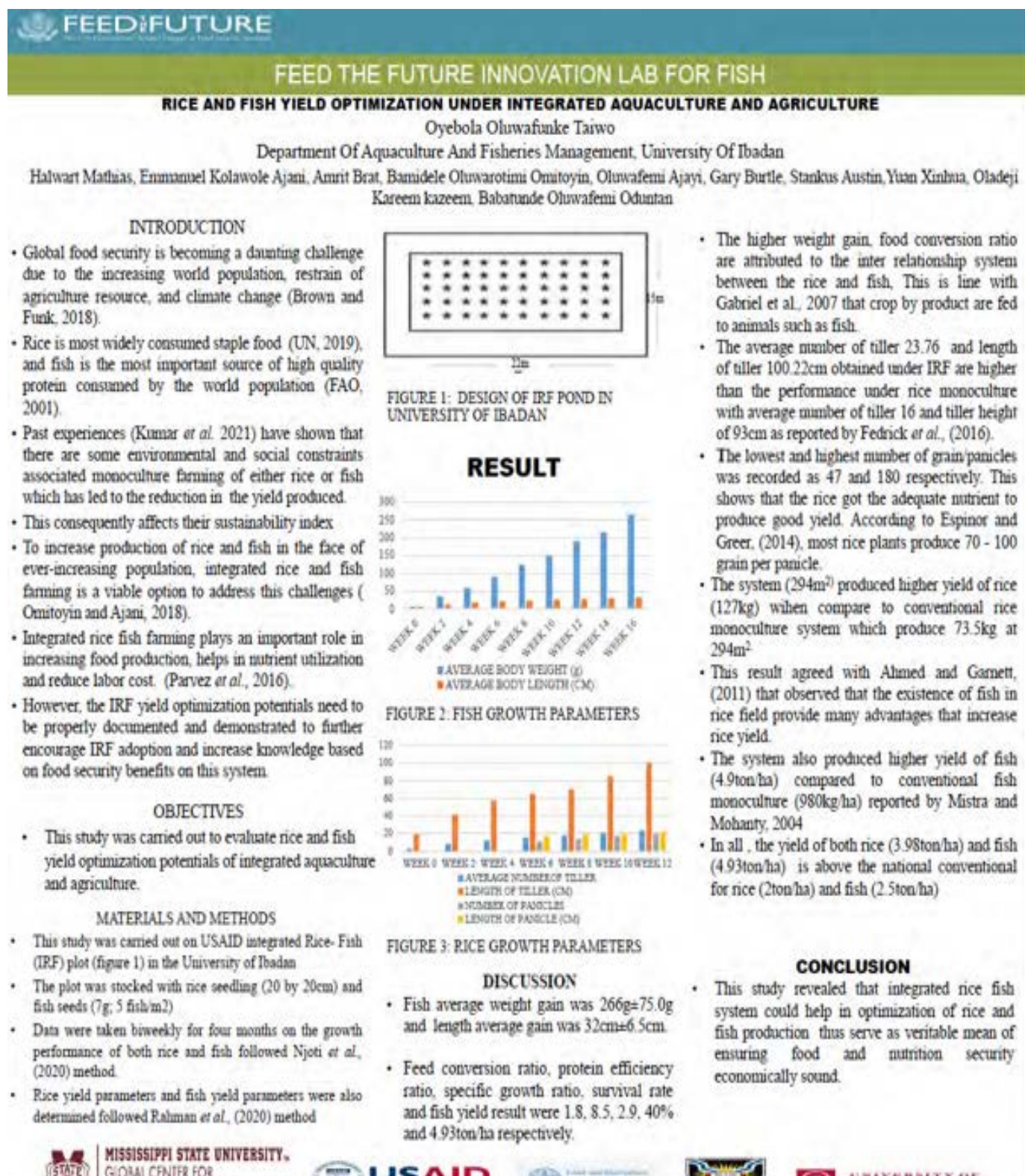
Annex 11: Integrated rice-fish research result II (water utilization, nutrient assessment and water quality performance under integration of rice and fish)



Annex 12: Integrated rice-fish research result III (Nutrients, Water Primary Productivity, Plankton and Macroinvertebrates Diversity of Integrated Rice and Fish (IRF) Farming in Nigeria)



Annex 13: Integrated rice-fish research result IV (rice and fish yield optimization under integrated aquaculture and agriculture)



Annex 14: Community socio-economics, food security and nutrition situational, fish consumption, consumer preference survey conducted at the beginning of the project in 2020, and a part in 2021

PART I

Food Insecurity Experience Scale (FIES) data (*extract from field survey 2020*)

In the last 12 MONTHS, was there a time when:		Kebbi n= 100			Ebonyi n= 114		
		% No	% Yes	% Don't know	% No	% Yes	% Don't Know
1	You were worried you or anyone else in your household would not have enough food to eat because of a lack of money or other resources?	12	88	0	13.16	85.96	0.88
2	Still thinking about the last 12 MONTHS, was there a time when you or anyone else in your household were unable to eat healthy and nutritious food because of a lack of money or other resources?	4	95	1	13.16	86.84	0
3	You or anyone else in your household ate only a few kinds of foods because of a lack of money or other resources?	1.99	97.98	0	11.39	87.72	0.88
4	You or anyone else in your household had to skip a meal because there was not enough money or other resources to get food?	20.00	79	1	22.80	77.19	0
5	Still thinking about the last 12 MONTHS, was there a time when you or anyone else in your household ate less than you thought you should because of a lack of money or other resources?	8.00	90.99	1	8.77	91.23	0
6	Your household ran out of food because of a lack of money or other resources	10	90	0	39.48	60.52	0
7a	You or anyone else in your household were hungry but did not eat because there was not enough money or other resources for food	44	55	1	32.46	67.54	0

7b	In the last MONTH (= 30 days, or 4 weeks), how often did it happen that you or anyone else in your household were hungry but did not eat because there was not enough money or other resources for food? Did this happen only once or twice, in some weeks but not every week, or almost every week? Note: If respondent says this did not happen in the last MONTH, go back to previous question and code "NO". TYPE: "SELECT_ONE" 133 out of 133 respondents answered this question. (0 were without data.) <table><thead><tr><th>State</th><th>In some weeks but...</th><th>Only once or twice</th><th>Almost every week</th><th>Did not happen</th><th>Don't Know</th></tr></thead><tbody><tr><td>Kebbi</td><td>22</td><td>13</td><td>7</td><td>0</td><td>1</td></tr><tr><td>Ebonyi</td><td>17</td><td>25</td><td>12</td><td>3</td><td>0</td></tr></tbody></table>							State	In some weeks but...	Only once or twice	Almost every week	Did not happen	Don't Know	Kebbi	22	13	7	0	1	Ebonyi	17	25	12	3	0
State	In some weeks but...	Only once or twice	Almost every week	Did not happen	Don't Know																				
Kebbi	22	13	7	0	1																				
Ebonyi	17	25	12	3	0																				
8a	In the last 12 MONTHS, was there a time when you or anyone else in your household went without eating for a whole day because of a lack of money or other resources?	4	96	0	28.06	71.94	0																		
8b	In the last MONTH (=30 days, or 4 weeks), how often did it happen that you or anyone else in your household went without eating for a whole day because of a lack of money or other resources? Did this happen only once or twice, in some weeks but not every week, or almost every week? Note: If respondent says this did not happen in the last MONTH, go back to previous question and code "NO". TYPE: "SELECT_ONE" 36 out of 36 respondents answered this question. (0 were without data.) <table><thead><tr><th>State</th><th>Only once or twice</th><th>Almost every week</th><th>In some weeks but...</th><th>Did not happen</th></tr></thead><tbody><tr><td>Kebbi</td><td>5</td><td>2</td><td>2</td><td>0</td></tr><tr><td>Ebonyi</td><td>50</td><td>20</td><td>18</td><td>2</td></tr></tbody></table>							State	Only once or twice	Almost every week	In some weeks but...	Did not happen	Kebbi	5	2	2	0	Ebonyi	50	20	18	2			
State	Only once or twice	Almost every week	In some weeks but...	Did not happen																					
Kebbi	5	2	2	0																					
Ebonyi	50	20	18	2																					

Note: This is the raw data from the survey. It has yet to be compared to global reference of food insecurity prevalence.

Source: Field survey 2020

A. PART II

Socio-economic characteristics of interviewees (*extract from field survey 2021*)

Items	Ebonyi	Kebbi	Pooled	Percentage
Sex				
Male	71	154	225	73.77
Female	60	20	80	26.23
Age				
0-20	27	5	32	10.49
21-40	87	105	192	62.95
41-60	0	53	53	17.38
61-80	17	11	28	9.18
Education level				
Adult Literacy	1	1	2	0.66
No formal education	15	22	37	12.13
Primary School	46	9	55	18.03
Religious Education	0	60	60	19.67
Secondary school	46	27	73	23.93
Tertiary(NCE, OND, HND, BSC)	23	55	78	25.57
Primary occupation				
Artisans	5	3	8	2.62
Civil Servants	6	10	16	5.25
Farming	117	157	124	89.84
Fish Farming	0	2	2	0.66
Others	1	2	3	0.98
Households size				
0-10	30	61	91	29.84
11-20	101	34	135	44.26
21-30		79	79	25.90
Farming experience (years)				
0-10	39	60	99	32.46
11-20	35	51	86	28.20
21-30	26	51	77	25.25
>31	28	12	40	13.11
Agricultural training				
No	113	97	210	68.85
Yes	16	77	93	30.49
Production system				
Smallholding	106	105	211	69.8

Cooperative	1	9	10	3.28
Commercial	18	58	76	24.92
Others	2	1	3	0.98
Source of land for rice farming				
Bought	24	11	35	11.48
Inherited	51	66	117	38.36
Personal land	32	67	99	32.46
Rented/Leased	24	29	53	17.38
Others		1	1	0.33
Cooperative association membership				
No	68	109	177	58.03
Yes	63	65	128	41.97
Access to extension				
No	100	99	199	65.25
Yes	31	75	106	34.75
Main labour source				
Both family and hired	--	50	50	16.39
Family	--	40	40	13.11
Hired	--	84	84	27.54

Source: Computation from Field Data, 2021

Willingness to Pay and Consumer Preference (Rice)

Type of rice preferred	Ebonyi	Kebbi	Pooled
Local rice	141	30	171
Foreign/imported rice	1	0	1
How often do you buy/consume local rice?			
Occasionally	28	18	46
Very often	114	12	126
How often do you buy/consume local rice per week			
1 time	4	3	7
2 times	18	7	25
3 times	65	12	77
>3 times	29	2	31
Everyday	26	5	31
How often will you buy/consume locally produced rice if readily available in market			
Occasionally	28	19	47
Very often	114	12	126
How often will you buy/consume any kind of rice if readily available in local market			
Occasionally	24	2	26
Very often	117	25	142
Never	1	3	4
How much will you be willing to pay for 1bag (25kg) of local rice if available in market			
20,000-30,000 NGN	12	2	14

<20, 000 NGN	129	27	156
> 30,000 NGN	1	2	3
How much will you be willing to pay for 1 MUDU or RUBBER of local rice			
1000-1500 NGN	101	2	103
< 1,000 NGN	37	26	63
>2000 NGN	4	3	7
Local rice variety preferred			
FARO-44	127	22	149
FARO-52	3	3	6
FARO-61	1	6	7
Others	11		11
Why Preferred local Rice			
Availability	29	15	44
Colour	1	2	3
Cooking	4	4	8
Cosmetic Appearance	10	3	13
Finger Size	2	2	4
Price	3	4	7
Sweetness	10	15	25
Taste/flavour	80	3	83
Texture	1	2	3

Consumer Preference for Imported and Local Fish in Ebonyi state (n = 142)

Preferred Fish Consumed		
Imported	25	17.61
Local	117	82.39
How often do you consume Local fish?		
Never	01	0.70
Occasionally	49	34.51
Very often	92	64.79
How often would you consume/buy local fish per week?		
1 time	11	7.75
2times	18	12.68
3 times	49	34.51
> 3times	19	13.38
Everyday	36	25.35
Zero time	09	6.34
Preferred Local fish		
Carp	02	1.41
Catfish	105	73.94
Tilapia	19	13.38
Others	16	11.27
Amount willing to pay for 1kg of your preferred local fish		
<500 NGN	34	23.94
500-1000 NGN	85	59.86
1000 NGN	12	8.45
> 1000 NGN	11	7.75
Why Preferred local fish		
Availability	30	21.13
Colour	01	0.70
Cosmetic appearance	08	5.63
Fish Length	02	1.41

Fish size	07	4.93
Sweetness	20	14.08
Taste/flavour	74	52.11
How often consumed Imported fish		
Never	31	21.83
Occasionally	79	55.63
Very often	32	22.54
How often consumed Imported fish if readily available in Market		
Never	24	16.90
Occasionally	59	41.55
Very often	59	41.55
Preferred imported fish		
Atlantic Mackerel (Tithus)	47	33.09
Bonga	20	14.08
Herring (Shawa)	19	13.38
Horse Mackerel (Kote)	16	11.27
Sardine	21	14.79
Others	19	13.38
Amount willing to pay for 1kg of your preferred imported fish		
1000-1500 NGN	46	32.39
<1000 NGN	65	45.77
2000 NGN	24	16.90
>2000 NGN	07	4.93

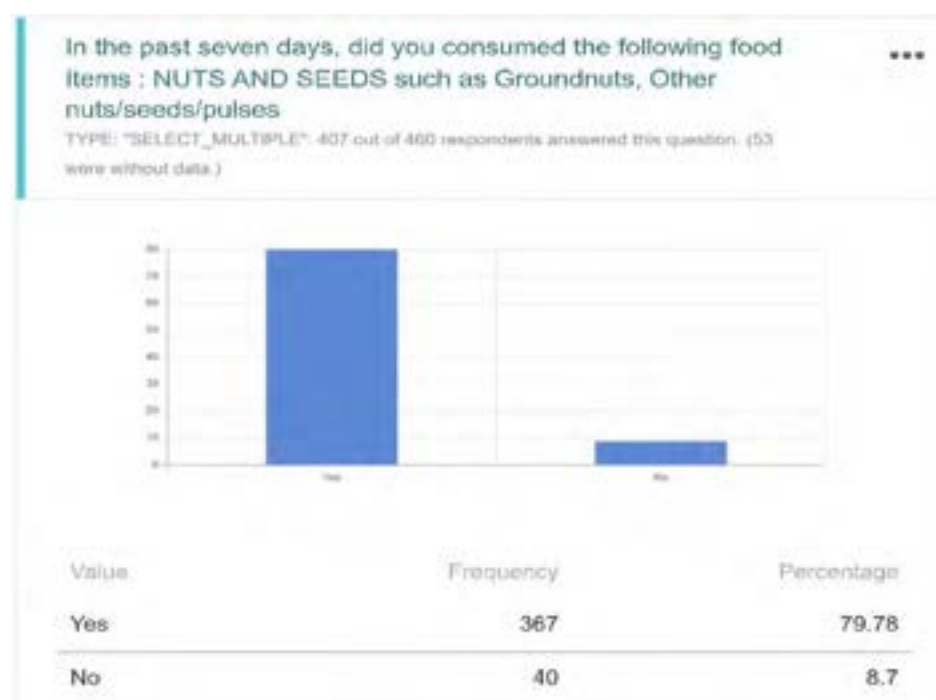
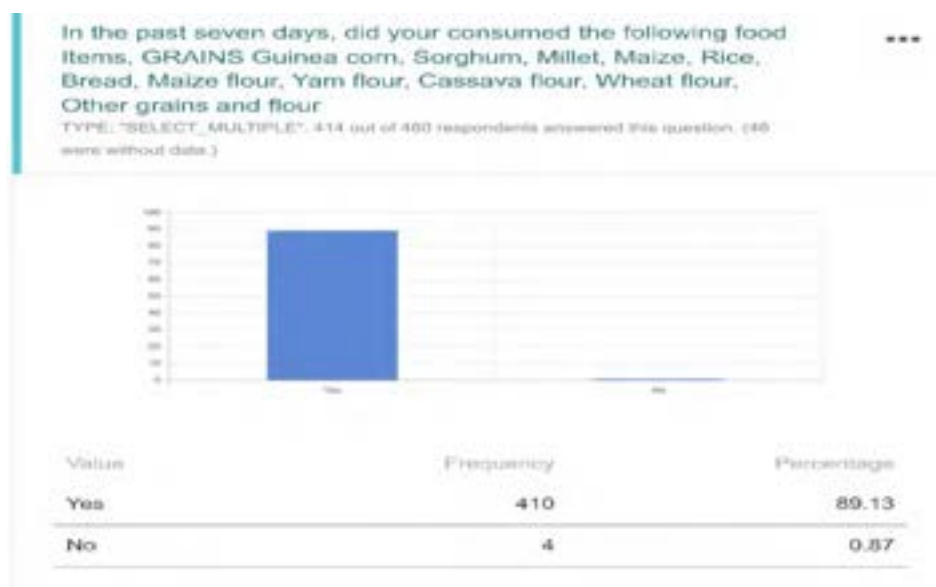
Source: Computation from Field Data, 2021

Reasons for chosen a fish to consume

Reasons for chosen a fish to consume	Kebbi (%)	Ebonyi (%)
Inexpensive, affordable and fits budget	75	38.56
Fresh and good quality	10	33.31
Like the taste	7.0	22.79
Easy to prepare	1	0
Can obtain from own pond	0	0.88
Specie considered to be healthier than many other species	0	2.63
Others	7	1.84

Source: Computation from Field Data, 2020

Annex 15: Final fish consumption survey, HDDS, FIES survey results conducted in July 2023



In the past seven days, did you consumed the following food items, ROOT, TUBERS AND PLANTAINS Cassava - roots, Yam-root, Gari-white, Gari-yellow, Cocoyam, Plantains, Potatoes, other roots and tuber

TYPE: "SELECT_MULTIPLE". 414 out of 460 respondents answered this question. (46 were without data.)



Value	Frequency	Percentage
Yes	400	86.96
No	14	3.04

In the past seven days, did you consumed the following food items: MEAT AND POULTRY such as Beef, Pork, Goat/Ram, Wild game meat, Other meat including poultry

TYPE: "SELECT_MULTIPLE". 412 out of 460 respondents answered this question. (48 were without data.)



Value	Frequency	Percentage
Yes	333	72.39
No	79	17.17

Yes	322	70
No	89	19.35

In the past seven days, did you consumed the following food items: ORGAN MEAT such as Liver, kidney, heart or other organ meats or blood-based foods

TYPE: "SELECT_MULTIPLE". 404 out of 400 respondents answered this question. (29 were without data.)



Value	Frequency	Percentage
Yes	214	46.52
No	190	41.3

In the past seven days, did you consume the following food items: FISH AND SEAFOOD such as Fish-Salmon, Tilthus, Mackerel, Clarias, Carp etc, Seafood-lobster, crab, crayfish, prawns etc.

TYPE: "SELECT_MULTIPLE". 414 out of 400 respondents answered this question. (19 were without data.)



Value	Frequency	Percentage
Yes	352	76.52
No	62	13.48

In the past seven days, did you consume the following food items: EGGS such as Eggs from poultry or any other bird

TYPE: "SELECT_MULTIPLE". 401 out of 400 respondents answered this question. (59 were without data.)



Value	Frequency	Percentage
Yes	273	59.35
No	128	27.83

In the past seven days, did you consume the following food items : GREEN LEAFY VEGETABLES such as Tomatoes fresh, Tomato puree (canned), Onions, Garden eggs/eggplant, Okra - fresh/Dried pepper Other vegetables (fresh or dried)

TYPE: "SELECT_MULTIPLE". 415 out of 460 respondents answered this question. (45 were without data.)



Value	Frequency	Percentage
Yes	405	88.04
No	10	2.17

In the past seven days, did you consume the following food items: COFFEE, TEA, COCOA AND THE LIKE BEVERAGE such as Coffee, Chocolate drinks e.g. Milo, Ovaltine, Bournvita), Tea (e.g. Lipton, green tea, etc.

TYPE: "SELECT_MULTIPLE". 399 out of 460 respondents answered this question. (61 were without data.)



Value	Frequency	Percentage
Yes	276	60
No	123	26.74

In the past seven days, did you consume the following food items: FRUITS AND VITAMINS such as Bananas Orange/Tangerine, Mangoes, Apple, Avocado, Pear, Pineapples, Fruit canned, other fruits

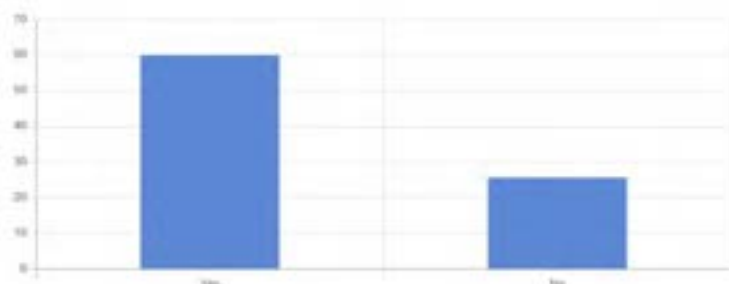
TYPE: "SELECT_MULTIPLE". 411 out of 460 respondents answered this question. (49 were without data.)



Value	Frequency	Percentage
Yes	372	80.87
No	39	8.48

In the past seven days, did you consume the following food items: **SUGAR, SWEETS ,AND CONFECTIONERY** such as Sugar, Jams, Marmalade, honey others

TYPE: "SELECT_MULTIPLE". 394 out of 460 respondents answered this question. (66 were without data.)



Value	Frequency	Percentage
Yes	276	60
No	118	25.65

In the past seven days, did you consume the following food items : **OTHER MISCELLANEOUS FOODS** such as Condiments (salt, spices, pepper, Ginger, Garlic etc.

TYPE: "SELECT_MULTIPLE". 409 out of 460 respondents answered this question. (51 were without data.)



Value	Frequency	Percentage
Yes	336	73.04
No	73	15.87

In the past seven days, did you consumed the following food items : **NON-ALCOHOLIC DRINKS** such as Bottled water, Sachet water, Malt drinks, Soft drinks (Coca Cola, spirit, etc.), Fruit juice canned/Packed

TYPE: "SELECT_MULTIPLE". 409 out of 460 respondents answered this question. (52 were without data.)



Value	Frequency	Percentage
Yes	303	65.87
No	106	23.04

In the past seven days, did you consume the following food Items **ALCOHOLIC DRINKS** such as Beer, Stars, Gulder and other alcoholic drinks

TYPE: "SELECT_MULTIPLE". 408 out of 460 respondents answered this question. (52 were without data.)

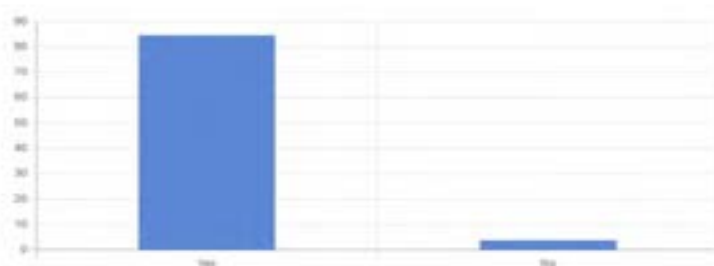


Value	Frequency	Percentage
No	222	48.2
Yes	186	40.4

In the past seven days, did you consumed the following food Items: **PULSES (BEANS, PEAS)** such as Soya beans, Brown beans, White beans,

...

TYPE: "SELECT_MULTIPLE". 406 out of 460 respondents answered this question. (54 were without data.)



Value	Frequency	Percentage
Yes	389	84.57
No	18	3.91

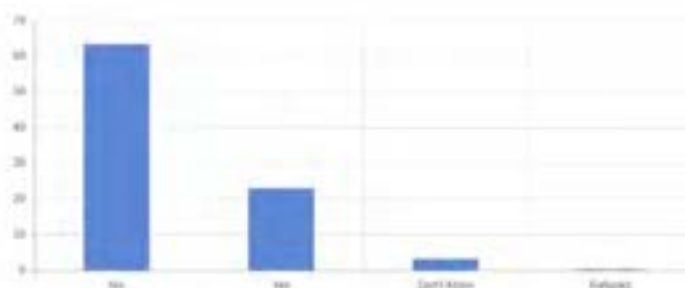
FOOD INSECURITY EXPERIENCE SCALE SURVEY MODULE (FIES-SM) FIES-SM Household – 12 months

TYPE: "ACKNOWLEDGE", 346 out of 460 respondents answered this question, (114 were without data.)

Value	Frequency	Percentage
OK	346	75.22

During the last 12 months, was there a time when you or others in your household were worried you would not have enough food to eat because of a lack of money or other resources? ***

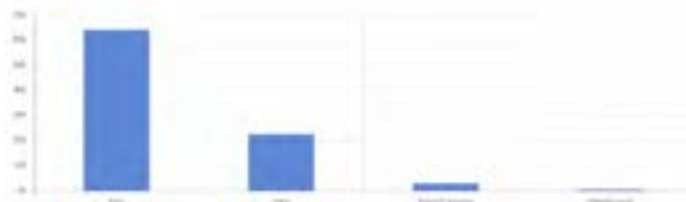
TYPE: "SELECT_MULTIPLE", 415 out of 460 respondents answered this question, (45 were without data.)



Value	Frequency	Percentage
No	292	63.48
Yes	106	23.04
Don't Know	15	3.26
Refused	2	0.43

Still thinking about the last 12 months, was there a time when you or others in your household were unable to eat healthy and nutritious food because of a lack of money or other resources?

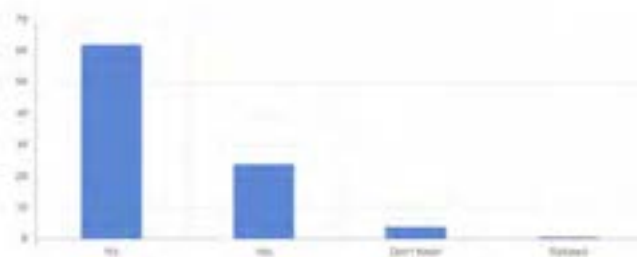
TYPE: "SELECT_MULTIPLE". 415 out of 460 respondents answered this question. (45 were without data.)



Value	Frequency	Percentage
No	295	64.13
Yes	104	22.61
Don't know	14	3.04
Refused	3	0.65

. During the last 12 months, was there a time when you or others in your household ate only a few kinds of foods because of a lack of money or other resources?

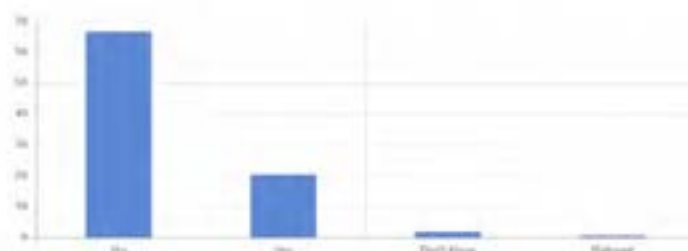
TYPE: "SELECT_MULTIPLE". 416 out of 460 respondents answered this question. (44 were without data.)



Value	Frequency	Percentage
No	296	62.17
Yes	110	23.91
Don't Know	18	3.91
Refused	3	0.65

During the last 12 months, was there a time when you or others in your household had to skip a meal because there was not enough money or other resources to get food?

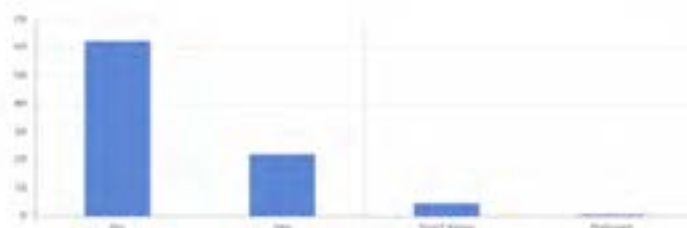
TYPE: "SELECT_MULTIPLE": 412 out of 460 respondents answered this question. (48 were without data.)



Value	Frequency	Percentage
No	307	66.74
Yes	94	20.43
Don't Know	9	1.96
Refused	3	0.65

Still thinking about the last 12 months, was there a time when you or others in your household ate less than you thought you should because of a lack of money or other resources?

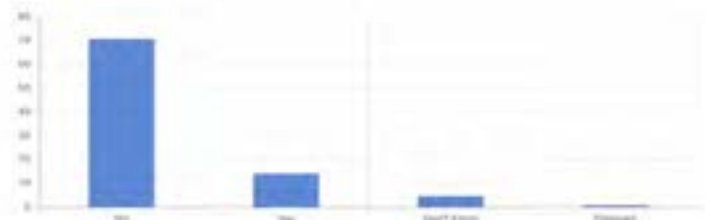
TYPE: "SELECT_MULTIPLE": 413 out of 460 respondents answered this question. (47 were without data.)



Value	Frequency	Percentage
No	287	62.39
Yes	102	22.17
Don't Know	21	4.57
Refused	3	0.65

In the past 12 months, was there a time when your household ran out of food because of a lack of money or other resources? ***

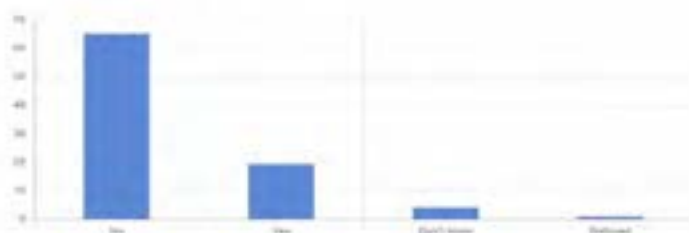
TYPE: "SELECT_MULTIPLE", 414 out of 460 respondents answered this question. (46 were without data.)



Value	Frequency	Percentage
No	325	70.65
Yes	64	13.91
Don't Know	22	4.78
Refused	4	0.87

In the past 12 months, was there a time when you or others in your household were hungry but did not eat because of a lack of money or other resources for food? ***

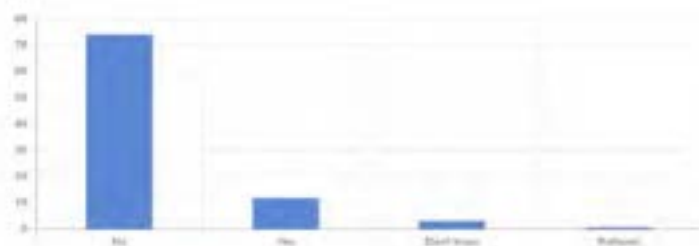
TYPE: "SELECT_MULTIPLE", 413 out of 460 respondents answered this question. (47 were without data.)



Value	Frequency	Percentage
No	300	65.22
Yes	89	19.35
Don't know	19	4.13
Refused	5	1.09

During the last 12 months, was there a time when you or others in your household went without eating for a whole day because of a lack of money or other resources?

TYPE: "SELECT_MULTIPLE". 415 out of 460 respondents answered this question. (45 were without data.)



Value	Frequency	Percentage
No	341	74.13
Yes	55	11.96
Don't know	15	3.26
Refused	4	0.87

Did you or anyone consume fish in your household in the last 24 hours or 1 day? ***

TYPE: "SELECT_MULTIPLE". 401 out of 460 respondents answered this question. (59

SECTION E: FISH CONSUMPTION AND NUTRITION

TYPE: "ACKNOWLEDGE". 320 out of 460 respondents answered this question. (140 were without data.)

Value	Frequency	Percentage
OK	320	69.57

No	105	22.83

If yes, what species of the fish consumed?

TYPE: "TEXT". 305 out of 460 respondents answered this question. (155 were without data.)

Value	Frequency	Percentage
Catfish	41	8.91
Catfish	29	6.3
Tilapia	22	4.78
Iced fish	21	4.57
Catfish and Tilapia	18	3.91
0	14	3.04
Titus	11	2.39
No	10	2.17

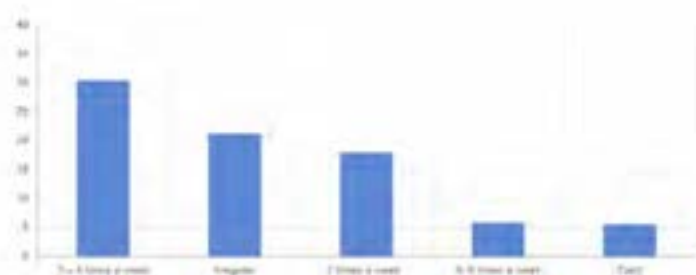
Kullume catfish	1	0.22
Catfish icefish	1	0.22
Catfish, mackerel, tilapia	1	0.22
Catfish, tilapia	1	0.22
Panla, catfish, tilapia,	1	0.22
Ok	1	0.22
Catfish, titus	1	0.22
Tilapia, catfish, panla	1	0.22
Mackerel, panla, catfish, panla	1	0.22
Makerel, panla	1	0.22
Tilapia, mackerel, panla, catfish	1	0.22
Tilapia, panla, catfish	1	0.22
Tilapia, mackerel, sardine	1	0.22
Tilapia and catfish	1	0.22
Panla, tilapia	1	0.22
O	1	0.22
Malapterurus electricus	1	0.22
Herring, tilapia, stock fish, mackerel	1	0.22
Herring, mackerel, tilapia, stock fish,	1	0.22
Tilapia, herring, mackerel	1	0.22
Tilapia, mackerel	1	0.22
Mackerel, herring, stock fish, tilapia	1	0.22
Herring, tilapia, mackerel,	1	0.22
Don't know	1	0.22
Tillapia	1	0.22

Kullume (catfish)	1	0.22
Electric fish	1	0.22
Kullume	1	0.22

Mackerel, tilapia, sardine	1	0.22
Catfish, mackerel, panla, stock fish, sardine	1	0.22
Tithus, panla, stock fish, sardine	1	0.22
Salmon	1	0.22
Tithus, sardine, kote, tilapia, catfish	1	0.22
Stockfish	1	0.22
Okporoko and dried fish	1	0.22
Catfish, okporoko,	1	0.22
Okporoko, catfish	1	0.22
Hake, Titus	1	0.22
Dry fish	1	0.22
Titus	1	0.22
Dry fish	1	0.22
Mackerel, Tithus, panla, catfish, sardines	1	0.22
Mackerel, panla, catfish, tilapia	1	0.22
Dried tilapia	1	0.22
Tilapia, catfish	1	0.22
Sardines	1	0.22
Catfish, tilapia, panla	1	0.22
Catfish cote	1	0.22
Cote catfish	1	0.22
Cat fish	1	0.22

How often do you consume fish in your household?

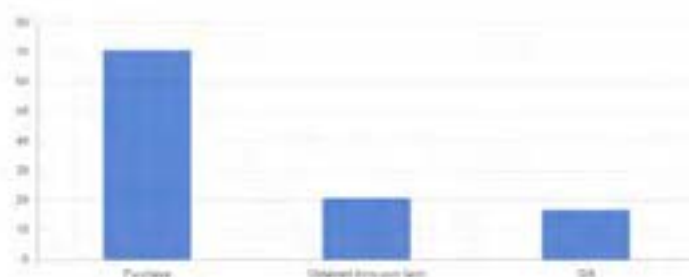
TYPE: "SELECT_MULTIPLE". 379 out of 466 respondents answered this question. (90 were without data.)



Value	Frequency	Percentage
3 – 4 times a week	140	30.43
Irregular	98	21.3
2 times a week	83	18.04
5- 6 times a week	27	5.87
Daily	26	5.65

How did you obtain the fish?

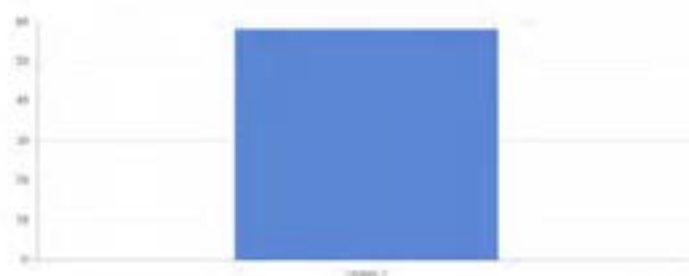
TYPE: "SELECT_MULTIPLE". 362 out of 480 respondents answered this question. (98 were without data.)



Value	Frequency	Percentage
Purchase	325	70.65
Obtained from own farm	96	20.87
Gift	78	16.96

If the fish was purchase, how much did you pay for the fish in Naira? (fill as applicable)

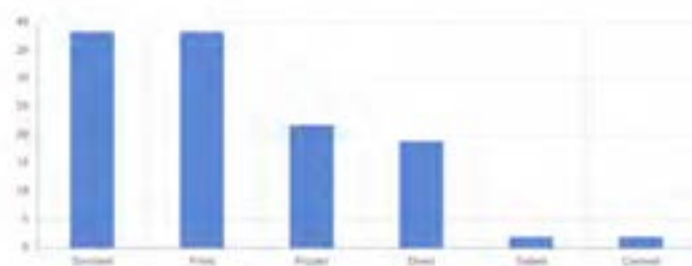
TYPE: "SELECT_MULTIPLE". 268 out of 480 respondents answered this question. (192 were without data.)



Value	Frequency	Percentage
Option 2	268	58.26

In what form was the fish when it was purchased?

TYPE: "SELECT_MULTIPLE", 349 out of 460 respondents answered this question. (111 were without data.)



Value	Frequency	Percentage
Smoked	176	38.26
Fried	176	38.26
Frozen	100	21.74
Dried	87	18.91
Salted	9	1.96
Canned	9	1.96

<https://kf.kobotoolbox.org/#/forms/aadEKVPFsz9ZBEJpcqm/RTD/data/report>

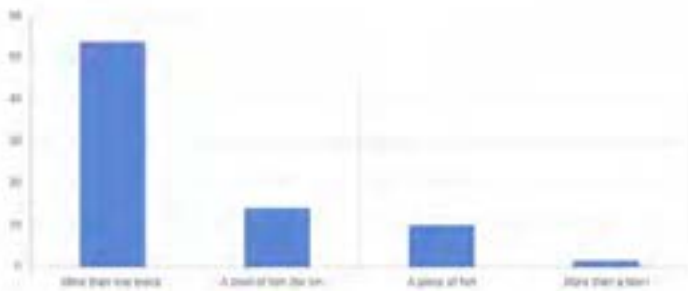
123/184

<https://kf.kobotoolbox.org/#/forms/aadEKVPFsz9ZBEJpcqm/RTD/data/report>

122/184

How much of the fish (in total) was consumed in your household? ***

TYPE: "SELECT_MULTIPLE". 353 out of 460 respondents answered this question. (107 were without data.)



Value	Frequency	Percentage
More than one piece	248	53.91
A bowl of fish (for small pieces of fish)	65	14.13
A piece of fish	46	10
More than a bowl	7	1.52

At what time of the year is this fish not available OR you want to eat this fish but can't find it always available? (Month)

TYPE: "TEXT". 249 out of 460 respondents answered this question. (211 were without data.)

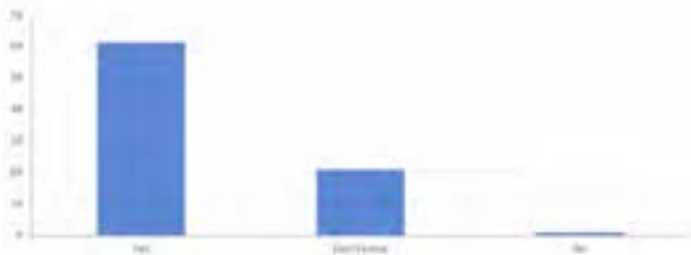
7/23/23, 12:42 PM

INTEGRATED RICE-FISH CULTURE TECHNOLOGY PRODUCTION IN NIGERIA | KoboToolbox

Value	Frequency	Percentage
June	44	9.57
August	40	8.7
August	17	3.7
January	16	3.48
December	16	3.48
June	15	3.26
0	15	3.26
No	14	3.04
None	13	2.83
July	8	1.74
January	7	1.52
July	5	1.09
December	4	0.87
February	2	0.43
April	2	0.43
Yes	2	0.43
Don't know	2	0.43
February	2	0.43
None	2	0.43
Catfish	2	0.43
November	2	0.43

Is eating fish good for a child's brain development?

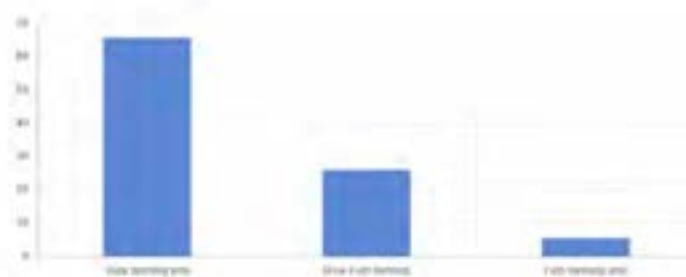
TYPE: "SELECT_MULTIPLE". 385 out of 460 respondents answered this question. (75 were without data.)



Value	Frequency	Percentage
Yes	283	61.52
Don't know	97	21.09
No	5	1.09

Do you practice any of the following? (select multiple answer if available)

TYPE: "SELECT_MULTIPLE", 395 out of 460 respondents answered this question. (65 were without data.)



Value	Frequency	Percentage
Rice farming only	303	65.87
Rice-Fish farming	120	26.09
Fish farming only	26	5.65

If you practice rice-fish farming, how do you make use of the fish harvested?

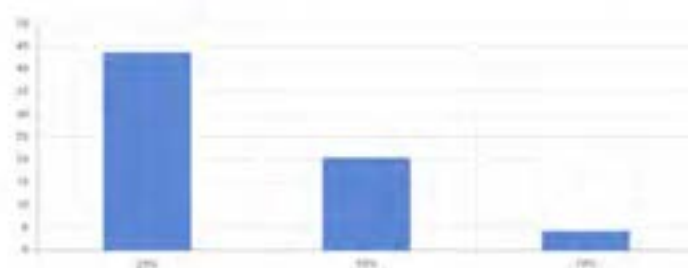
TYPE: "SELECT_MULTIPLE". 312 out of 460 respondents answered this question. (148 were without data.)



Value	Frequency	Percentage
Both (home consumption and selling)	282	61.3
Home consumption	32	6.96
Selling	31	6.74

If you choose Both (home consumption and selling), what percentage do you consume at home? ***

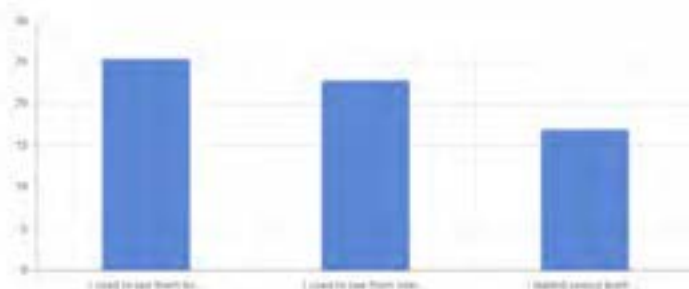
TYPE: "SELECT_MULTIPLE". 315 out of 460 respondents answered this question. (145 were without data.)



Value	Frequency	Percentage
20%	201	43.7
50%	94	20.43
70%	20	4.35

Do you use to see any of these aquatic animals in your ricefield before you converted to rice-fish farming OR you just started seeing them?

TYPE: "SELECT_MULTIPLE", 279 out of 460 respondents answered this question. (181 were without data.)



Value	Frequency	Percentage
I used to see them but their number has increased since I started rice-fish farming	117	25.43
I used to see them when it was just ricefield alone	105	22.83
I started seeing them after converting to rice-fish farming	78	16.96

Annex 16: Questionnaire on integrated rice-fish marketing and consumer preference

QUESTIONNAIRE ON INTEGRATED RICE-FISH CULTURE TECHNOLOGY, MARKETING AND CONSUMER PREFERENCE IN NIGERIA

Ethical consent

Thank you for the opportunity to speak with you. You have been selected to participate in this interview that includes information on questions such as the socio-economic and demographic information, consumption of rice-fish culture technology product and willingness to pay. These questions in total will take approximately 45 minutes to 1 hour to complete and your participation is voluntary. You can refuse to participate. If you agree to participate, you can choose to stop at any time or to skip any questions you do not want to answer. Your answers will be completely confidential. We will not share information that identifies you with anyone. There are no direct benefits to you from participating in this interview. However, the information collected from you can significantly help in improving on the profitability and nutrition security especially among the rice-fish farmers in your area, as well as Nigeria in general. You can ask questions about the research anytime during the interview. Kindly provide the necessary information as truthfully as you can. All information will be held with the strictest confidence.

Thank you.

Questionnaire ID:	STATE	LGA	Town/Village	Date: dd/mm/yyyy
Section A: LOCATION GENERAL INFORMATION				
Location Name:				
Latitude:		Longitude:		
Time Interview Starts:		Time Interview Ends:		

Section A: DEMOGRAPHIC, SOCIO-ECONOMIC CHARACTERISTICS

S/N	Item	Options	Response
1	Age of respondent (in years)		
2	Gender of the respondents	[1] = Male [0] = Female	
3	Marital status of the respondents	[0] = Not married [1] = Married [2] = Single [3] = Divorced [4] = Separated	
4	Educational level of the respondents	[0] = No Formal Education [1] = Religious Education [2] = Adult Literacy [3] = Primary School [4] = Secondary School [5] = Tertiary(NCE, OND, HND, BSC)	
5	Total years education		
6	Household size		
7	Primary occupation	[1] = Rice Farming [2] = Fish Farming	

		[2] = Civil Servants [3] = Artisans [4] = Farming [5] = Others (please specify)	
8	Do you have access to credit for your enterprise?	[1] = Yes [0] = No	
9	If YES to Q 8, where is the source of the credit?	[1] = Money lender [2] = Commercial Bank [3] = Microfinance Bank [4] = Cooperative/Social group [5] = Government [6] = Friends/Families	
10	Are you a member of any Co-operative associations or groups?	[1] = Yes [0] = No	
11	If YES to Q 10, How long (years) have you been a member?		
12	Distance from home to the market in km		
13	Transportation cost from home to the market in Naira		

14. Households Assets Owned by the Consumers

	Assets own by the households	Yes	No	Purchase Price
	Generator			
	Irrigation pump			
	Domestic animals (Cattle/sheep/goat etc.)			
	Mobile phone(s)			
	Television			
	Radio			
	Vehicle(s)			
	Car(s)			
	Motorcycle (s)			
	Bicycle (s)			
	Washing machine			
	Others not listed			

SECTION B: CONSUMER PREFERENCE AND WILLINGNESS TO PAY FOR INTEGRATED FISH –RICE FARMING PRODUCT

CONSUMERS PREFERENCE ATTRIBUTES ON LOCAL RICE

15. What kind of rice do you prefer to buy/consume? Imported [] or Local []

16. How often do you buy/consume local rice? Very Often [] Occasionally [] Never []

17. How often do you buy/consume local rice per week? 1 time [] 2 times [] 3 times [] >3 time [] Everyday [] zero time []

18. How often will you buy/consume locally produced rice if readily available in markets? Very often [] occasionally [] Never []

19. How often will you buy/consume any kind of rice if readily available in local markets? Very often [] occasionally []
[] Never []

20. How much will you be willing to pay for 1 bag of local rice if available in market? <20, 000 NGN [] 20,000-30,000 NGN [] > 30,000 NGN []

21. How much will you be willing to pay for 1 MUDU or RUBBER of local rice if readily available? < 1,000 NGN [] 1000-1500 NGN [] >2000 NGN []

22. Which of the locally grown rice do you prefer to buy if readily available in local markets? FARO-44 [] FARO-52 [] FARO-61 [] FARO-59 GAWAL R1 [] others (Specify) _____ []

23. How much will you be willing to pay for 1 KG local variety of rice such as? FARO-44 [] FARO-52 [] FARO-61 [] FARO-59 GAWAL R1 < 1000 NGN [] 1000-1500 NGN [] 2000 NGN [] > 2000 NGN []

24. Why do you prefer the selected local cultivar or varieties? Cosmetic appearance [] Finger Length [] Finger size [] Taste/flavour [] Colour [] Sweetness [] Texture [] Cooking [] availability [] Price [] Religious reasons [] Family reasons [] others Specify) _____ []

25. Indicate your reasons in order of preference, i.e. 1, 2, 3, 4 etc. Cosmetic appearance [] Finger Length [] Finger size [] Taste/flavour [] Colour [] Sweetness [] Texture [] Cooking [] Availability [] Price [] Religious reasons [] Family reasons [] others Specify) _____ []

SECTION C: PREFERENCE AND WILLINGNESS TO PAY FOR IMPORTED RICE

26. How often do you buy/consume imported rice? Very often [] occasionally [] Never []

27. How often will you buy/consume imported rice if readily available in local markets? Very often [] occasionally [] Never []

28. How often will you buy/consume imported rice if readily available in local markets? Very often [] occasionally [] Never []

29. Which of the imported rice do you prefer to buy if readily available in local markets? MAMA GOLD [] ROYAL STALLION [] ELEPHANT PRIDE [] BISMATI RICE [] OTHERS (SPECIFY) _____ []

30. Why do you prefer the the imported rice? Cosmetic appearance [] Finger Length [] Taste/flavour [] Colour [] Sweetness [] Texture [] Cooking [] availability [] Price [] Religious reasons [] others Specify) _____ []

31. Indicate your reasons in order of preference, i.e. 1, 2, 3, 4 etc. Cosmetic appearance [] Finger Length [] Finger size [] Taste/flavour [] Colour [] Sweetness [] Texture [] Cooking [] Availability [] Price [] Religious reasons [] Family reasons [] others Specify) _____ []

32. How much will you be willing to pay for 1 bag of imported rice if available in market? <20, 000 NGN [] 20,000-30,000 NGN [] > 30,000 NGN []

33. How much will you be willing to pay for 1 MUDU or RUBBER of imported rice if readily available? < 1,000 NGN [] 1000-1500 NGN [] >2000 NGN []

34. How much will you be willing to pay for 1 KG imported rice such as? MAMA GOLD [] ROYAL STALLION [] ELEPHANT PRIDE [] BISMATI RICE [] _____ < 1000 NGN [] 1000-1500 NGN [] 2000 NGN [] > 2000 NGN []

SECTION D: QUALITY, ATTRIBUTES AND ADDED VALUE – PACKAGING FOR RICE

35. Is the quality of any kind of rice important to you? Yes [] No []

36 Have you ever seen rice packaged in bags before? Very Often [] Occasionally [] Never []

37. Have you ever bought rice already packed in bags instead buying without packaged? Yes [] No []
38. If no, would you like to try? Yes [] No []
39. If no, Why? Don't know [] Don't want to change [] Costly [] More work [] Not sure if profitable [] others (please specify) _____ []
40. As a consumer, which weight/packaging/bag size would you prefer: 1Kg bag [] 2 Kg bag []; 3 Kg bag []; 4 Kg 5 Kg bag [] 10 Kg []; 15 Kg bag []; 20 Kg bag; []; 25 Kg bag []; 50 Kg bag [] Others [] (Please specify)

41. What would be your packaging preference? Jute bag [] Plastic bag pack [] Carton pack [] Others [] (Specify)

42. Would you pay a higher price for better quality: Yes [] No []

CONSUMERS PREFERENCE ATTRIBUTES ON LOCAL FISH

43. What is your preferred fish you buy/consume? Imported [] Local []
44. How often do you buy/consume local fish? Very Often [] Occasionally [] Never []
45. How often do you buy/consume local fish per week? 1 time [] 2 times [] 3 times [] >3 time [] Everyday [] zero time []
46. How often do you buy/consume local fish week? 1 time [] 2 times [] 3 times [] >3 time [] Everyday [] zero time []
47. How often will you buy/consume local fish if readily available in markets? Very often [] Occasionally [] Never []
48. How often will you buy/consume any kind of local raised fish if readily available in markets? Very often [] Occasionally [] Never []
49. Which of the fish do you prefer to buy if readily available in local markets? CATFISH [] TILAPIA [] CARP [] OTHERS [] OTHERS (SPECIFY) _____ []
50. How much will you be willing to pay for 1kg of preferred local fish such as CATFISH, TILAPIA, CARP < 500 NGN [] 500-1000 NGN [] 1000 NGN [] > 1000 NGN []
51. Why do you prefer the selected local fish? Size [] Taste/flavour [] Colour [] Availability [] Religious reasons [] Price/Cost [] Others please specify) _____ []
52. Indicate your reasons in order of preference, i.e. 1, 2, 3, 4 etc. Cosmetic appearance [] Fish Length [] Size [] Taste/flavour [] Colour [] Sweetness [] Availability [] Religious reasons [] Others please specify) _____ []

SECTION C: PREFERENCE AND WILLINGNESS TO PAY FOR IMPORTED FISH

53. How often do you consume imported fish? Very often [] Occasionally [] Never []
54. How often will you consume/buy imported fish if readily available in local markets? Very often [] Occasionally [] Never []
55. How often will you consume/buy imported fish if readily available in local markets? Very often [] Occasionally [] Never []
56. How often will you consume/buy any kind of fish if readily available in local markets? Very often [] occasionally [] Never []

57. Which of the imported fish do you prefer to buy if readily available in local markets? ATLANTIC MACKEREL (TITHUS) [] HORSE MACKEREL (KOTE) [] SALMON [] BONGA [] SARDINE [] HERRING (SHAWA) [] OTHERS (Specify) _____ []

58. How much will you be willing to pay for 1kg of your preferred imported fish such as ATLANTIC MACKEREL, HORSE MACKEREL, SALMON, BONGA, SARDINE FISH < 1000 NGN [] 1000-1500 NGN [] 2000 NGN [] > 2000 NGN []

59. Why do you prefer the selected imported fish? Cosmetic appearance [] Fish Length [] Size [] Taste/flavour [] Colour [] Sweetness [] Availability [] Religious reasons [] Price/Cost [] Others please specify) _____ []

60. Indicate your reasons in order of preference, i.e. 1, 2, 3, 4 etc. Cosmetic appearance [] Fish Length [] Size [] Taste/flavour [] Colour [] Sweetness [] Availability [] Religious reasons [] Others please specify) _____ []

SECTION D: QUALITY, ATTRIBUTES AND ADDED VALUE – PACKAGING FOR FISH

61. Is the quality of any kind of fish important to you? Yes [] No []

62. If yes, tell us what quality attribute? Cosmetic appearance [] Fish Length [] Fish size [] Taste/flavour [] Texture [] Odour [] Others Specify) []

63. Would you pay a higher price for better fish quality: Yes [] No []

64. Have you ever seen fish packaged before? Very Often [] Occasionally [] Never []

65. Have you ever bought fish already packaged instead buying without packaged? Yes [] No []

66. If no, would you like to try? Yes [] No []

67. If no, Why? Don't know [] Don't want to change [] Costly [] More work [] Not sure if profitable [] others (please specify) []

68. If yes, which weight/packaging size would you prefer 1Kg packed [] 2 Kg packed []; 3 Kg packed []; 4 Kg packed [] Others []

69. What would be your packaging preference? Paper/Cartron bag [] Plastic bag pack [] Nylon [] Others [] (Specify) []

SECTION F: GOVERNMENT POLICY

70 Do you pay tax to the government at any level? Yes [] No []

71. If yes to the above question, in what form and how much do you pay in production period?

Taxable items	Frequency of payment	Rate	Amount paid
Facilities			
Income/profit			
Land/rental tax			
Tax on association			
Others (please specify)			

72. Do you receive subsidies from government in any form? Yes [] No []

73. If yes to the above question, in what form and how much do you pay in production period?

Taxable items	Frequency of payment	Rate	Amount paid
Credit			
Feeds			
Training			
Technical assistance			

Others (please specify)			

We've finished the interview / data collection - thank you very much for your time and participation.

Annex 17: Questionnaire on integrated rice and profitability

QUESTIONNAIRE ON INTEGRATED RICE-FISH CULTURE TECHNOLOGY PRODUCTION, PROFITABILITY AND FOOD SECURITY IN NIGERIA

Ethical consent

Thank you for the opportunity to speak with you. You have been selected to participate in this interview that includes information on questions such as the socio-economic and demographic information, rice-fish culture technology, profitability and food security in Nigeria. These questions in total will take approximately 45 minutes to 1 hour to complete and your participation is voluntary. You can refuse to participate. If you agree to participate, you can choose to stop at any time or to skip any questions you do not want to answer. Your answers will be completely confidential. We will not share information that identifies you with anyone. There are no direct benefits to you from participating in this interview. However, the information collected from you can significantly help in improving on the profitability and nutrition security especially among the rice-fish farmers in your area, as well as Nigeria in general. You can ask questions about the research anytime during the interview. Kindly provide the necessary information as truthfully as you can. All information will be held with the strictest confidence.

Thank you.

Questionnaire ID:	STATE	LGA	Town/Village	Date: dd/mm/yyyy
Section A: LOCATION GENERAL INFORMATION				
Location Name:				
Latitude:		Longitude:		
Time Interview Starts:		Time Interview Ends:		

Section A: DEMOGRAPHIC, SOCIO-ECONOMIC CHARACTERISTICS

S/N	Item	Options	Response
1	Status of the respondent	[1] = Owner of farm [2] = Owner's Spouse [3] = Manager [4] = Staff [5] = Family member [6] = Others	
2	Age of respondent (in years)		
3	Gender of the respondents	[1] = Male [0] = Female	
4	Marital status of the respondents	[0] = Not married [1]= Married [2]= Single [3] = Divorced [4] = Separated	
5	Educational level of the respondents	[0] = No Formal Education [1] = Religious Education [2] = Adult Literacy [3] = Primary School [4] = Secondary School [5] = Tertiary(NCE, OND, HND, BSC)	
6	Total years education		

7	Household size		
8	Total years of farming experience		
9	Total years of Rice-Fish production experience		
10	Total years of Rice production experience		
11	Did you receive any formal agricultural training?	[1] = Yes [0] = No	
12	If yes to Q. 10, where did you obtain the training?	[1] = Extension agents [2] = Technical school [3] = School of agriculture [4] = Others (please specify)	
13	Primary occupation	[1] = Rice Farming [2] = Fish Farming [2] = Civil Servants [3] = Artisans [4] = Farming [5] = Others (please specify)	
14	Total farm size in (acres)		
15	What is your rice production operational modality?	[1] = Commercial/industrial [2] = Smallholding [3] = Cooperative [4] = Others (please specify)	
16	Do you have access to credit for your farming?	[1] = Yes [0] = No	
17	If YES to Q.16, where is the source of the credit?	[1] = Money lender [2] = Commercial Bank [3] = Microfinance Bank [4] = Cooperative/Social group [5] = Government [6] = Friends/Families	
18	Source of land for rice-fish farming	[1] = Personal land [2] = Inherited [3] = Rented/Leased [4] = Bought [5] = Others (please specify)	
19	Are you a member of any Co-operative associations or groups?	[1] = Yes [0] = No	
20	If YES to Q 19, How long (years) have you being a member?		
21	Do you have access to extension services?	[1] = Yes [0] = No	
22	If yes to Q 22, from which source?	[1] = Government [2] = NGO [3] = Corporate organization [4] = Hired [5] = Others.	
23	Distance to Input Market (KM)		
24	Distance from home to the farm (KM)		
25	Cost of distance to input market (Naira)		
26	Cost of distance from home to market (Naira)		

27. Production and Households Assets

Assets own by the households	Yes	No	Purchase Price
Tractor			
Hoe (s)			
Cutlass (s)			
Knapsack sprayer			
Grain storage silos			
Motorcycle (s)			
Fish pond/fishing equipment			
Generator			
Irrigation pump			
Threshing machine			
Domestic animals (Cattle/sheep/goat etc.)			
Mobile phone(s)			
Television			
Radio			
Vehicle(s)			
Car(s)			
Motorcycle (s)			
Bicycle (s)			
Washing machine			
Others not listed			

SECTION B: PROFITABILITY AND YIELD OF INTEGRATED RICE-FISH FARMING

What is your **main** source of household income? [a] Farming []; [b] Fishing/aquaculture []; [c] Rice production [d] Trading []; [e] Artisan []; [f] Civil servant

28. Do you engage/practice integrated Rice-Fish technology? Yes [] No []

29. Is the technology profitable than mono-practice of rice or fish? Yes [] No []

30. Give reasons for adopting the technology? -----

31. Which of the two give the highest profit? Integrated Rice-Fish culture Technology [] Non-integrated Rice-Fish Culture Technology []

32. Please complete this table on paddy rice harvested and sold from integrated rice-fish technology

No of time Harvested	Price per(kg)	100Kg bag	75Kg bag	50Kg bag	Total Revenue (N)
First harvest					
Second harvest					
Third harvest					
Fourth harvest					
Total					

33. Where do you sell your paddy rice? (a) Farm Gate (b) Rural Market (c) Urban Market (d) Others; (please specify)

34. Who do you sell your paddy rice to? (a) Retailers [] (b) Wholesalers [] (c) Agro-processors [] (d) Contracted off-takers [] (e) Farmers Associations [] (f) Others [], (please specific)._____

35. Who are your most important input suppliers for rice production?

Inputs suppliers		Nature of supply
Contracted off-takers		
Retailers		
Wholesalers		
Agro-processors		
Farmers Associations		
Others (please specify)		

36. What is your total expenditure on rice production as indicated in the table below;

Items	Price per one or quantity/kg/bag	Quantity used	Amount/day (Naira)
Land rent/acquisition (Naira)			
Irrigation/water supply			
Labour (Mandays)			
Fertilizer			
Herbicides (litres)			
Insecticides (litres)			
Rice seed (kg)			
Harvesting			
Transportation (Naira)			
Milling and others			
Storage			
Others			
Total			

SECTION C: INTEGRATED RICE-FISH VALUE CHAIN

37. Please complete this table on the trends in rice production for the past three years

Items	Year 2020	Year 2019	Year 2018	Year 2017	Year 2017
Price per bag of rice					
Quantity harvested					
Total revenues					

38. What Main Type of pond do you use? Mode of production [a] Excavated Earthen pond []; [b] Concrete ponds []; [c] Hard plastic/wooden collapsible tanks []; [d] Cage culture []; [e] others specify

39. What type of fish feed do you use? [a] Self-made []; [b] Locally made []; [c] Imported

40. Types of fish cultured [a] Tilapia []; [b] Clarias []; [c] Heterobranchus [d] Hybrids fish [e] others [] (Please specify)

41. Number of fish stocked and harvested?

Number of fish stocked	Number of fish harvested

42. Where do you sell your fish? (a) Farm Gate [] (b) Rural Market [] (c) Urban Market [] (d) Others []; (please specify) _____

43. To which of the participant in the value chain do you frequently sell your fish? (a) Retailers [] (b) Wholesalers []; (c) Agro-processors []; (d) Contracted off-takers []; (e) Farmers Associations [] (f) Others []; (Please specify).

44. What is the main source of labour for Rice-fish production? Family [] Hired [] both family and Hired []

45. How many household members are engaged in your production? -----

46. Please provide information on labour usage

	Male		Female	
	Number	Amount paid	Number	Amount paid
Family labour				
Hired labour				

47. Please complete this table on fish harvested and sold from rice-fish technology

Quantity	No harvested	Price per kg	Quantity harvested(kg)	Total Revenue (N)
First harvest				
Second harvest				
Third harvest				
Fourth harvest				
Total				

48. Who are your most important fish input suppliers?

<i>Inputs suppliers</i>		<i>Nature of supply</i>
Contracted off-takers		
Retailers		
Wholesalers		
Agro-processors		
Farmers Associations		
Others (please specify)		

49. What is your total expenditure on fish production as indicated in the table below;

Items	Price per one or quantity/kg/bag	Quantity used	Amount/day (Naira)
Land rent/acquisition (Naira)			
Irrigation/water supply			
Labour (Man days)			
Fish Feeds (Local)			
Fish Feeds (Foreign)			
Fertilizer			
Lime			
Herbicides (litres)			
Insecticides (litres)			

Fingerling/ (kg)			
Juveniles (kg)			
Harvesting			
Transportation (Naira)			
Processing and others			
Storage			
Others			
Total			

50. How do you preserved unsold fish? Smoking [] Salting [] Sun-drying [] Refrigerator [] others [] (Please specify)

51. Please complete this table on the trends in fish production for the past three years

	Year 2020	Year 2019	Year 2018	Year 2017	Year 2016
Price per kg of fish (fresh)					
Quantity harvested					
Total revenues					

52. Would the price increase in the nearest future for fish? Yes [] No []

53. Would the price increase in the nearest future for paddy rice? Yes [] No []

54. Do you cultivate other crops? Yes [] No []

55. If yes, what are the other crops? _____

56. If yes, what is the total revenue from other crops produced? -----

57. Please complete this table for other crops cultivate

Items	Price per one or quantity/kg/bag	Quantity used	Amount/day (Naira)
Land rent/acquisition (Naira)			
Irrigation/water supply			
Labour (Mandays)			
Fertilizer			
Herbicides (litres)			
Insecticides (litres)			
Rice seed (kg)			
Harvesting			
Transportation (Naira)			
Milling, processing and others			
Storage			
Others			
Total			

SECTION D: HOUSEHOLD FOOD EXPENDITURE AND FOOD SECURITY

58. In the past one month, did your consumed the following food Items and much did your household spend on the food items consumed in the past one month?

S/N	Food Group	Description Of Food Types	Did You Consume this Item	How much did your Household Spend on the food items in the past ne month?

			0=No 1=Yes	
1	GRAINS	Guinea corn, Sorghum, Millet, Maize, Rice, Bread, Maize flour, Yam flour, Cassava flour, Wheat flour, Other grains and flour		
2	ROOT, TUBERS AND PLANTAINS	Cassava - roots, Yam-root, Gari-white, Gari-yellow, Cocoyam, Plantains, Potatoes, other roots and tuber		
3	PULSES (BEANS, PEAS)	Soya beans, Brown beans, White beans,		
4	NUTS AND SEEDS	Groundnuts, Other nuts/seeds/pulses		
5	MILK AND MILK PRODUCT	Fresh milk, Milk powder, Baby milk, Powder, other milk Products		
6	ORGAN MEAT	Liver, kidney, heart or other organ meats or blood-based foods		
7	MEAT AND POULTRY	Beef, Pork, Goat/Ram, Wild game meat, Other meat including poultry		
8	FISH AND SEAFOOD	Fish-Salmon, Tithus, Mackerel, Clarias, Carp etc. Seafood- lobster, crab, crayfish, prawns etc.		
9	EGGS	Eggs from poultry or any other bird		
10	GREEN LEAFY VEGETABLES	Tomatoes fresh, Tomato puree (canned), Onions, Garden eggs/eggplant, Okra - fresh/Dried pepper Other vegetables (fresh or dried)		
11	FRUITS AND VITAMINS	Bananas Orange/Tangerine, Mangoes, Apple, Avocado, Pear, Pineapples, Fruit canned, other fruits		
12	COFFEE, TEA, COCOA AND THE LIKE BEVERAGE	Coffee, Chocolate drinks e.g. Milo, Ovaltine, Bournvita), Tea (e.g. Lipton, green tea, etc.		
13	SUGAR, SWEETS AND CONFECTIONARY	Sugar, Jams, Marmalade, honey others		
14	OTHER MISCELLANEOUS FOODS	Condiments (salt, spices, pepper, Ginger, Garlic etc.		
15	NON-ALCOHOLIC DRINKS	Bottled water, Sachet water, Malt drinks, Soft drinks (Coca Cola, spirit, etc.), Fruit juice canned/Packed		

In the past one month, did your household used or spent on the following items and how much did your household spend on the items in the past one month?

NON-FOOD EXPENDITURES

S/N	ITEMS	DESCRIPTION OF ITEMS	Did you spend on this item 0=No 1=Yes	How much did your Household Spend on items in the past ne month?
1	EDUCATION	School fees, hostel/accommodation rent, notebook and textbook, pencil, uniform, pen, school bags etc.		
2	HEALTH	Drug bills, health consultancy charges etc.		
3	RENT	Accommodation rent		
4	HOUSE REPAIR AND MAINTENANCE	Utility bills, light, water, fuel for cars and generator etc.		
5	TOILETRIES, SOAP, DETERGENTS ETC.	Households soap, washing, bathing etc.		
6	SOCIAL FUNCTION	Ceremonies like wedding, burial, birthday, graduation etc.		

MINIMUM DIETARY DIVERSITY FOR WOMEN (MDD-W)

In the past one week, how many times were the following food types eaten by female members (15-49 years) of your household either as part of meals or snacks?

S/N	Food Group	Description of Food types	Consumed Yes=1, No=0
1	GRAINS	Guinea corn, Sorghum, Millet, Maize, Rice, Bread, Maize flour, Yam flour, Cassava flour, Wheat flour, Other grains and flour	
2	ROOT, TUBERS AND PLANTAINS	Cassava - roots, Yam-root, Gari-white, Gari-yellow, Cocoyam, Plantains, Potatoes, Other roots and tuber	
3	PULSES (BEANS, PEAS)	Soya beans, Brown beans, White beans,	
4	NUTS AND SEEDS	Groundnuts, Other nuts/seeds/pulses	
5	MILK AND MILK PRODUCT	Fresh milk, Milk powder, Baby milk, Powder Other milk Products	
6	ORGAN MEAT	Liver, kidney, heart or other organ meats or blood-based foods	
7	MEAT AND POULTRY	Beef, Pork, Goat/Ram, Wild game meat, Other meat including poultry	
8	FISH AND SEAFOOD	Fish-Salmon, Tithus, Mackerel, Clarias, Carp etc. Seafood- lobster, crab, crayfish, prawns etc.	
9	EGGS	Eggs from poultry or any other bird	
10	GREEN LEAFY VEGETABLES	Tomatoes fresh, Tomato puree (canned), Onions, Garden eggs/eggplant, Okra - fresh/Dried pepper Other vegetables (fresh or dried)	
11	FRUITS AND VITAMINS	Bananas Orange/Tangerine, Mangoes, Apple Avocado, Pear, Pineapples, Fruit canned, other fruits	
12	COFFEE, TEA, COCOA AND THE LIKE BEVERAGE	Coffee, Chocolate drinks e.g. Milo, Ovaltine, Bournvita), Tea (e.g. Lipton, green tea, etc.	
13	SUGAR, SWEETS AND CONFECTIONARY	Sugar, Jams, Marmalade, honey others	
14	OTHER MISCELLANEOUS FOODS	Condiments (salt, spices, pepper	
15	NON-ALCOHOLIC DRINKS	Bottled water, Sachet water, Malt drinks, Soft drinks (Coca Cola, spirit, etc.), Fruit juice canned/Packed	

SECTION E: GOVERNMENT POLICY

59. Do you pay tax to the government at any level? Yes [] No []

60. If yes to the above question, in what form and how much do you pay in production period?

Taxable items	Frequency of payment	Rate	Amount paid
Facilities			
Income/profit			
Land/rental tax			
Tax on association			
Animal tax			
Others (please specify)			

61. Do you receive subsidies from government in any form? Yes [] No []

62. If yes to the above question, in what form?

Taxable items	Frequency of payment	Rate	Amount paid
Credit			
Feeds			
Training			

Technical assistance			
Others (please specify)			

SECTION F: CHALLENGES AND CONSTRAINTS TO RICE-FISH TECHNOLOGY

63. What are the major challenges/constraint affecting Integrating Rice-Fish farmers and their production? Rank in order of severity?

Constraints	Encountered	Level of severity (Tick the appropriate)		
	1=Yes/2=No	Not Severe	Severe	
Lack of funds/capital				
High cost of inputs/unavailability of inputs				
Poor supervision				
Pilfering and vandalization				
Lack of support from government and private agencies				
Inconsistencies in government policies				
Lack of technical-know-how				
Crop failures/pest infestation				
Inadequate transport facilities				
Inadequate market information				
High cost of production				
Lack of labour				
Training/poor extension service				
Land accessibility				
Lack of rain, flooding and drought				
Destruction by animals grazing				
Conflicts				

We've finished the interview / data collection - thank you very much for your time and participation.

Integrating rice-fish farming

A Technology Package for its promotion

*Technical recommendations and lessons learned by farmers and researchers on water management
from adaptive rice-fish farming trials in Ebonyi, Kebbi, Oyo and Sokoto States of Nigeria*

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PREPARATION OF THIS DOCUMENT

This document was written based on observed water management challenges experienced by farmers during the on-farm adaptation of ricefield into integrated rice-fish farming. More than 200 farmers from six rice-producing communities in Ebonyi and Kebbi states of Nigeria participated in the trials, including researchers from the University of Ibadan, Oyo state, and Usmanu Dan Fodiyo University, Sokoto, State. The trials included university researchers and local extension workers of the four states.

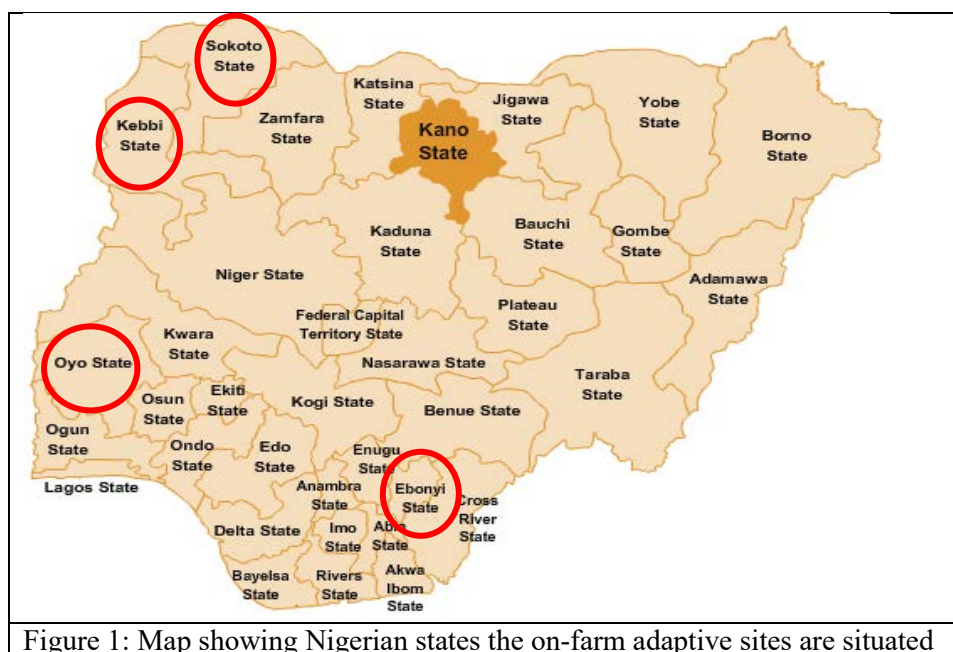


Figure 1: Map showing Nigerian states the on-farm adaptive sites are situated

This document summarizes the findings and observations of farmers and researchers on water use challenges, water management, biological interactions, and the importance of water in cultural management practices of an integrated rice-fish system. The document reports on a series of collaboratively managed farmer field trials, that aimed to improve the local promotion of integrated rice-fish farming.

The farm diversification project in Nigeria elucidated among other things, the challenges related to water use and management for rice-fish farming under tropical conditions. The water management challenges and the observed outcomes of the adaptation measures during the project's implementation phase furthered the necessity to describe the importance of water management regimes' on the outputs of an integrated rice-fish system. The document is designed to be useful reference for technical experts, agricultural extension agents and other practitioners to provide recommendations for current and new farmers.

ACKNOWLEDGEMENTS

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1.0 Introduction

The farm diversification through rice-fish farming project in Nigeria provided rice farmers with the opportunity to diversify traditional farming activities by modifying their fields to produce fish in addition to rice, without compromising the output of rice that would have been expected if they were to only practice rice monocropping.

This production system optimizes the use of land and water used for rice production to instead produce two food commodities, rice and fish, in the same production area. This leads to an increase in the amount of food produced per unit area, making more rice and more fish available both on the table and for the market. In addition to fish, other edible aquatic organisms (crabs, snails, frogs) are also found within the farming system. Rice yield is similar and even has potential to be higher than in rice-mono-cropping when just 10 percent of the paddy area needs to be modified for growing fish.

The rice-fish farming requires good knowledge of the environmental and climatic characteristics of each location where production is going to be established. It is essential to take into account the ideal requirements for both rice and fish in order to maximize output.

In growing fish in rice fields, there is the need to look at the physicochemical and biological characteristics of the hosting environments. The benefits of rice for fish include an overall improvement in the fish's habitat, which includes shade, shelter, and a reduction in water temperature on hot, sunny days. Additionally, it serves as a nitrogen sink, lowers ammonia levels in the water, and offers food, such as weeds and insects that fall from rice plants into the water. The presence of fish benefits rice production since they act as biocontrol agents, uprooting weeds for food and avoiding the need for pesticides. Fish, which feed on insects, contribute to the eradication of insect pests, hence lowering the need for pesticides.

For farmers, rice-fish farming has several advantages. It enhances nutrition and livelihood options, boosts yields and earnings, promotes land and water productivity, and decreases susceptibility to total farm loss via diversifying of production systems. It helps make farmers more resilient to environmental challenges such as climate change and their farming system more sustainable.

2.0 Importance of water in Rice-Fish culture

It is crucial to have access to water of the highest quality and quantity in order to properly raise rice and fish. Water is the sole medium that enables the cultivation of fish with rice. There must be enough water in the right quality and quantity to support fish's life cycle to harvest. Too little of water could harm the fish, as will pesticides and other agricultural chemicals. Therefore, for fish to coexist harmoniously in the same field with rice, water availability and proper water management are crucial.

2.1 Water as one of the key factors influencing fish culture in rice-fish farming

2.1.1 Water supply

Water is the most important element to farm aquatic animals and there should be sufficient volumes to guarantee for a growth cycle of the fish. In general 1200 mm of rain a year is the minimal condition for farming and keep flooded an area for at least a crop cycle (FISHADAPT, 2020). Therefore, plans should be put in action to secure enough water in the ricefields for co-culture of rice and fish. Water availability may be from rainfall, nearby lakes, storage tanks, tube well or irrigation canals.

Many factors, however, may impact water in the rice-fish plot, such as temperature changes, soil characteristics, and wind, which can then cause evaporation or seepage, resulting in water exhaustion from the field. This may then require the replenishment of the water from water sources, or creating an adaptation measure to prevent or reduce water loss.

For example, in Wawu community of Kebbi state, where one of the on-farm rice-fish adaptation plots was sited, water exhaustion due to seepage into the ground, and rapid evaporation was a main challenge, necessitating

actions by the farmers to mitigate the water loss problem. After consultation with farmers, the first mitigation measure was to line the floor of the sump/trenches with plastic to prevent seepage (see Figure 1 below). The plastic liner was anchored to the rice growing area by covering with soil. The outside of the fish trench liner is anchored with cord and stakes. The liner is high enough to allow filling of the trench to the point of overflow into the paddy at six inches or more. The liner width was adequate because the trench sides are vertical and mostly intact.

The use of the liner was a valuable learning experience for local farmers and extension workers. The intervention served as a temporary solution to prevent loss of water from the field. However, the consensus of stakeholders participating in this on-farm research was that:

- rice-fish farming should be done in this area during the rainy/wet season or
- further investments could be made for a tube well or irrigation system for water replenishment to the field.



Figure 2: Plastic lining as an initial adaptation measure to prevent water seepage.

Another example of a water supply measure is in the Nwannu community, Ebonyi state, where the rice-fish farm was sited opposite a lake (figure 3). This ensures adequate water supply to the rice-fish field whenever needed, **emphasizing importance of water supply in choosing sites for rice-fish farming.**



Figure 3: Rice-fish site opposite a water source (lake)

2.1.2 Water quality

The water turbidity in ricefields is usually high. Rain and the presence of clayey soils always bring a lot of suspended particles into the rice-fish plot. Lack of transparency hinders photosynthesis, however in paddy fields, the water is shallow enough that light penetrates to support phytoplankton growth, negating the impact of the suspended particles causing high turbidity levels. The soil's tendency to suspend particles should, however, also be considered while choosing the site and the type of fish to culture.

Figures 4(a) and 4(b) below shows the turbidity of water in the on-farm experimental plot of the project at the Okpiutumo at different times during the rice-fish culture cycle. It will be noticed in Figure 5(b) that fish movement in the field caused the suspension of clayish soil in the water, leading to increased water turbidity. However, participants in the farming trial noted that the expected fish growth rate and rice yield were not negatively affected, indicating that the primary production of phytoplankton which contributes to fish food was maintained to an appreciable extent. These observations by trial participants, are corroborated in the FISHADAPT rice-fish result in Myanmar (FISHADAPT 2020). Figure 4(a) shows another period during the rice-fish cycle when the water turbidity is low.

Figures 5, 6, 7, 8, 9 and 10 show the water quality in the on-farm adaptation and farmers sites in Ibadan (Oyo state), Amachi (Ebonyi state), Nwanna (Ebonyi state), Ikwo (Ebonyi state), Onicha (Ebonyi) and Wawu (Kebbi state), respectively. Farmers and local researchers at this site, observed that the water turbidity in the sites differs, however, the water turbidity does not impact negatively the expected growth of the fish. The type of soil in which the rice-fish plot is sited is also a determinant factor. For example, in Wawu, the soil is of high clay content (see Figure 2). This clay layer was disrupted during trench excavation and a “core” of compacted soil was not used to seal the sandier and more porous layer. Since the soil did not retain water due to seepage and rapid evaporation, the trial participants agreed to apply a locally sourced plastic liner. Unfortunately, the liner had several tears below the intended water level over time, making way for clayish sand to repeatedly increase water turbidity. This was a valuable learning experience for the trail participants, but despite these challenges, the fish sampled from this site (Wawu, Kebbi state) the farmers judged the fish healthy and fit for consumption.



Figure 4(a): Water quality in a farmer rice-fish plot in Okpiutumo, Ebonyi state, Nigeria



Figure 4(b): Water quality in a farmer rice-fish plot in Okpiutumo, Ebonyi state, Nigeria



Figure 5: Water turbidity in a rice-fish plot in Ibadan



Figure 6: Water quality in Amachi village, Ebonyi state



Figure 7: Water quality in Nwannu rice-fish plot, Ebonyi state



Figure 8: Water turbidity in a rice-fish plot in Ikwo community, Ebonyi state



Figure 9: Water turbidity in a rice-fish farm in Onicha, Ebonyi state, Nigeria



Figure 10: Water quality of a rice-fish site in Wawu, Kebbi state

2.1.3 Between agrochemical and organic manure/fertilizer use in Rice-Fish System

In contemporary industrial agricultural production systems, chemical fertilisers and other agrochemicals are usually employed. This substantially restricts the potential for co-cultivating aquatic animals and plants, barring

any concessions or a move towards organic rice farming. In addition to potentially harming animals and planktonic species, the presence of chemicals raises serious questions about the safety of food since they may accumulate in fish muscle and edible portions. The decision must be made on a case-by-case basis, though, since rice-fish co-culture may be more advantageous in regions with (a) less risk of pest and disease issues; (b) more extensive, low-input farming areas where agricultural chemicals are not routinely used. This makes rice-fish co-culture potentially more suitable to the more remote, poorer communities who do not practice industrial agricultural production.

2.1.4 Organic manure/fertilizer use in Rice-Fish system

Fertilizer application, especially organic fertilizers, can benefit plants and the aquatic ecosystem since their nutrients are utilized to promote phytoplankton and zooplankton development. However, it is important to take into account the dangers of overloading the paddies and causing anaerobic conditions that might kill the fish or produce methane gas and hydrogen sulphide, a harmful gas for fish. Taking this into account, farmers participating in the trials, were advised to carefully manage their crops in order to avoid harming fish while also preventing failure to properly nourish the plants. Therefore, researchers advised the farmers apply in dry conditions weeks before the paddy is flooded with water, as this allowed the applied organic matter to mineralize and be of benefit to the plant. The correct application of organic matter is an important component of the advice rice-fish farmers require to use organic manure instead of chemical fertilizer.

Furthermore, the trial participants agreed that plants should be continually given extremely modest amounts of organic fertilizer during wet seasons. Fish consume the feed, grow, and fertilize the pond on a regular basis with their discharge of faeces and urine. Farmers generally saw this as a wonderful combination of fertilizer - switching from fertilizer to fish feed during the monsoon season was seen by trial participants as highly beneficial.

During trial consultations with university researchers, the issue of climate change was discussed. In order to prevent nitrogen losses into the atmosphere brought on by a lack of oxygen and to control any gas emissions contributing to climate change, such as methane (from the anaerobic decomposition of organic matter) and nitrous oxide (from the anaerobic decomposition of nitrogen fertilizer), the approach to slowly applying fertilizers and adding manure/organic matter in dry conditions was considered most beneficial.

In the context of the trials, it was agreed that natural soil fertilization through organic nutrient decomposition and recycling is preferable to the application of chemical fertilizer.



Figure 11: Cattle manure give slower nutrients and make the soil fertile with organic matter

Highlighting the fact that aquatic species' digestive waste includes ammonia, was seen as an important element of the trial dialogue between farmers, extension workers and university researchers. It was important for farmers to understand that the buildup of ammonia in rice-fish systems might result in hazardous conditions that increase fish mortality, which is additionally exacerbated by high water temperature and a high pH (over 7.5). Rice-fish culture requires farmer to balance a number of natural processes. The combination of one or more of: high stocking rate for fish, excessive feeding (if feed is provided), liming, and intensive fertilisation with ammonia, quick-release fertilisers, or ammonium sulphate, might result in dangerous environmental condition for fish.

3.0 Water Management in the context of rice-fish farming cultural Practices

The trials also highlighted how the cultural management of water in setting up a rice-fish system is of great importance. All participants agreed that rice farmers who are interested in converting their fields to a rice-fish farm will need to make slight adjustments into their farms. Notably, is water inflow and outflow into the field, maintenance of water level in the field, rice transplanting and fish stocking schedule, among others.

The subsection below detailed generic advise for farmers wishing to establish rice-fish farming. These cultural practices for farmers are suggested. However, farmers are urged to adapt the measures to meet the prevailing farm situations, especially owing to a number of local factors, such as rainfall or a high rate of evaporation

3.1 Resources needed by the farmer to initiate the cultural practice

- A fish trench dug and connected to the rice field
- A 5-inch diameter inlet-outlet PVC pipe with a fine mesh screen at one or two ends of the modified rice field
- Water supply (source of water- could be water flowing adjacent to the rice field from a nearby river or a tube well dug by the side of the rice field)

7.



Figure 12: A field intended for rice-fish farming with water flowing through from a nearby river

3.2 Cultural activities to be carried out

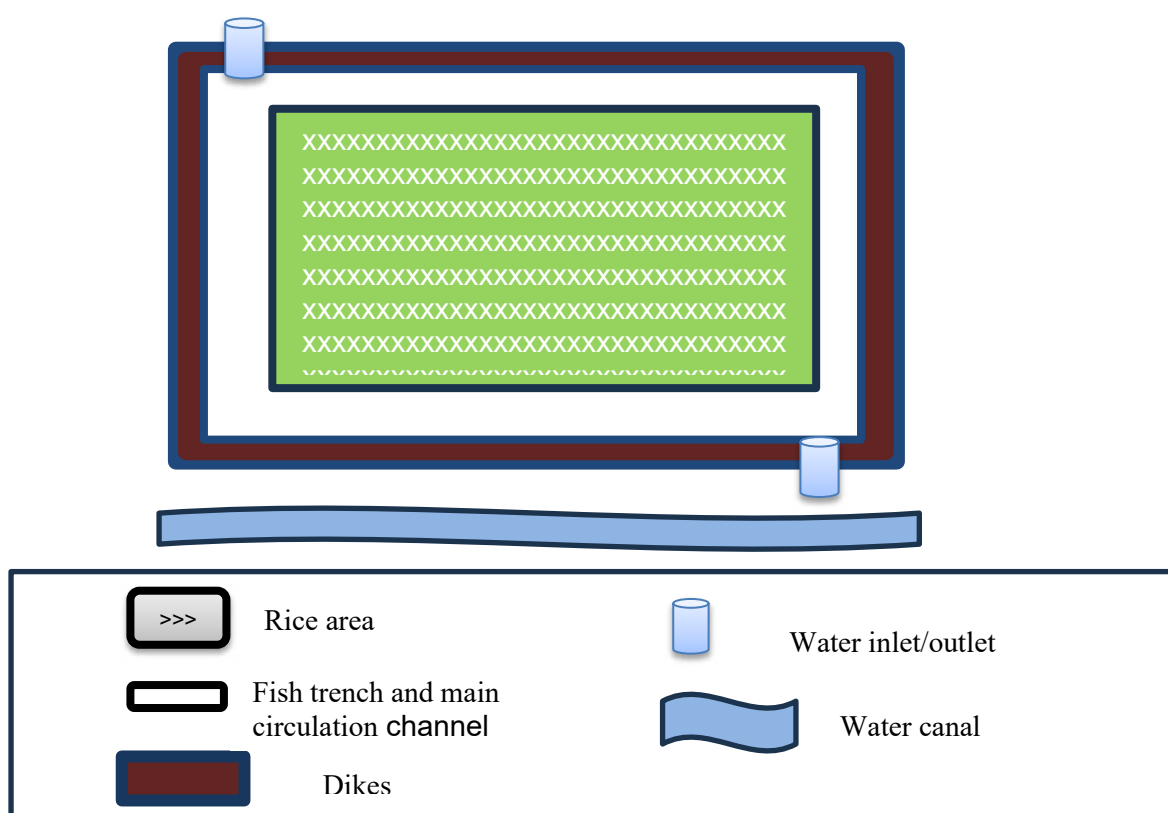


Figure 13: A schematic diagram of the ricefield modification design for rice-fish farming

- Install the screened PVC pipe into the dike of the rice field with the rotating elbow located inside of rice-fish plot for the water inlet/outlet flow.
 - The elbow should be tilted at an angle that would enable water to be maintained at the depth desired for the rice-fish plot.
- Water management starts at the point of letting water into the pond or rice field, and its preparation for the growth of natural food.
- At this time (the pond and the rice field are still separated by a dike), gradually let the water come inside to the pond and maintain to the level of the rice field bed.
- During transplanting/sowing of rice in the field, irrigate water into the pond at 3 inches higher than the water level in the rice field.
- In the second week after sowing, irrigate water into the rice field.
- As much as possible, maintain the pond water level at 3 inches higher than the water in the rice field.
- In the third week after sowing, when the rice is fertilized, stock the fish at a rate of five fish per square meter.
- On the 25th day after sowing open the dike/blockade in-between the pond dike and rice field and let fishes swim out from the pond into the rice field through the center trench.
- On the 45th day after sowing raise water level in the rice field 5 to 8 inches deep (water level in the pond rises at the same level as the rice field).
- On the 60th day after sowing raise the water level in the rice field from 8 to 12 inches deep (water level in the pond also rises at the same level with the rice field).

4.0 Water management to control pest and diseases

According to the result of similar rice-fish research activity in Myanmar (FISHADAPT 2020) which is applicable globally, the impact of the lack of water on respiration would cause pests like whorl maggots, root-feeding midges, water weevils and caseworms to become less active for 1 or 2 days in a field that had been drained. The study also found that insect species including black bugs, hopperburn, planthoppers, armyworms, gall midges, hispa, and the majority of stem borers will be affected by draining circumstances. Although draining might result in a shortage of water in the pond region, which would encourage the growth of weeds, these could eventually be controlled by the presence of fish. (FISHADAPT, 2020).



Figure 14: A drained rice-fish plot in Wawu, Kebbi state, Nigeria

5.0 Conclusion and summary

Proper water management in a rice-fish farm is crucial to the success of the operation. A number of factors may have an impact on water availability, which might accelerate its exhaustion through evaporation or seepage. These factors include soil qualities, wind, and temperatures. The application of adaptation measures (see table 1) to replenish the water will mitigate this challenge.

The usefulness of water management for the stimulation of the culture system for production of natural fish food, paddy fertilization and the control of pests and diseases is equally important. As elucidated in sections 2.1.3, 3.2 and 4.0 of this report, the dry application of organic manure before the paddy is flooded with water, and the controlled application of same at intervals during the production cycle, provides the necessary nutrient for paddy development and when fish releases their waste into the water, both helps to reduce the need of chemical fertilizer. Furthermore, the growth of weeds is controlled by the fish when uprooted for food, thereby reducing the need for herbicide application.

Table 1 below indicated some adaptation measures to the challenges related to water during the farm diversification trials in the three States.

Table 1: Summary of water management considerations for rice-fish farming

Challenges	Adaptation techniques
Water availability	Irrigation system
	Borehole
	Collect rainwater in storage tanks near the farm
	Refill from water storage tanks or tube well
Flood incidence	Site selection in areas not prone to flooding

	Raising bunds/dykes higher than usual
	Planting crops along the bunds
Seepage	Site selection in soil that has a high water-holding capacity
	Use plastic lining to prevent seepage
	Conduct rice-fish farming during the rainy/wet season
	Replenishment of water from borehole/irrigation/storage tanks/tubewell
Soil characteristics	Select sites with proper water-holding capacities

Following simple steps and recommendations to avoid or adapt to challenges related to water availability, management and biological reactions as described in this publication, would enable farmers to effectively manage their farms for the desired output.

7.0 References

- FISHADAPT. 2020. Rice-fish farming manual: FishAdapt project. Also available: <http://fishadapt.org/sites/default/files/pdf/resources/rice-fish%20manual.pdf>
- Halwart, M. and M.V. Gupta (eds.) 2004. Culture of fish in rice fields. FAO and The WorldFish Center, 83 p. <http://www.fao.org/3/a-a0823e.pdf>

Annex 19: Instructional care for rice-fish farming in Nigeria

INSTRUCTIONAL CARE FOR RICE-FISH FARMING IN NIGERIA

Brief Description

Rice-fish farming as a farm diversification strategy is an approach to assist rural communities to transform their traditional ricefield environments into a more productive, resilient and biologically diverse agro-ecological landscape, with efficient use of land and water resources to produce fish in addition to rice within their existing rice fields. This production system optimizes the production of two food commodities, rice and fish in the same production area either simultaneously or on a rotational basis. In addition to fish, other edible aquatic organisms (crabs, snails, frogs) are also found within the farming system. Rice yield is similar and even has potential to be higher than in rice-mono-cropping when just 10 percent of the paddy area is used for growing fish. The rice-fish farming system has triple-win benefits for farming families by increasing total farm yields, incomes, and levels of nutrition.

Target beneficiaries

Rural rice farmers (youth, women, men), extension workers, researchers

Instructional Care of Technology

Step 1: Rice field modification



- **Dig Fish circulation channel (trench)** round the four corners of the rice field:
 - width: 1 m
 - depth: 1 m
 - **Size of the fish trench:** total size of the channel and refuge to be $\leq 10\%$ of the total area of the rice-fish plot
-

Step 2: Rice field and pond preparation



- Add lime
- Fill with water
- Add manure: Low-cost options- organic manure (cow dung, poultry droppings, stems, leaves, straw, etc.) for fertilizing the plot

Step 3: Rice transplanting and fish stocking



- **Rice variety:** Rice variety (FARO-44-National code: NGOS-91-44))
- **Rice spacing:** 20 X 25 cm spacing



- **Fish stocking:** Done 2 weeks after transplanting rice
 - Float fish container on water surface for 15 minutes to balance the temperature between the water containing the fish feed and that of the rice field. Thereafter, allow fish to swim into the pond.
 - 1000 juveniles of Catfish (*Clarias gariepinus*) of 8-10 g (recommended average size) stocked
-

Step 4: Fish feeding



- Stocked fish are fed two times a day with fish feed developed by the project.
 - Additionally, fish could be fed with agricultural by-products (rice bran, and cow dung, poultry droppings, stems, leaves, straw to fertilize the pond to aid primary production needed to produce natural food for fish in the pond)
-

Step 5: Water management



- After stocking, maintain the water depth between 25-30 cm in the rice-fish plot, minimize water loss (leakage through cracks in dykes, holes dug by rats, mice, monitor lizards, amphibians, etc.) through regular monitoring
-

Step 6: General/Key rice-fish management considerations



- Reinforce/raise the bund/dyke to contain water and/or prevent overflow of water to prevent loss of fish. This is also helpful to limit/break the flow of water during flooding



- Install PVC pipe to control water (inlet & outlet) in the rice field
- installation of wire netting at the opening of the irrigation canal and the spillway to prevent the exit of farmed fish from the rice-fish plot



- Maintenance of the plot (weeding), protection/ guarding of the plot (control of rice and fish pests),

Step 6: Harvesting (fish is harvested after rice)



- Rice and fish ready for harvest between 3 – 4 months of co-culture.

Rice harvest



Fish harvest after 3 months of co-culture



Technical Performance/Technical Characteristics of the rice-fish system

The system maximizes the use of both land and water for food production. Rice offers benefits for the fish by improving the overall environment for the fish by providing shade, shelter and reduces the water temperature during hot sunny days. It also acts as Nitrogen sink and helps reduce ammonia in the water, and provides food including in the form of the weeds and insects that fall from the rice plants into the water. Rice benefits by the presence of fish, in which the latter act as biocontrol agents in controlling the growth of weeds by uprooting for eating, thereby reducing the use of herbicides. By preying on the insects, fish helps in eradicating insect pests, thereby reducing the use of pesticides. The complimentary use of Nitrogen, coming from fish feeds and fish wastes, between rice and fish results in low fertilizer application and low release into the surrounding environment. Thus, the need for fertilizers, pesticides and herbicides are reduced, compared to rice mono-cropping.

Conclusion

The farming system offers multiple benefits which includes: increased land and water use efficiency, increased yield, increased economic profitability, diversification of income generating activities, increased resilience and insurance against crop failure, production of two crops on same piece of land; thus minimized production cost, minimized environmental impacts, increased aquatic species diversification at the farm site, improved food and nutrition security, minimized dependence on the use of chemicals, such as pesticides, fertilizers, and herbicides.

Annex 20: Business manual for rice-fish farming

**Investment and Business Manual for Fish-Rice Production System in
Ebonyi State, Southeast Region and Kebbi State, Northwest Region of Nigeria**

The Feed-the-Future Innovation Lab for Fish Farm Diversification

Start-up Business Plan in Nigeria



By

University of Georgia (UGA), Tifton, USA

University of Ibadan (UI), Nigeria

FAO, Italy

EXECUTIVE SUMMARY

Despite Nigeria being Africa's largest rice-producing and consuming country, its rice consumption demand still exceeds its local production supply. This contributes to the state of food insecurity in Nigeria, with the country having a 38kcal/person/day food energy deficit and an indication of a critical shortage of nutrient-rich foods. Also, the poverty situation in the country is a pointer or a sign of the likelihood that the country might not attain the Sustainable Development Goals (SDG) 2. Thus, the study examines the impact of the adoption of integrated rice-fish culture technology on profitability and food security in Nigeria.

The integrated system fosters a positive social impact by supporting local communities. It generates employment opportunities and promotes self-sufficiency, increasing economic resilience and well-being in the community. The newly introduced production system opens up opportunities for value-added products. For instance, customers may be interested in purchasing rice and fish-based meal kits or ready-to-cook products that cater to their convenience and culinary preferences. The product can be an educational tool for raising awareness about sustainable agriculture and responsible consumption. Customers who support the integrated system can feel proud of their role in promoting environmentally friendly practices. Overall, the unique features of this newly implemented integrated rice-fish product lie in its innovative, sustainable, and environmentally conscious approach, offering customers a unique and meaningful way to support responsible agriculture while enjoying fresh and nutritious products. For instance, providing hatchery training and value addition to farmers who adopt the integrated rice-fish production system offers several significant advantages that contribute to the success and sustainability of their farming practices. Furthermore, the provided hatchery training equips farmers with specialized knowledge and skills related to fish breeding, rearing, and management. Also, sharing of knowledge's with project communities about best practices for maintaining water quality, alternative fish feeding and feeding techniques, disease prevention, and overall fish health empowers

farmers to make informed decisions, leading to improved fish productivity and better outcomes. While training on value addition help farmers to improve profits margin, create more job opportunity, diversification of products and markets, enhancing food security through the reduction in post-harvest losses thus maximizing sustainable management of the rice -fish production system,

The integrated rice and fish production system is a sustainable and innovative approach to agriculture that combines rice farming and fish cultivation in a harmonious ecosystem. The integrated rice and fish production system is an innovative and sustainable agricultural approach that promotes resource efficiency, environmental stewardship, and economic viability for farmers. By harnessing the power of nature and embracing ecological principles, this integrated system offers a promising solution to the challenges of modern agriculture. It is designed to optimize land use, increase productivity, and enhance resource efficiency while promoting environmental sustainability.

The Ebonyi State, South-eastern Nigeria study shows the net profit for one cycle production of rice in an integrated rice-fish farming system is N6, 213 while the net profit of producing fish in an integrated fish-rice farming system in the region is N210,644 on 330 m² farm. The combined total net profit is N216,857. This is expected under normal circumstance, i.e., “all things being equal”. Rice profit margin ranges from the best of N20,160 to the worst of -N7,734 whereas fish profit margins range from the best of N285,190 to the worst of N136,097 respectively. Overall, implementing an integrated fish-rice production system in Ebonyi State in the South-eastern Region of Nigeria is a profitable venture with a net profit of N216,857, with 87 percent chances of obtaining profits, “all things being equal”. An initial capital of N300,000 – N400,000 could get the farmer or farming community started with a 330m² size farm.

The Kebbi State, North-western Region of Nigeria study shows the net profit for one cycle production of rice in an integrated rice in a rice-fish farming system is N138,164 while the net profit of producing fish in an integrated fish-rice farming system in the region is N1,401,109 on 2,000m² size farm. The combined total net profit is N1,539,273. This is expected under normal circumstance, i.e., “all things

being equal”. Rice profit margin ranges from the best of N261,658 to the worst of N14,671 whereas fish profit margins range from the best of N1,848,389 to the worst of N953,828 respectively. Overall, implementing an integrated fish-rice production system in Kebbi State in the North-western Region of Nigeria is a profitable community venture with a net profit of N1,539,273, with 97 percent chances of obtaining profits, “all things being equal”. An initial capital of N800, 000 – N900,000 could get the farmer or farming community started with a 2,000m² size farm.

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INTRODUCTION

1.0. Geographic Focus

This research project will tackle the challenge of poverty and food nutrition and insecurity in two Nigerian States (Kebbi and Ebonyi), which are important rice-producing areas and benefit from the support of the Federal Government to increase their rice production for national self-sufficiency. The study area Kebbi and Ebonyi represents two different rice-producing agroecological zones in the country and are ranked very high among Nigerian states that are food and nutrition insecure (USAID, 2018). The poverty rate in the two states stands at 50.2 percent and 79.76 percent for Kebbi and Ebonyi States, respectively, above the national average (NBS and Statista, 2019) (Fig. 1).

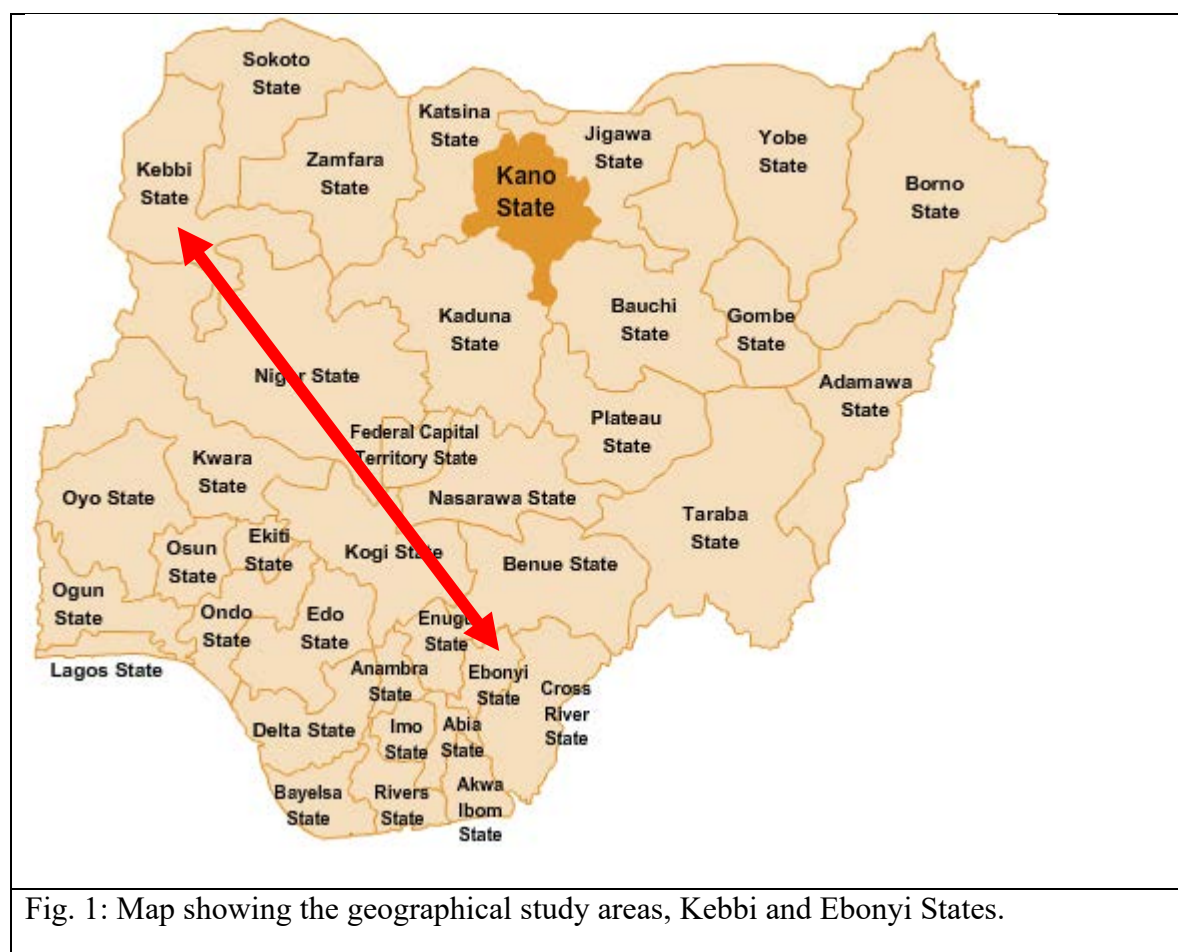
1.1. Study Area

This study's area is Nigeria, where two States, Ebonyi (Southeast) and Kebbi (Northwest) States, were selected from the list of Nigeria's leading rice-producing states. Ebonyi state is one of the states in the Southeast region of Nigeria. The State occupies 5,533 km² (2,136 mi²) and, based on 2016 figures 3, 49 million people (NBS, 2017). Agriculture is the principal occupation of the inhabitants, and the State is popularly renowned for producing *Ebonyi or Abakaliki rice*, with an estimated production of 6 million tonnes per hectare. The vegetation in the State is rainforest and derived savannah that is suitable for rice production (Chidiebere-Mark *et al.*, 2019).

On the other hand, Kebbi State is a state in Northwest Nigeria. The State occupies 36800 km². Based on 2016 figures of 4.4 million people and an annual growth rate of 3.2 percent. The State's population for 2020 is estimated to be 5 million people. The vegetation in the states is savannah that is suitable for rice production. Farming is the primary activity of residents of the State.

The State is popularly known for producing *Lake rice*, a joint and partnership initiative between Kebbi and Lagos state governments. The rice production capacity in the State is estimated at 8 million tonnes

per year. The two states are also part of the staple crops processing zones (SCPZ) according to Agricultural Transformation Agenda (FMARD, 2016).



1.2. Relevance and Motivation for the Integrated Fish-Rice Production System

Nigeria's food and nutrition insecurity menace still requires more empirical research and information. However, there needs to be more information on the state of the debilitating food insecurity in the country. Numerous factors, including poverty, lack of nutrition education, knowledge gap in agriculture/aquaculture practices, and inefficient market system, justify widespread food insecurity and nutrition challenges across Nigerian states (FMARD, 2016). These challenges manifest in rural communities through stunting, wasting and underweight children, under-employment for youths, gender disparity in resource use and allocation, and limited access to food (USAID, 2018). If adequately managed, the Rice-Fish culture system can sustainably support vulnerable communities'

nutritional needs. FAO (2017c) reported that introducing fish into a rice-farming system will not only result in a shift from a cropping system but will also be a shift to a more balanced diet consumption for the farming communities. Hence, this study will add to the body of literature on the benefits inherent in rice-fish culture adoption and its effects on the profitability and food security of rural farmers in Nigeria. Given that there are few studies on rice-fish culture adoption, profitability, and food security in Nigeria.

The introduction of a community-based study is necessary when considering the various advantages of integrating rice and fish production, both in the farmers' profitability and food and nutrition security status. Following the theory that a strong relationship exists between food production and consumption, this study is expected to help in policy formulation on integrating aquaculture into agricultural production in increased yield, profitability, and nutritionally food-secure households among the farmers. In addition, the study is expected to provide valuable guides in determining the best farming systems, either the rice or fish-monoculture or the rice-fish poly-culture, i.e. the integrated rice-fish system. Identifying the rice-fish systems that are more profitable, i.e. give the farmers higher income and contribute better to their food and nutrition security. A decision can be made by the government and other organized farmer's bodies on the types of farming systems that will be adopted in tackling the menace of food and nutrition security in the country.

1.3. Product and Services

The integrated rice and fish production system is a sustainable and innovative approach to agriculture that combines rice farming and fish cultivation in a harmonious ecosystem. The integrated rice and fish production system is an innovative and sustainable agricultural approach that promotes resource efficiency, environmental stewardship, and economic viability for farmers. By harnessing the power of nature and embracing ecological principles, this integrated system offers a promising solution to the challenges of modern agriculture. It is designed to optimize land use, increase productivity, and

enhance resource efficiency while promoting environmental sustainability. The following are the critical components of the system:

Rice Paddies: The system starts with the cultivation of rice in paddies. These paddies serve as the primary farming area where rice crops are grown. Traditional rice farming practices can be used, but modern techniques such as SRI (System of Rice Intensification) may also be implemented to improve yields.

Fish Production: Fish ponds are dug around the rice paddies. Depending on the region's suitability and market demand, these ponds are designed to accommodate various types of freshwater fish. Common fish species include Tilapia, Catfish, Carp, and other indigenous varieties. The newly implemented integrated rice-fish system adopted Catfish, simply because it is the favourite fish in Nigeria.

Water Management: The key aspect of the integrated system is water management. The run-off water from the rice paddies, enriched with organic matter, nutrients, and detritus, is directed into the fish ponds. The fish, in turn, benefit from the nutrient-rich water, as it promotes natural food sources such as plankton and aquatic plants.

Symbiotic Relationship: The integration of rice and fish creates a symbiotic relationship. The fish help control pests and weeds in the rice paddies, reducing the need for chemical pesticides. On the other hand, the rice paddies provide shade and shelter for the fish, creating a balanced and natural environment.

Nutrient Cycling: The integrated system facilitates nutrient cycling. Fish waste, uneaten food, and organic matter in the fish ponds act as natural fertilizers for the rice paddies. In return, the rice paddies filter and purify the water before it returns to the fish ponds, creating a closed-loop nutrient cycle.

Biodiversity and Sustainability: This system promotes biodiversity and ecological balance by creating diverse habitats for plants and animals. It reduces the dependency on external inputs, minimizes environmental pollution, and enhances the overall sustainability of agricultural practices.

The benefits of the integrated rice-fish system are:

Increased Productivity: Integrating rice and fish production leads to increased overall productivity.

Farmers can harvest rice and fish simultaneously, generating multiple sources of income from the same land area.

Resource Efficiency: Water, nutrients, and land are efficiently utilized in this integrated system, making it a sustainable approach to agriculture. It requires less water than conventional rice monoculture and reduces the need for chemical fertilizers and pesticides.

Risk Diversification: Farmers are less susceptible to market fluctuations and climate-related risks since they have diversified income streams from rice and fish production.

Environmentally Friendly: By relying on natural processes for pest control and fertilization, the integrated system minimizes the use of harmful chemicals, reducing the environmental impact.

Food and Nutrition Security: The integrated rice and fish production system can contribute to food security by providing a diverse range of nutritious food products.

1.4. Special Benefits of Integrated Rice-Fish Technology

High Quality and Freshness: The integrated rice and fish production system ensures the highest quality and freshness of the products. Since the fish are cultivated close to the rice paddies, customers can enjoy fish harvested at the peak of their quality, resulting in superior taste and texture.

Sustainable and Environmentally Friendly: Your production system is designed with a solid commitment to sustainability and environmental responsibility. Customers can feel good about supporting a product that promotes biodiversity, reduces the use of harmful chemicals, and minimizes environmental impact.

Nutritional Value: The combination of rice and fish provides a well-balanced and nutritious meal. Rice is a staple carbohydrate, while fish is an excellent source of protein, Omega-3 fatty acids, and various essential nutrients. Health-conscious consumers will appreciate the nutritional benefits of your integrated produce.

Local and Community Support: Buying from your integrated rice and fish production supports local farmers and the community. Customers can take pride in knowing they are contributing to the growth of a sustainable and thriving local agricultural system.

Diversified Product Offering: Your integrated system allows customers to access diverse products from a single source. They can conveniently purchase rice and fish, simplifying their shopping experience and broadening their culinary options.

Transparent and Traceable Supply Chain: Your commitment to sustainability and customer satisfaction includes maintaining a transparent and traceable supply chain. Customers can have confidence in the origin and handling of the products they purchase, ensuring food safety and ethical sourcing.

Competitive Pricing: While offering premium quality and sustainable products, your pricing strategy remains competitive. Customers get the best value for their money, making your integrated rice and fish produce an attractive option in the market.

Innovation and Technology: Your production system embraces innovative agricultural practices and may incorporate advanced technologies to optimize yields and resource efficiency. Customers who value modern and forward-thinking approaches will be drawn to your products.

Positive Brand Image: By promoting sustainable agriculture and environmental responsibility, your brand stands out as a socially conscious and responsible choice. Customers may feel strongly about your brand due to its positive ecological and societal impact.

Customer Education and Engagement: You can invest in customer education and engagement initiatives to further distinguish your products. Information about the integrated system, benefits, and sustainable practices can build customer loyalty and trust.

By effectively communicating these advantages, one can establish a strong value proposition differentiating your rice and fish produce from competitors and attracting a loyal customer base that appreciates your products' quality, sustainability, and positive impact.

Our product, which involves the integration of rice and fish production in the same pond, offers several unique and special features that set it apart from conventional rice or fish farming practices. Some of the advantages are:

Enhanced Nutrient Cycling: By cultivating rice and fish in the same pond, your system maximizes the efficient use of nutrients. Fish waste and uneaten food serve as natural fertilizers for the rice paddies, nourishing the rice plants and promoting their growth. The rice paddies act as a biological filter, purifying the water before it returns to the fish, creating a self-sustaining nutrient cycling process.

Increased Land Utilization: Unlike traditional farming practices that require separate land areas for rice and fish, your integrated system optimizes land utilization. It allows farmers to make the most out of limited land resources by producing rice and fish simultaneously in the same pond, thereby increasing overall productivity.

Biodiversity and Ecological Balance: The co-existence of rice and fish in the same ecosystem fosters biodiversity and ecological balance. Fish help control pests and weeds in the rice paddies, reducing the need for chemical pesticides. The rice plants, in turn, provide shade and shelter for the fish, creating a harmonious and natural environment for both flora and fauna.

Sustainable and Environmentally Friendly: Your integrated system embodies sustainable agriculture principles. It minimizes chemical inputs, reduces water consumption, and lowers greenhouse gas emissions compared to conventional rice and fish farming methods. This eco-friendly approach aligns with the growing demand from environmentally conscious consumers.

Freshness and Quality: The proximity of fish and rice cultivation ensures the freshest possible products. Customers can enjoy rice and fish harvested at their peak freshness, resulting in superior taste and nutritional value.

Risk Diversification for Farmers: Integrated rice and fish production offer risk diversification for farmers. By having multiple sources of income from the same land area, they are less susceptible to market fluctuations and climate-related risks that may affect only one type of cultivation.

Innovation and Modern Farming Practices: Your product represents an innovative and modern approach to farming. Embracing such a forward-thinking system demonstrates your commitment to adopting cutting-edge agricultural practices that benefit the environment and the farming community.

2.2. Unique Features of Integrated Rice-Fish Technology

Social and Community Impact: The integrated system fosters a positive social impact by supporting local communities. It generates employment opportunities and promotes self-sufficiency, increasing economic resilience and well-being in the community.

Potential for Value-Added Products: The integration of rice and fish opens up opportunities for value-added products. For instance, customers may be interested in purchasing rice and fish-based meal kits or ready-to-cook products that cater to their convenience and culinary preferences.

Educational and Awareness-Building Value: The product can be an educational tool for raising awareness about sustainable agriculture and responsible consumption. Customers who support the integrated system can feel proud of their role in promoting environmentally friendly practices. Overall, the unique features of your integrated rice-fish product lie in its innovative, sustainable, and environmentally conscious approach, offering customers a unique and meaningful way to support responsible agriculture while enjoying fresh and nutritious products.

Advantage of the hatchery training given to farmers who adopt our production system.

Providing hatchery training to farmers who adopt your integrated rice-fish production system offers several significant advantages that contribute to the success and sustainability of their farming practices:

Increased Knowledge and Skills: Hatchery training equips farmers with specialized knowledge and skills related to fish breeding, rearing, and management. They learn about best practices for maintaining water quality, feeding techniques, disease prevention, and overall fish health. This knowledge empowers farmers to make informed decisions, leading to improved fish productivity and better outcomes.

Improved Fish Stock Quality: Through hatchery training, farmers gain insights into selecting and breeding high-quality fish species well-suited to the local environment and market demands. This results in improved fish stock quality, better growth rates, and enhanced disease resistance, ultimately leading to higher profitability.

Enhanced Productivity: Farmers who receive hatchery training are better equipped to manage fish reproduction and breeding cycles. They can control the timing of fish stocking in the ponds, leading to consistent and optimized fish production throughout the year. This enhanced productivity translates to increased income potential for farmers.

Risk Mitigation: With hatchery training, farmers become aware of potential risks and challenges associated with fish farming. They learn preventive measures and management strategies to mitigate these risks, such as disease outbreaks or adverse environmental conditions. This proactive approach minimizes losses and ensures the long-term viability of their fish production.

Increased Income Streams: Hatchery training allows farmers to diversify their income streams. By having the knowledge and capability to breed and rear fish in their hatcheries, they can sell fingerlings to other farmers or interested parties, creating an additional revenue source.

Sustainable Fish Farming: Proper hatchery management contributes to sustainable fish farming practices. Farmers learn about responsible breeding, avoiding overexploitation of wild fish populations, and maintaining genetic diversity in farmed fish. This sustainable approach aligns with consumers' preferences for eco-friendly and ethically produced products.

Empowerment and Confidence: The training instils confidence in farmers as they become proficient in fish hatchery operations. This empowerment fosters a positive attitude towards adopting innovative and modern farming techniques, making them more receptive to embracing integrated rice-fish production practices.

Networking and Collaboration: Hatchery training often involves interactions with other farmers, experts, and trainers. This facilitates networking and collaboration opportunities within the agricultural

community. Farmers can exchange ideas, share experiences, and learn from each other, fostering a sense of camaraderie and continuous improvement.

Sustainable Community Development: As more farmers adopt your integrated production system and receive hatchery training, the overall impact extends beyond individual farms. Sustainable practices contribute to community development, economic growth, and environmental conservation.

Long-Term Investment: Providing hatchery training demonstrates your commitment as a company to supporting the success of the farmers who embrace your integrated system. This long-term investment in their training and skill development establishes a sense of loyalty and trust between the farmers and your brand.

Offering hatchery training to farmers who adopt the integrated rice-fish production system benefits both the farmers and your business. It enhances their knowledge and skills, improves fish productivity, mitigates risks, fosters sustainable practices, and contributes to community development. As a result, farmers are better equipped to succeed in the integrated system, positively impacting their product's overall success and reputation in the market.

2.3. Smoking of fish (added value) to extend shelf life

Smoking fish is a traditional method of adding value to the product by extending its shelf life while enhancing flavour and taste. The process involves exposing the fish to smoke produced by burning wood or other aromatic materials. This value-added technique offers several benefits:

Shelf-Life Extension: Smoking fish helps preserve the product by reducing water content and inhibiting the growth of spoilage bacteria. The smoke's antimicrobial properties and the drying effect extend the fish's shelf life, making it safe for consumption over an extended period.

Enhanced Flavour and Aroma: Smoking imparts the fish a unique and pleasant smoky flavour. The process adds depth and complexity to the taste, making it more appealing to consumers, especially those who appreciate the distinctive flavour of smoked fish.

Improved Texture: Smoking partially cooks the fish during the process, resulting in a firmer texture. This change in texture can be desirable, providing a more enjoyable eating experience.

Versatility and Culinary Applications: Smoked fish is a versatile product used in various culinary applications. It can be consumed as is, incorporated into salads, sandwiches, or pasta dishes, or used as a flavouring agent in soups and stews. This versatility increases the product's market appeal and potential customer base.

Convenience and Portability: Due to the reduced water content, smoked fish becomes lightweight and less perishable, making it a convenient and portable food option. It can be easily stored and transported, making it ideal for outdoor activities or on-the-go consumption.

Premium Product and Higher Pricing: Smoked fish is often perceived as a premium product due to its unique flavour and extended shelf life. As a result, it can command higher prices in the market, leading to increased profitability for producers.

Market Demand and Niche Opportunities: A growing demand for value-added and speciality food products, including smoked fish. Offering smoked fish opens up opportunities to cater to niche markets and consumers seeking premium, artisanal, and gourmet options.

Utilization of By-catch and Varietal Fish: Smoking fish can be an excellent way to utilize fish species that may not be as popular in their fresh form or are considered by-catch. By smoking these varieties, producers can diversify their product range and reduce waste in the seafood industry.

Cultural and Culinary Heritage: Smoking fish is often tied to cultural and culinary traditions in various regions worldwide. Continuing this practice, it preserves and honours the cultural heritage of fish preservation and preparation methods.

Export Potential: Smoked fish products have export potential, especially in regions where the culinary tradition of smoked fish is not widely available. Exporting smoked fish can be an avenue for market expansion and revenue growth. Smoking fish adds value by extending shelf life, enhancing flavour, and creating a premium product with various culinary applications. This value-added process

can increase profitability, cater to niche markets, and contribute to cultural heritage preservation while meeting the demand for innovative and unique food offerings.

2.4. Additional Services Provided by Integrated Rice-Fish Culture Technology

Extension Services

Providing free extension services for implementing integrated rice-fish farming is crucial to supporting farmers, promoting successful system adoption, and ensuring sustainable agricultural practices. The provision of free extension services is a critical component of the successful implementation of integrated rice-fish farming. It empowers farmers with the necessary skills, knowledge, and support to adopt sustainable and profitable practices, leading to improved livelihoods, environmental conservation, and food security in the farming community. These services encompass various aspects of technical support, training, and knowledge dissemination to assist farmers throughout the process by the team of experts from the University of Ibadan, Ibadan, Nigeria, Usman Dan Fodio University, Sokoto, University of Georgia, Atlanta, and the Food and Agriculture Organization (FAO), Italy. This team of experts provided the technical expertise needed to implement and adopt integrated rice technology in Nigeria successfully. These experts guided the design and construction of fish ponds, rice paddy management, water control structures, and the incorporation of both systems. In site selection and planning, they assiduously helped the farmer's select suitable sites for the integrated rice-fish farming project. Factors considered in the site selection include soil type, water availability, climate conditions, and topography to optimize the integration of rice and fish production.

Furthermore, farmers received comprehensive training through workshops conducted by a team of experts in areas such as business planning and management, the importance of records keeping, the economic feasibility of integrated rice-fish technology, fish breeding and hatchery management, rice planting techniques, fish stocking, pest and disease management, and the principles of sustainable farming practices. Emphasis was placed on the adoption of Good Agricultural Practices (GAP). This includes guidelines on the responsible use of inputs, water management, waste recycling, and

biodiversity conservation, all of which contribute to environmental sustainability and long-term productivity.

Integrated rice-fish farming involves dealing with potential pests and diseases in rice paddies and fish ponds. The experts also educate the farmers on identifying common pests and diseases, implementing prevention measures, and adopting integrated pest management strategies. Proper fish stocking and management are crucial for achieving successful integration. The farmers were assisted in selecting suitable fish species, determining stocking densities, and monitoring fish growth and health. Continuous or ongoing monitoring and evaluation of farmers' integrated rice-fish farming practices is always constant. This helps identify challenges, measure progress, and provide timely feedback for continuous improvement. Farmer-to-Farmer Exchange programs where successful adopters of integrated rice-fish farming converged in the exact location to share their experiences and lessons learned with others. Stakeholders from the state's Ministry of Agriculture, World Fish, and other related projects implemented by Feed the Future gave insightful feedback on the farmer's experience.

2.5. Market Penetration and Distribution Channels

The distribution channels of integrated rice-fish products involve the various stages and intermediaries through which the products reach end consumers. The distribution channels can vary depending on the location, production scale, market demand, and infrastructure. Effective distribution channels are essential for the success of integrated rice-fish products, as they ensure that the produce reaches consumers efficiently and sustainably. By leveraging a mix of distribution channels, farmers can increase market access, build strong customer relationships, and capitalize on the unique benefits of their integrated products. Thus, the following distribution channels are suggested:

Direct Sales to Local Markets: Many integrated rice-fish farmers sell their products directly to local markets or consumers. They may set up stalls at farmers' markets, and roadside stands or sell from their farm gate. This direct-to-consumer approach allows farmers to establish personal connections with their customers and communicate the unique value of their integrated produce.

Wholesale to Retailers and Restaurants: Farmers can sell their integrated rice-fish products in bulk to local retailers, such as grocery stores, supermarkets, and speciality food stores. Additionally, they may establish relationships with restaurants and hotels that value the quality and freshness of their products.

Cooperatives and Farmer Groups: Integrated rice-fish farmers may form cooperatives or farmer groups to pool their resources, collectively market their products, and negotiate better prices with buyers. These organized groups help streamline distribution and increase the market reach of the products.

On-line Platforms: E-commerce platforms and on-line marketplaces allow farmers to reach a wider audience beyond their local region. Integrated rice-fish products can be delivered through on-line sales to customers' doorsteps, catering to urban consumers and those seeking speciality products.

Food Processing and Packaging Companies: Some integrated rice-fish farmers may collaborate with food processing and packaging companies to value-add their products. These companies can process the fish and rice into value-added products like smoked fish, fish fillets, rice-based snacks, or ready-to-cook meals, which can then be distributed to broader markets.

Export Markets: Farmers may explore export opportunities in regions with a strong demand for integrated rice-fish products. Exporting allows them to tap into international markets and leverage the uniqueness and sustainability of their products.

Government Procurement Programs: Integrated rice-fish farming may be supported by government procurement programs that promote sustainable agriculture and provide nutritious food for public institutions, such as schools, hospitals, and military bases. Farmers can participate in tenders or contracts with these programs.

Community-Supported Agriculture (CSA): CSA initiatives involve consumers directly supporting farmers by pre-purchasing a share of the farm's harvest. This model provides farmers with a stable income and loyal customers who receive regular deliveries of integrated rice-fish products.

Non-Governmental Organizations (NGOs) and Development Projects: Integrated rice-fish products may be distributed through NGO partnerships or development projects focusing on sustainable agriculture and rural development. These organizations often help farmer's access markets and provide training and resources.

Value Chain Partnerships: Integrated rice-fish farmers can collaborate with other stakeholders in the value chain, such as fish feed suppliers, input providers, and logistics companies. These partnerships can optimize the supply chain and enhance market access.

2.6. Production and Delivery Suppliers

Delivery policies for the integrated rice-fish system are essential to ensuring that the products are transported and delivered efficiently, safely, and in a manner that preserves their quality. These policies may vary based on the specific business model, scale of production, and market reach. By having well-defined and comprehensive delivery policies, the integrated rice-fish system can ensure a smooth and reliable supply chain, meet customer expectations, and uphold the reputation of the products in the market.

Timely Delivery: The policy should specify the time-frame for delivery to customers, retailers, or other stakeholders. Timely delivery is crucial to ensuring the products reach consumers when they are fresh and in demand.

Transportation and Logistics: The policy should outline product delivery transportation and logistics arrangements. It should include information on the mode of transportation (e.g., refrigerated trucks, vans, tricycle or motorcycles), routes, and delivery schedules.

Packaging and Handling: Integrated rice-fish products are perishable, so the policy should include proper packaging and handling guidelines to maintain their quality during transportation. Adequate packaging materials, such as insulated containers or ice packs, should keep the products fresh.

Quality Control: The delivery policy should outline quality control measures to ensure that only high-quality products are delivered to customers. This may involve inspecting the products before shipment and maintaining temperature control during transit.

Traceability and Documentation: To maintain traceability and track the product's journey from farm to consumer, the policy should require proper documentation. This includes labelling, batch numbers, and other information allowing product identification and origin verification.

Delivery Charges: If applicable, the policy should clearly state any delivery fees or charges customers may incur. Transparent pricing is essential for building trust and avoiding misunderstandings.

Delivery Range: Define the geographic area or regions where the integrated rice-fish products will be delivered. This helps manage expectations and ensures the delivery infrastructure is well-suited for the designated areas.

Customer Communication: Establish clear communication channels for customers to inquire about deliveries, track their orders, or report any issues. Prompt and helpful customer service is vital for a positive customer experience.

Return and Refund Policies: Outline the process for handling product returns and refunds in case of damaged or spoiled products during delivery. A fair and efficient return policy builds customer confidence and loyalty.

Environmental Sustainability: Consider including environmentally sustainable delivery practices in the policy, such as optimizing delivery routes, minimizing packaging waste, and encouraging eco-friendly transportation options.

Compliance with Regulations: Ensure the delivery policies comply with relevant regulations and health standards for food safety, transportation, and handling.

Continuous Improvement: Establish a system for gathering feedback and monitoring the effectiveness of the delivery policies. Regularly review and update the guidelines based on customer feedback and changing market needs.

3.0. Marketing and Advertising Strategies

A strategic marketing and communication plan is essential to effectively communicate the integrated rice-fish product's benefits and raise customer awareness. Ultimately, consistent and targeted marketing efforts and a focus on educating consumers about the integrated rice-fish system's benefits will help create awareness and demand for the product, attracting customers who appreciate its unique qualities and sustainable attributes. The following key steps are essential to promoting the integrated rice-fish technology product and its advantages:

Branding and Packaging: Develop attractive and informative product branding and packaging. The packaging should highlight the integration of rice and fish and critical benefits such as sustainability, freshness, and nutritional value.

Digital Marketing: A digital marketing channel can reach a broad audience by creating a professional website with detailed information about the integrated rice-fish system, its benefits, and the story behind the product. Social media platforms can then engage with potential customers and share informative content, images, and videos.

Content Marketing: this can be achieved by creating engaging educational content highlighting the integrated rice-fish product's unique features and advantages. This could include blog posts, infographics, recipe ideas, and customer testimonials.

Product Demos and Tastings: Organization of product demonstrations and tastings at farmers' markets, food festivals, and community events like the Argungu fish festival in Kebbi State. In Ebonyi State, farmers can experience the taste and quality of the product first-hand through showcasing at any state cultural event.

Educational Workshops: Educational and entertainment workshops and seminars can be conducted for consumers, chefs, and food enthusiasts. Here, there could be a demonstration of the benefits of integrated rice-fish farming, its impact on sustainability, and the nutritional value of the products. A role-play or stage play, skits, or comedy can be invoked to support the workshops.

Collaborations and Partnerships: There can be a collaboration with local restaurants, food bloggers, and influencers to promote the product. Offers can be made for their samples to be reviewed and shared, reaching a broader audience. Use in-store marketing materials such as posters, brochures, and shelf talkers to educate customers about the product's benefits while they shop. Customers can be engaged to provide testimonials and reviews about the integrated rice-fish product. Positive feedback builds credibility and trust among potential buyers.

3.1. Potential Competitors and Threats

Understanding the strengths and weaknesses of potential competitors can help position the integrated rice-fish product effectively and differentiate it in the market. By highlighting the unique advantages and benefits of the product, it can appeal to the target audience and gain a competitive edge. Farmers or agricultural enterprises in the study areas who have adopted or are considering adopting the integrated rice-fish production system could be direct competitors. They may be offering similar products in the local market. Also, conventional rice farmers who do not practice integrated rice-fish farming but are known for their high-quality rice may indirectly compete with your product. Consumers looking for rice products may have the option to choose between traditional rice and your integrated rice-fish rice. Fish farmers specializing in raising fish in separate ponds or aquaculture systems may offer products that could compete with your integrated rice-fish fish in the market. Businesses focusing on producing and selling specialty seafood products, such as smoked or value-added fish, may offer choices for customers interested in fish products. Companies that promote sustainable agriculture practices and provide a range of sustainable food products, including integrated farming systems, may compete for environmentally conscious consumers seeking sustainable food options. Aquaponics farms that combine fish and vegetable production in a closed-loop design could also be considered indirect competitors, as they offer an alternative approach to integrated farming. Brands that emphasize organic and eco-friendly practices in their food production may also compete for customers seeking sustainable and environmentally conscious products.

3.2. Delivery policies

Delivery policies for the integrated rice-fish system are essential to ensuring that the products are transported and delivered efficiently, safely, and in a manner that preserves their quality. These policies may vary based on the specific business model, scale of production, and market reach. By having well-defined and comprehensive delivery policies, the integrated rice-fish system can ensure a smooth and reliable supply chain, meet customer expectations, and uphold the reputation of the products in the market.

Timely Delivery: The policy should specify the timeframe for delivery to customers, retailers, or other stakeholders. Timely delivery is crucial to ensuring the products reach consumers when they are fresh and in demand.

Transportation and Logistics: The policy should outline product delivery's transportation and logistics arrangements. It should include information on the mode of transportation (e.g., refrigerated trucks, vans, or motorcycles), routes, and delivery schedules.

Packaging and Handling: Integrated rice-fish products are perishable, so the policy should include proper packaging and handling guidelines to maintain their quality during transportation. Adequate packaging materials, such as insulated containers or ice packs, should keep the products fresh.

Quality Control: The delivery policy should outline quality control measures to ensure that only high-quality products are delivered to customers. This may involve inspecting the products before shipment and maintaining temperature control during transit.

Traceability and Documentation: To maintain traceability and track the product's journey from farm to consumer, the policy should require proper documentation. This includes labelling, batch numbers, and other information allowing product identification and origin verification.

Delivery Charges: If applicable, the policy should clearly state any delivery fees or charges customers may incur. Transparent pricing is essential for building trust and avoiding misunderstandings.

Delivery Range: Define the geographic area or regions where the integrated rice-fish products will be delivered. This helps manage expectations and ensures the delivery infrastructure is well-suited for the designated areas.

Customer Communication: Establish clear communication channels for customers to inquire about deliveries, track their orders, or report any issues. Prompt and helpful customer service is vital for a positive customer experience.

Return and Refund Policies: Outline the process for handling product returns and refunds in case of damaged or spoiled products during delivery. A fair and efficient return policy builds customer confidence and loyalty.

Environmental Sustainability: Consider including environmentally sustainable delivery practices in the policy, such as optimizing delivery routes, minimizing packaging waste, and encouraging eco-friendly transportation options.

Compliance with Regulations: Ensure the delivery policies comply with relevant regulations and health standards for food safety, transportation, and handling.

Continuous Improvement: Establish a system for gathering feedback and monitoring the effectiveness of the delivery policies. Regularly review and update the guidelines based on customer feedback and changing market needs.

3.3. Marketing and Selling Strategies

A strategic marketing and communication plan is essential to effectively communicate the integrated rice-fish product's benefits and raise customer awareness. Ultimately, consistent and targeted marketing efforts and a focus on educating consumers about the integrated rice-fish system's benefits will help create awareness and demand for the product, attracting customers who appreciate its unique qualities and sustainable attributes. The following key steps are essential to promoting the integrated rice-fish technology product and its advantages:

Branding and Packaging: Develop attractive and informative product branding and packaging. The packaging should highlight the integration of rice and fish and critical benefits such as sustainability, freshness, and nutritional value.

Digital Marketing: A digital marketing channel can reach a broad audience by creating a professional website with detailed information about the integrated rice-fish system, its benefits, and the story behind the product. Social media platforms can then engage with potential customers and share informative content, images, and videos.

Content Marketing: this can be achieved by creating engaging educational content highlighting the integrated rice-fish product's unique features and advantages. This could include blog posts, infographics, recipe ideas, and customer testimonials.

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Educational Workshops: Educational and entertainment workshops and seminars can be conducted for consumers, chefs, and food enthusiasts. Here, there could be a demonstration of the benefits of integrated rice-fish farming, its impact on sustainability, and the nutritional value of the products. A role-play or stage play, skits, or comedy can be invoked to support the workshops.

Collaborations and Partnerships: There can be a collaboration with local restaurants, food bloggers, and influencers to promote the product. Offers can be made for their samples to be reviewed and shared, reaching a broader audience. Use in-store marketing materials such as posters, brochures, and shelf talkers to educate customers about the product's benefits while they shop. Customers can be engaged to provide testimonials and reviews about the integrated rice-fish product. Positive feedback builds credibility and trust among potential buyers.

3.4. Strength, Weaknesses, Opportunity and Threats (SWOT Analysis)

Understanding the strengths and weaknesses of potential competitors can help position the integrated rice-fish product effectively and differentiate it in the market. By highlighting the unique advantages and benefits of the product, it can appeal to the target audience and gain a competitive edge. Farmers or agricultural enterprises in the study areas who have adopted or are considering adopting the integrated rice-fish production system could be direct competitors. They may be offering similar products in the local market. Also, conventional rice farmers who do not practice integrated rice-fish farming but are known for their high-quality rice may indirectly compete with your product. Consumers looking for rice products may have the option to choose between traditional rice and your integrated rice-fish rice. Fish farmers specializing in raising fish in separate ponds or aquaculture systems may offer products that could compete with your integrated rice-fish fish in the market. Businesses focusing on producing and selling speciality seafood products, such as smoked or value-added fish, may offer choices for customers interested in fish products. Companies that promote sustainable agriculture practices and provide a range of sustainable food products, including integrated farming systems, may compete for environmentally conscious consumers seeking sustainable food options. Aquaponics farms that combine fish and vegetable production in a closed-loop design could also be considered indirect competitors, as they offer an alternative approach to integrated farming. Brands that emphasize organic and eco-friendly practices in their food production may also compete for customers seeking sustainable and environmentally conscious products.

3.5. Transportation Management

Transportation and Logistics: The policy should outline product delivery transportation and logistics arrangements. It should include information on the mode of transportation (e.g., refrigerated trucks, vans, or motorcycles), routes, and delivery schedules.

Packaging and Handling: Integrated rice-fish products are perishable, so the policy should include proper packaging and handling guidelines to maintain their quality during transportation. Adequate packaging materials, such as insulated containers or ice packs, should keep the products fresh.

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Continuous Improvement: Establish a system for gathering feedback and monitoring the effectiveness of the delivery policies. Regularly review and update the guidelines based on customer feedback and changing market needs.

4.0. Financial Analysis: Integrated Rice-Fish Production System in Ebonyi State, Southeast Nigeria

Assumptions:

The results of the integrated rice-fish research conducted in a controlled atmosphere at the University of Ibadan (UI) and Usmanu Danfodiyo University, Sokoto (UDUS) depicted similar rice yields of 168.3 Kg and 145.5 Kg, respectively, equivalent to 146.43 Kg on the average of the two controlled sites. We assumed that the results may not be the same in the actual field conditions by reducing it by 32 percent. Therefore, our calculations of the integrated rice-fish production system in Southeast Nigeria, Ebonyi state in particular, is based on an expected rice yield of 100 kg on a 330 m² plot, i.e., the same size as in both universities. We also assumed five-case scenarios for yields and prices, i.e., “Best”, “Optimistic”, “Expected”, “Pessimistic”, and “Worst”. We assumed the “Best” and “Worst” case scenario to occur 7 percent of the time of once in a blue moon. While the “Expected” case scenario is assumed to occur 50 percent of the time (Table 1).

Table 1: Yields and Prices of integrated rice-fish production system in the Southeast Nigeria, 2023

	Best	Optimistic	Expected	Pessimistic	Worst
Rice Yield (Kg)	120	110	100	90	80
Rice Price (Naira)	840	770	700	630	560

As illustrated in Table 1, the expected rice yield in the Southeast Region of Nigeria (Ebonyi state) in particular, is expected to attain 100 Kg, and price per Kg of N700, 50 percent of the time. The

pessimistic and worst-case scenarios are 10 percent and 20 percent additional decrease in yields and prices. On the other hand, the optimistic and best yield and price are 10 percent and 20 percent increase in both parameters, a situation commonly seen with farmers who adhere to all good agricultural practices and scientific recommendations (Fonsah and Hudgins, 2007; Fonsah *et al.*, 2007; Fonsah *et al.*, 2008; Fonsah and Chidebelu, 2012).

We attempted to capture all the possible pre-variable cost (P-VC) of producing rice with fish in the same field. Pre-variable cost (P-VC) is defined as costs that vary or fluctuate when volume changes during the production of rice and fish. Classic examples of P-VC are cost of rice seeds, land preparation, lime application etc. These inputs can change depending on the size and dept of the pond or rice plots. The P-VC in Tables 2 does not include harvesting and marketing costs (H&MC). Also, some of the P-VC were divided by two because the implemented rice-fish plots serve two commodities, rice and fish, so we shared the costs between the two. For instance, the price for land-prep was supposed to be $330 \text{ m}^2 \times \text{₦}10 = \text{₦}3300/2 = \text{₦}1,650$ (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022).

Table 2: Calculations of Pre-Variable Cost of producing rice with fish on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023.

Descriptions	Unit	Quantity	Price	Amt/sqm	Yours
Rice seeds	Kg	20.00	1500.00	30000.00	
Fertilizer	Kg	0.00	5000.00	0.00	
Land prep (22 x 15 m)	Sq. m	330.00	10.00	1650.00	
Lime	Sq. m	15.00	200.00	1500.00	
Insecticide	Sq. m	0.00	2500.00	0.00	
Fungicide	Sq. m	0.00	2800.00	0.00	
Herbicide	Sq. m	0.00	3000.00	0.00	

Machinery (fuel, lub and maintenance)	Naira	1.00	6000.00	3000.00	
Fish feed	Naira	1.00	2500.00	1250.00	
Land rent 1/-	Sq. m	0.03	20000.00	330.00	
Fish-rice net	Naira	1.00	5000.00	2500.00	
Twine	Naira	8.00	200.00	800.00	
Transportation	Naira	100.00	100.00	5000.00	
Labor	Naira	0.00	0.00	0.00	
Irrigation (Water recycling)	Sq. m	0.03	50000.00	825.00	
Interest on Operating Capital	Naira	46855.00	0.18	4216.95	
Pre-Variable Cost	Sq. m	330.00		51071.95	

Furthermore, part of the farmer-to- farmer workshop and/or training in this project was record management. In order to facilitate the record management process and encourage farmers to keep records, we have purposively included the “Yours” column in most of our input tables so the farmer can easily input his/her own data/figures if it is different from ours (Table 2).

As the name implies, harvesting and marketing costs are the costs incurred during harvesting, threshing and processing of the rice grown with fish concomitantly (Table 3). Hand harvest labor cost was N5,000 while hauling and processing was N1,900. The total H&MC was N8,800. Note that this cost may also vary depending on the farmers and regions. The total variable cost (TVC) in this study was N59,872. TVC is the sum of P-VC plus H&MC (Table 3) (Fonsah and Hudgins, 2007; Fonsah *et al.*, 2007; Fonsah *et al.*, 2008; Fonsah and Chidebelu, 2012) (Table 3).

Table 3: Harvesting and Marketing cost of integrated rice-fish production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023.

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labor	Each	2.0	2500	5,000	
Hauling and Processing	Each	95	20	1,900	
Grading	Each	95	10	950	
Packaging	Kg	95	5	475	
Drying	Each	95	5	475	
Total Harvest and Marketing				8,800	
Total Variable Costs (TVC)				59,872	

Total fixed cost (TFC) is defined as cost implements that can be used for over a year (Table 4). These costs are being amortized based on the number of years a farmer can utilize them. A classic example is pond construction which can last and be used for several years. Other examples of fixed costs items are illustrated in Table 8. In this study, cost of machinery was N64. Overhead and management costs is 15 percent of the total P-VC (Table 4).

Table 4: Fixed Costs of integrated rice-fish production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023.

Description	Unit	Quantity	Price	Amt/m ²	Yours
Machinery	m ²	1.00	127.09	64	
Water Supply	m ²	1.00	42.73	21	
Overhead and Management	Naira	51,071.95	0.15	3,830	
Total Fixed Costs (TFC)	Naira			3,915	
Total budgeted cost per 330 m ² (TC)*	Naira			63,787	

*Note rounding errors.

And management is also a fixed cost item. Most of the time, the farmers fail to pay themselves because they assume the project is theirs. However, if they had hired labour, they would have paid for their services. Over and Management cost is 15 percent of total P-VC, which brings the total fixed cost (TFC) to N3,915. Finally, total cost (TC), was N63,787. There are two methods of calculating TC. The first method is to add P-VC + H&MC+ TFC while the second method is the sum of TVC + TFC (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022) (Table 4).

Break-even (BE) analysis is very important in analyzing financial project or enterprise budget. BE analysis tells the farmer or investor the minimum output whereby they are not losing money. BE point (BE-P) refers to when total cost (TC) and total revenue (TR) are equal. In other words, it means there is no loss or gain for the enterprise or business, i.e., it is when the farmer has reached the level of production at which the costs of production equal the revenues for a product. BE-P is calculated by dividing the total fixed costs (TFC) associated with production by the revenue (R) per individual unit minus the variable costs (VC) per unit (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022) (Table 5).

For instance, the BE P-VC is N510.72 which means that if a farmer's P-VC is below that level, he/she will not be profitable and vice versa. Same analysis applies to all the BE H&MC, BE FC, BE TC and BE Yields (Table 5).

Table 5: Break-Even (BE) Analysis of integrated rice-fish production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023.

Description	Total
BE Preharvest Variable Cost (P-VC) (Naira)	510.72
BE Harvest and Marketing Cost (H&MC) (Naira)	88.00
BE Fixed Costs (FC) (Naira)	39.15
BE Total Cost (TC) (Naira)	637.87
BE Rice Yield (Kg)	91.12

The risk-rated returns over cash flow were calculated 7 scenarios; thus, “Best” and “Worst” expected 7 percent of the time, “Optimistic” and “Pessimistic” expected 16 percent and 31 percent of the time and “Expected” also called “Median” expected 50 percent of the time. In order words, if ten farmers adopted the integrated rice-fish production system, we assume that at least 5 would achieve the “Expected” yield, price or profit margin. The “Expected” returns which are the same as the net returns or profit for rice was N6,213. “All things being equal” is an economic terminology which simply means that the farmer followed all the recommendations provided by experts and there was no natural calamity such as excessive rain, flooding, dry spell or some situation that disrupted production, he or she is capable of obtaining between N6,213 to N20,160 profit for rice alone on an integrated rice-fish production system. On the other hand, he/she can equally experience the worst-case scenario and lose as much as -N7,734 on rice production in a rice-fish production system (Table 6).

Table 6: Risk-Rated Returns over Cash Flow costs of integrated rice-fish production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023.

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (N)	20,160	15,511	10,862	6,213	1,564	-3,085	-7,734
Chances (%)	7%	16%	31%	50%			
Chances (%)				50%	31%	16%	7%
Chances for Profit		75%	Net Profit (Naira)				6,213

It is worth mentioning here that, this is one of the major advantages amongst other of adopting the integrated rice-fish production system in the Ebonyi State, Southeast Nigeria, because the farmer is spreading his/her production risks. If one, say rice fails, the farmer still has fish to make up for the loss whereas in the conventional system where only rice or fish is grown at a time, any failure translates to total loss. In our study, the farmer has 75 percent chances of obtaining profit on the rice production not counting the fish production (Table 6).

The sensitivity risk-rated analysis shows five yields scenario, starting from 80 to 120 kg. The goal is for the farmer to strive for higher yields as the “best” case-scenario can fetch from N5,278 to as much

as N35,116. On the other hand, the worst-case scenario can fetch from -N7027 to as much as N19,453. The chances of obtaining profit vary from as low as 20 percent to as much as 97 percent. These scenarios also explain why the farmer-2-farmer and the trainer-2-trainer and extension services are a necessary and sufficient conditions for success and sustainability, especially that this technology is new in Nigeria (Table7).

Table 7: Sensitivity Risk-Rated Returns over Cash Flow Cost of integrated rice-fish production system on 330 m² plot in Ebonyi State, Southeast Region, Nigeria, 2023.

Yield (Kg) /Price	Best	Optimistic		Expected (100 Kg)	Pessimistic		Worst	Net Returns	Chances of Profit (%)
80.00	5278	1176	-2925	-7027	-11129	-	15231	19333	20
90.00	12710	8337	3965	-407	-4780	-9152	-	13524	48
100.00	20160	15511	10862	6213	1564	-3085	-7734	6213	75
110.00	27629	22697	17765	12833	7901	2969	-1964	12833	90
120.00	35116	29895	24674	19453	14232	9010	3789	19453	97

The fixed cost calculation includes cost of the equipment or implement, the salvage value, the life-span, depreciation, interest rate, taxes and insurance. Some of these parameters may not exist in the Ebonyi state or the entire region but for sound economic analysis, we have to include them. The fixed costs (FC) items included but not limited to such things as pond construction, machetes, spades, digger axle, shovel etc. (Table 8).

Table 8: Annual Fixed Cost Calculations of integrated rice-fish production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023.

Item	% of time for This crop	Cost	Salvage Value	Life	Depr.	Yrs. of Int.	Tax&Ins	FC/Ac.
Pond construction	33%	200000	40000	15	3520	7128	554	34
Machetes	33%	4000	800	2	528	143	11	2
Spade	33%	3000	600	3	264	107	8	1
DiggerAxe	33%	5000	1000	5	264	178	14	1
Shovel	33%	3000	600	3	264	107	8	1
Hoe	33%	3000	600	4	198	107	8	1
Weighning Scale	33%	15000	3000	5	792	535	42	4
Plastic Baskets	50%	2500	500	3	333	135	11	1
Drag net	100%	35000	7000	8	3500	3780	294	23
Sprayer (napsack)	0%	0	0	0	0	0	0	0
Plastic bins (2) (harve	50%	2500	500	2	500	135	11	2
Miscellaneous	100%	0	0	1	0	0	0	0
Installation	100%	0	0	15	0	0	0	0
Total		273000	54600		10163	12354	961	71
Interest on Investment (Ave. Inv. X Int. Rate)					29484.00			
Taxes and Insurance (Ave. Inv. X .014)					2293.20			
Total Annual Fixed Costs					41940.53			
Total Annual Fixed Costs Per Acre					127.09			

Also, the life-span may vary farmer to farmer, state to state or region to region. It could also vary based on the use. For instance, a farmer in the Southeast Region may use a machete for multiple purposes such as, rice and fish farming, cassava, yam and palm farming, whereas a farmer in the North-western states might only use the machetes for rice-fish farming. The total fixed cost was N127 (Table 8).

4.1. Financial Analysis: Integrated fish in a fish-rice Production System in Ebonyi State, Southeast Nigeria

Assumptions

The results of the integrated fish-rice research conducted in a controlled atmosphere at the University of Ibadan (UI) and Usmanu Danfodiyo University, Sokoto (UDUS) depicted similar rice yields or 168.3 Kg and 145.5 Kg respectively, equivalent to 146.43 Kg on the average of the two controlled sites. We assumed that the results may not be the same in the actual field conditions by reducing it by 50 percent. Therefore, our calculations of the integrated fish-rice production system in the Southeast Nigeria, Ebonyi state in particular, is based an expected fish yield of 178 kg on a 330 m² plot, i.e., same size as in both universities. We also assume five-case scenario for yields and prices, i.e., “Best”,

“Optimistic”, “Expected”, “Pessimistic”, and “Worst”. We assume the “Best” and “Worst” case scenario to occur 7 percent of the time of once in a blue moon. While the “Expected” case scenario is assumed to occur 50 percent of the time (Table 9).

Table 9: Yields and Prices of integrated fish-rice production system on 330 m² size farm in the Ebonyi State, Southeast Nigeria, 2023

Descriptions	Best	Optimistic	Expected	Pessimistic	Worst
Fish Yield (Kg)	214	196	178	160	142
Fish Price (Naira)	2,400	2,200	2,000	1,800	1,600

As illustrated in Table 9, the expected fish yield in the Southeast Region of Nigeria, or Ebonyi state in particular, is 178 Kg, and price per Kg of N2,000, 50 percent of the time. The pessimistic and worst-case scenarios are 10 percent and 20 percent additional decrease in yields and prices. On the other hand, the optimistic and best yield and price are 10 percent and 20 percent increase in both parameters, a situation commonly seen with farmers who adhere to all good agricultural practices and scientific recommendations (Fonsah *et al.*, 2007; Fonsah and Chidebelu, 2012).

This study attempted to capture all the possible pre-variable cost (P-VC) of producing fish with rice in the same field. Variable cost (VC) is defined as costs that vary or fluctuate when volume changes during the production of rice and fish. Classic examples of P-VC are cost of fingerlings, land preparation, lime application etc. These inputs can change depending on the size and dept of the pond or rice plots. The P-VC in Tables10 does not include harvesting and marketing costs (H&MC) (Table 10). Also, some of the P-VC were divided by two because the plot served two commodities, rice and fish, so we shared the costs between the two. For instance, the price for land-prep is supposed to be $330 \text{ m}^2 \times \text{N}10 = \text{N}3300/2 = \text{N}1,650$.

Furthermore, one of the topics covered during the farmer-2-farmer workshop and/or training and trainer-2-trainer workshops conducted in this project was record management. In order to facilitate and

re-emphasize the importance of the record management process and encourage farmers to keep records, we have purposively included “Yours” column in most of our input tables so the farmer can easily input his/her own data/figures if it is different from ours.

The most expensive cost component in the Pre-variable cost (P-VC) for fish in the fish-rice production system was fingerlings. We assumed 5 fingerlings per square meter. It is also worth mentioning here that the project provided free fingerlings to farmers who participated in this study in both the Southeastern and North-western regions respectively (Table 10).

Table 10: Calculations of Pre-Variable Cost of producing fish with rice on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023

Description	Unit	Quantity	Price	Amt/m ²	Yours
Fish seeds (fingerlings)	Each	1,650.00	40.00	66,000.00	
Fertilizer	Kg	0.00	0.00	0.00	
Land prep (22 x 15 m)	m ²	330.00	10.00	1,650.00	
Lime	m ²	15.00	200.00	1,500.00	
Insecticide	m ²	0.00	2,500.00	0.00	
Fungicide	m ²	0.00	2,800.00	0.00	
Herbicide	m ²	0.00	3,000.00	0.00	
Machinery (fuel, lub and maintenance)	Naira	1.00	6,000.00	3,000.00	
Fish feed	Naira	1.00	2,500.00	1,250.00	
Land rent 1/-	Sq.m	0.03	20,000.00	330.00	
Fish-rice net	Naira	1.00	5,000.00	2,500.00	
Bowl Plastic	Naira	2.00	1,500.00	1,500.00	
Twine	Naira	8.00	200.00	800.00	
Transportation	Naira	100.00	100.00	5,000.00	
Labor	Naira	1.00	12,000.00	6,000.00	
Irrigation (Water recycling)	Sq.m	0.08	9.34	0.37	
Interest on Operating Capital	Naira	88,030.37	0.18	7,922.73	
Pre-Variable Cost (P-VC)	Naira	330.00		97,453.11	

It is also worth noting that no fertilizer, insecticide, fungicide or herbicide was used. Other expensive cost components were machinery, fish-rice nets to prevent predatory insects including birds, transportation and labour. The total P-VC was N97, 453.11 (Table 10).

The total harvesting and marketing costs (H&MC) was N9,228, while the total variable costs (TVC) was N106,681 (Table 11).

Table 11: Harvesting and Marketing cost of an integrated fish-rice production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labour	Each	2.00	2,500	5,000	
Grading	Each	169	10	1,691	
Packaging	Kg	169	5	846	
Plastic bags	Each	169	5	846	
Drying (smoking)	Kg	169	5	846	
Total Harvest and Marketing (H&MC)	Naira			9,228	
Total Variable Costs (TVC)	Naira			106,681	

Total fixed costs (TFC) included machinery, water supply overhead and management at N38,676. Total fixed cost (TC), which is the sum of TVC plus TC was N145,356 (Table 12).

Table 12: Fixed Costs of integrated fish-rice production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023

Annual Fixed Cost	Unit	Quantity	Price	Total	Yours
Machinery	m ²	1.00	59752.27	29,876	
Water Supply	m ²	1.00	57.67	29.00	
Overhead and Management	Naira	97,453.11	0.18	8,771	
Total Fixed Costs (TFC)	Naira			38,676	
Total budgeted cost per acre (TC)	Naira			145,356	

Break-even (BE) analysis is very important in analyzing financial project or enterprise budget. BE analysis tells the farmer or investor the minimum output whereby they are not losing money. BE point (BE-P) refers to when total cost (TC) and total revenue (TR) are equal. In other words, it means there is no loss or gain for the enterprise or business, i.e., it is when the farmer has reached the level of production at which the costs of production equals the revenues for a product. BE-P is calculated by dividing the total fixed costs (TFC) associated with production by the revenue (R) per individual unit minus the variable costs (VC) per unit (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022). For instance, the BE P-VC is N547, the BE FC is N217 and the BE TC is N817 respectively. The BE fish yield is 73Kg (Table 13).

Table 13: Break-Even (BE) Analysis of integrated fish-rice production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023

Description	Total
BE Pre-harvest Variable Cost (P-VC) (Naira)	547
BE Harvest and Marketing Cost (H&MC) (Naira)	51
BE Fixed Costs (FC) (Naira)	217
BE Total Cost (TC) (Naira)	817
BE Fish Yield (Kg)	73

The risk-rated returns over cash flow were calculated 7 scenarios thus, “Best” and “Worst” expected 7 percent of the time, “Optimistic” and “Pessimistic” expected 16 percent and 31 percent of the time and “Expected” also called “Median” expected 50 percent of the time. In order words, if ten farmers adopted the integrated rice-fish production system, we assume that at least five of them would achieve the “Expected” yield, price or profit margin. The “Expected” returns which happen to be the same as the net returns or profit for rice, was N210, 644. “All things being equal” is an economic terminology which simply means that the farmer followed all the recommendations provided by experts and there were no natural calamities such as excessive rain, flooding, dry spell or some situation that disrupted production, he or she is capable of obtaining between N210,644 to N285,190 profit for fish alone on

an integrated rice-fish production system. On the other hand, he/she can equally experience the worst-case scenario of N210,644 to N136,097 on fish production in a fish-rice production system (Table 14).

Table 14: Risk-Rated Returns over Cash Flow costs of integrated fish-rice production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (N)	285,190	260,341	235,493	210,644	185,795	160,946	136,097
Chances (%)	7%	16%	31%	50%			
Chances (%)				50%	31%	16%	7%
Chances for Profit		99%	Net Profit (Naira)				210,644

It is worth mentioning here that, this is one of the major advantages amongst other of adopting the integrated fish-rice production system in the Ebonyi State, Southeastern Nigeria, because the farmer is spreading his/her production risks. If one, say fish fails, the farmer still has rice to make up for the loss whereas in the conventional system where only rice or fish is grown at a given time, any failure translates to total loss. In our study, the farmer has 99 percent chances of obtaining profit on the fish production not counting the rice production (Table 14).

The sensitivity risk-rated analysis shows five yields scenario, starting from 142 to 214 kg. The goal is for the farmer to strive for fish higher yields as the “best” case-scenario can fetch from N204,090 to as much as N370,559. On the other hand, the worst-case scenario can fetch from -N143,807 to as much as N280,998. The chances of obtaining profit was alarmingly strong at 99 percent. These scenarios also explain why the farmer-2-farmer and the trainer-2-trainer and extension services are a necessary and sufficient conditions for success and sustainability, especially that this technology is new in Nigeria (Table15).

Table 15: Sensitivity Risk-Rated Returns over Cash Flow Cost of integrated fish-rice production system on 330 m² plot in Ebonyi State, Southeast Region, Nigeria, 2023

Yields (kg)	Best	Optimistic		Expected (178 Kg)	Pessimistic		Worst	Net Returns	Chances of Profit (%)
142.00	204090	183996	163901	143,807	123712	103618	83523	143,807	99
160.00	242506	220160	197813	175,466	153120	130773	108427	175,466	99
178.00	285190	260341	235493	210,644	185795	160946	136097	210,644	99
196.00	327875	300523	273172	245,821	218470	191118	163767	245,821	99
214.00	370559	340705	310852	280,998	251145	221291	191437	280,998	99

The fixed cost calculation includes cost of the equipment or implement, the salvage value, the life-span, depreciation, interest rate, taxes and insurance. Some of these parameters may not exist in the Ebonyi state or the entire region but for sound economic analysis, we have to include them. The fixed costs (FC) items included but not limited to such things as pond construction, machetes, spades, digger axle, shovel etc., (Table 16).

Table 16: Annual Fixed Cost Calculations of integrated fish-rice production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023

Descriptions	% of time for This crop	Cost	Salvage Value	Yrs. of Life	Depr.	Int.	Tax&Ins	FC/Sq.m.
Pond construction	33%	320000	64000	15	5632	11405	887	17924
Machetes	33%	4000	800	2	528	143	11	682
Spade	33%	3000	600	3	264	107	8	379
DiggerAxe	33%	5000	1000	5	264	178	14	456
Shovel	33%	3000	600	3	264	107	8	379
Hoe	33%	3000	600	4	198	107	8	313
Weighning Scale	33%	15000	3000	5	792	535	42	1368
Plastic Baskets	50%	5000	1000	3	667	270	21	958
Drag net	100%	35000	7000	8	3500	3780	294	7574
Sprayer (napsack)	0%	0	0	0	0	0	0	0
Plastic bins (2) (harve	50%	6000	1200	2	1200	324	25	1549
Miscellaneous	100%	0	0	1	0	0	0	0
Installation	100%	0	0	15	0	0	0	0
Total		399000	79800		13309	16955	1319	31582
Interest on Investment (Ave. Inv. X Int. Rate)					43092.00			
Taxes and Insurance (Ave. Inv. X .014)					3351.60			
Total Annual Fixed Costs					<u>59752.27</u>			
Total Annual Fixed Costs Per Cycle					<u>29876.13</u>			

This study shows the net profit for producing rice in an integrated rice-fish farming system in Ebonyi State, Southeast Nigeria is N6,213 while the net profit of producing fish in an integrated fish-rice farming system in the region is N210,644 on 330 m². The combined total net profit is N216,857. This is expected under normal circumstances, i.e., “all things being equal”. Rice profit margin ranges from the best of N20,160 to the worst of -N7,734 whereas fish profit margins range from the best of N285,190 to the worst of N136,097 respectively. Overall, implementing an integrated fish-rice production system in Ebonyi State or the Southeast, Nigeria is a profitable venture with a net profit of N216,857, with 87 percent chance of obtaining profits, “all things being equal” (Table 17).

Table 17: Summary: Profitability of integrated fish-rice production system on 330 m² plot in Ebonyi State, Southeast Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Fish Profit (N)	285,190	260,341	235,493	210,644	185,795	160,946	136,097
Rice Profits	20,160	15,511	10,862	6,213	1,564	-3,085	-7,734
Net Profits Levels	305,350	275,852	246,355	216,857	187,359	157,861	128,363
Chances for Profit		99%	Net Profit (Naira)				216,857

4.2. Financial Analysis: Integrated fish in a fish-rice Production System in Kebbi State, Northwest Nigeria

Assumptions

The results of the integrated fish, in a fish-rice research conducted in a controlled atmosphere at the University of Ibadan (UI) and Usmanu Danfodiyo University, Sokoto (UDUS) depicted similar rice yields or 168.3 Kg and 145.5 Kg respectively, equivalent to 146.43 Kg on the average of the two controlled sites. We assumed that the results may not be the same in the actual farmer's field conditions in the Northwest, Nigeria, thereby reducing the yield by 50 percent. Therefore, our calculations of the integrated fish in the fish-rice production system in Kebbi State, the Northwest, Nigeria, is based on an expected fish yield of 1,068 kg on a 2,000 m² size farm. We also assume five-case scenario for yields and prices, i.e., “Best”, “Optimistic”, “Expected”, “Pessimistic”, and “Worst”. We assumed the “Best” and “Worst” case scenario to occur 7 percent of the time of “once in a blue moon”. While the “Expected” case scenario is assumed to occur 50 percent of the time (Table 18).

Table 18: Yields and Prices of integrated fish in a fish-rice production system on 2,000 m² plot in the Kebbi State, Northwest Nigeria, 2023

Descriptions	Best	Optimistic	Expected	Pessimistic	Worst
Fish Yield (Kg)	1,282	1,175	1,068	961	854
Rice Price (Naira)	2,400	2,200	2,000	1,800	1,600

As illustrated in Table 18, the expected fish yield in Kebbi State, Northwest, Nigeria, was 1,068 Kg, and price per Kg of N2, 000, 50 percent of the time. The pessimistic and worst-case scenarios are 10 percent and 20 percent additional decrease in yields and prices. On the other hand, the optimistic and best yield and price are 10 percent and 20 percent increase in both parameters, a situation commonly seen with farmers who adhere to all good agricultural practices and scientific recommendations (Fonsah *et al.*, 2007; Fonsah and Chidebelu, 2012).

We attempted to capture all the possible pre-variable cost (P-VC) of producing fish with rice in the same field. Variable cost is defined as costs that vary or fluctuate when volume changes during the production of fish in a fish-rice system. Classic examples of P-VC are cost of fingerlings, land preparation, lime application etc. These inputs can change depending on the size and depth of the pond or rice plots. The P-VC in Tables 19 does not include harvesting and marketing costs (H&MC). Also, some of the P-VC were divided by two because the plot served two commodities, rice and fish, so we shared the costs between the two. For instance, the price for land-prep is supposed to be $2,000 \text{ m}^2 \times \text{₦}10 = \text{₦}20,000/2 = \text{₦}10,000$ (Table 19). Furthermore, part of the farmer-to-farmer workshop and/or training in this project was record management. In order to facilitate the record management process and encourage farmers to keep records, we have purposively included “Yours” column in most of the input tables so the farmers can easily input their own data/figures if it is different from ours (Table 19).

Table 19: Calculations of Pre-Variable Cost of producing fish with rice on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Descriptions	Unit	Quantity	Price	Total	Yours
Rice seeds	Kg	0.00	0.00	0.00	
Fish seeds (fingerlings)	Each	10000.00	40.00	400,000	
Fertilizer	Kg	0.00	0.00	0.00	
Land prep (50 x 40 m)	m ²	2000.00	10.00	10,000	
Lime	m ²	90.00	200.00	9,000	
Insecticide	m ²	0.00	2,500.00	0.00	
Fungicide	m ²	0.00	2,800.00	0.00	
Herbicide	m ²	0.00	3,000.00	0.00	
Machinery (fuel, lub and maintenance)	Naira	6.00	6,000.00	18,000	
Fish feed	Naira	6.00	2,500.00	7,500	
Land rent	m ²	0.20	20,000.00	2,000	
Fish-rice net	Naira	6.00	5,000.00	15,000	
Bowl Plastic	Naira	12.00	1,500.00	9,000	
Twine	Naira	48.00	200.00	4,800	
Transportation	Naira	100.00	100.00	5,000	
Labor	Naira	6.00	12,000.00	36,000	
Irrigation (Water recycling)	m ²	4.80	2.39	6.00	
Interest on Operation Capital	Naira	50,7305.73	0.18	45,658	
Pre-Variable Cost	Naira	2,000.00		561,963	

It is also worth mentioning here that no fertilizer, insecticide, fungicide or herbicide was used. Other expensive cost components were machinery, fish-rice net to prevent predatory insects including birds, transportation and labor. The total P-VC was N561,963 (Table 19). On the other hand, the total harvesting and marketing costs (H&MC) was N55,365 while the total variable costs (TVC) was N617,328.24 (Table 20).

Table 20: Harvesting and Marketing cost of integrated fish-rice production system on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labor	Each	12.00	2500	30,000	
Hauling and Processing	Each	1014.6	0	0	
Grading	Each	1014.6	10	10,146	
Packaging	Kg	1014.6	5	5,073	
Plastic bags	Each	1014.6	5	5,073	
Drying (smoking)	Kg	1014.6	5	5,073	
Fish Middle-men and Commission	Kg	1014.6	0	0	
Total Harvest and Marketing (H&MC)	Naira			N55,365	
Total Variable Costs (TVC)	Naira			N617,328.24	

Total fixed costs (TFC) included machinery, water supply overhead and management was N50,577.

Total fixed cost (TC), which is the sum of TVC plus TC was N117,563.06 (Table 21).

Table 21: Fixed cost of integrated fish-rice production system on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Annual Fixed Cost	Unit	Quantity	Price	Total	Yours
Machinery	m ²	1.00	133961.60	66,981	
Water Supply	m ²	1.00	5.55	6.00	
Overhead and Management	Naira	561,963.24	0.18	50,577	
Total Fixed Costs (TFC)	Naira			117,563.06	
Total budgeted cost per acre (TC)				734,891.29	

Break-even (BE) analysis is very important in analysing financial project or enterprise budget. BE analysis tells the farmer or investor the minimum output whereby they are not losing money. BE point (BE-P) refers to when total cost (TC) and total revenue (TR) are equal. In other words, it means there is no loss or gain for the enterprise or business, i.e., it is when the farmer has reached the level of production at which the costs of production equals the revenues for a product. BE-P is calculated

by dividing the total fixed costs (TFC) associated with production by the revenue (R) per individual unit minus the variable costs (VC) per unit (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022). For instance, the BE P-VC was N526.18, the BE FC was N110.08 and the BE TC is N688.10 respectively. The BE fish yield is 368 Kg (Table 22).

Table 22: Break-Even Analysis of integrated fish-rice production system on 2,000 m² plot in Kebbi State, Northwest Region, Nigeria, 2023

Description	Total
BE Preharvest Variable Cost (P-VC) (Naira)	526.18
BE Harvest and Marketing Cost (H&MC) (Naira)	51.82
BE Fixed Costs (FC) (Naira)	110.08
BE Total Cost (TC) (Naira)	688.10
BE Fish Yield (Kg)	368

The risk-rated returns over cash flow was calculated 7 scenarios thus, “Best” and “Worst” expected 7 percent of the time, “Optimistic” and “Pessimistic” expected 16 percent and 31 percent of the time and “Expected” also called “Median” expected 50 percent of the time. In order words, if ten farmers adopted the integrated rice-fish production system, we assume that at least five of them would achieve the “Expected” yield, price or profit margin. The “Expected” returns and the net profit for fish was N1,401,109. “All things being equal” is an economic terminology which simply means that the farmer followed all the recommendations provided by experts and there were no natural calamities such as excessive rain, flooding, dry spell or some situation that disrupted production, he or she is capable of obtaining between N1,848,389 to N1,401,109 profit for fish alone on an integrated fish in a rice-fish production system. On the other hand, he/she can equally experience the worst-case scenario of N1,252,015 to N953,828 on fish production in a fish, fish-rice production system (Table 23).

Table 23: Risk-Rated Returns over Cash flow costs of integrated fish-rice production system on 2,000 m² plot in Kebbi State, Northwest region, Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (N)	1,848,389	1,699,296	1,550,202	1,401,109	1,252,015	1,102,922	953,828
Chances (%)	7%	16%	31%	50%			
Chances (%)				50%	31%	16%	7%
Chances for Profit		99%	Net Profit (Naira)				1,401,109

It is worth mentioning here that, this is one of the major advantages amongst other of adopting the integrated fish-rice production system in the Kebbi State, Northwest, Nigeria, because the farmer or community are spreading their production risks. If one, say rice fails, the farmer or community still has rice to make-up for the loss whereas in the conventional system where only rice or fish is cultivated at a given time, any failure translates to total loss. In our study, the farmer has 99 percent chances of obtaining profit on the fish production not counting the rice production (Table 23).

The sensitivity risk-rated analysis shows five yields scenario, starting from 854 to 1,282 kg. The goal is for the farmer or community to strive for fish higher yields as the “best” case-scenario can fetch from N2,360,600 to N2,002,357. On the other hand, the pessimistic and worst-case scenario can fetch from N859,916 to as low as N621,785. The chances of obtaining profit were an alarming strong at 99 percent. These scenarios also explain why the farmer-2-farmer and the trainer-2-trainer and extension services are a necessary and sufficient conditions for success and sustainability, especially that this technology is new in Nigeria (Table 24).

Table 24: Yield and Price Sensitivity Risk-Rated Returns Over Cash Flow Cost of integrated fish-rice production system on 2,000 m² plot in Kebbi State, Northwest Region, Nigeria, 2023

Yield (kg)	Best	Optimistic		Expected (1,068 Kg)	Pessimistic		Worst	Net Returns	Chances Of Profit (%)
854	1336178	1217113	1098047	978,982	859916	740851	621785	978,982	99
961	1592284	1458204	1324125	1,190,045	1055966	921886	787807	1,190,045	99
1068	1848389	1699296	1550202	1,401,109	1252015	1102922	953828	1,401,109	99
1174	2104495	1940387	1776280	1,612,172	1448065	1283957	1119850	1,612.172	99
1282	2360600	2181479	2002357	1,823,236	1644114	1464993	1285871	1,823,236	99

The fixed cost calculation includes cost of the equipment or implement, the salvage value, the life-span, depreciation, interest rate, taxes and insurance. Some of these parameters may not exist in the Kebbi State or the entire region but for sound economic analysis, we have to include them. The fixed costs (FC) items included but not limited to such things as pond construction, machetes, spades, digger axle, shovel etc., (Table 25).

Table 25: Annual Fixed Cost Calculation of integrated rice-fish production system on 2,000 m² plot in Kebbi State, Northwest Region, Nigeria, 2023

Descriptions	% of time for This crop	Cost	Salvage Value	Yrs. of Life	Depr.	Int.	Tax&Ins	FC/m2.
Pond construction	33%	320000	64000	15	5632	11405	887	17924
Machetes	33%	24000	4800	2	3168	855	67	4090
Spade	33%	18000	3600	3	1584	642	50	2275
DiggerAxe	33%	30000	6000	5	1584	1069	83	2736
Shovel	33%	18000	3600	3	1584	642	50	2275
Hoe	33%	18000	3600	4	1188	642	50	1879
Weighning Scale	33%	30000	6000	5	1584	1069	83	2736
Plastic Baskets	50%	30000	6000	3	4000	1620	126	5746
Drag net	100%	210000	42000	8	21000	22680	1764	45444
Sprayer (napsack)	0%	0	0	0	0	0	0	0
Plastic bins (2) (harve	50%	36000	7200	2	7200	1944	151	9295
Miscellaneous	100%	0	0	1	0	0	0	0
Installation	100%	0	0	15	0	0	0	0
Total		734000	146800		48524	42567	3311	94402
Interest on Investment (Ave. Inv. X Int. Rate)					79272.00			
Taxes and Insurance (Ave. Inv. X .014)					6165.60			
Total Annual Fixed Costs					#####			
Total Annual Fixed Costs Per Cycle					<u>66980.80</u>			

Note: The total Annual fixed costs and total annual fixed costs per cycle are the same.

4.3 Financial Analysis: Integrated Rice-Fish Production System in Kebbi State, Northwest Nigeria

Assumptions:

The results of the integrated rice-fish research conducted in a controlled atmosphere at the University of Ibadan (UI) and Usmanu Danfodiyo University, Sokoto (UDUS) depicted similar rice yields or 168.3 Kg and 145.5 Kg respectively, equivalent to 146.43 Kg on the average of the two controlled sites. We assumed that the results may not be the same in the actual field conditions by reducing it by 32 percent. Therefore, our calculations of the integrated rice-fish production system in Kebbi State, Northwest Nigeria is based an expected rice yield of 867 kg on a 2,000 m² plot. We also assume five-case scenario for yields and prices, i.e., “Best”, “Optimistic”, “Expected”, “Pessimistic”, and “Worst”.

We assume the “Best” and “Worst” case scenario to occur 7 percent of the time of once in a blue moon. While the “Expected” case scenario is assumed to occur 50 percent of the time (Table 26).

Table 26: Yields and Prices of integrated rice-fish production system on 2,000 m² plot in the Kebbi State, Northwest Nigeria, 2023

Description	Best	Optimistic	Expected	Pessimistic	Worst
Rice Yield (Kg)	1,040	954	867	780	694
Rice Price (Naira)	840	770	700	630	560

As illustrated in Table 26, the expected rice yield in the Northwest Region of Nigeria (Kebbi state) in particular, is expected to attain 867 Kg, and price per Kg of N700, 50 percent of the time. The pessimistic and worst-case scenarios are 10 percent and 20 percent additional decrease in yields and prices. On the other hand, the optimistic and best yield and price are 10 percent and 20 percent increase in both parameters, a situation commonly see with farmers or communities who adhere to all good agricultural practices and scientific recommendations (Fonsah and Hudgins, 2007; Fonsah *et al.*, 2007; Fonsah *et al.*, 2008; Fonsah and Chidebelu, 2012).

We attempted to capture all the possible pre-variable cost (P-VC) of producing rice with fish in the same field, i.e., 2,000 m². Variable cost is defined as costs that vary or fluctuate when volume changes during the production of rice and fish. Classic examples of P-VC are cost of rice seeds, land preparation, lime application etc. These inputs can change depending on the size and dept of the pond or rice plots. The P-VC in Tables 27 does not include harvesting and marketing costs (H&MC) (Table 28). Also, some of the P-VC were divided by two because the plot served two commodities, rice and fish, so we shared the costs between the two. For instance, the price for land-prep was supposed to be 2,000 m² x ₦10 = ₦20,000/2 = ₦10,000 (Table 27) (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022).

Furthermore, part of the farmer-to- farmer workshop and/or training in this project was record management. In order to facilitate the record management process and encourage farmers to keep

records, we have purposively included “Yours” column in most of our input tables so the farmer can easily input his/her own data/figures if it is different from ours.

Table 27: Calculations of Pre-Variable Cost of producing fish with rice on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Rice seeds	Kg	120.00	1500.00	180,000	
Fish seeds (fingerlings)	Each	0.00	40.00	0	
Fertilizer	Kg	0.00	0.00	0	
Land prep (50 x 40 m)	m ²	2000.00	10.00	10,000	
Lime	m ²	90.00	200.00	9,000	
Insecticide	m ²	0.00	2500.00	0	
Fungicide	m ²	0.00	2800.00	0	
Herbicide	m ²	0.00	3000.00	0	
Machinery (fuel, lub. and maintenance)	Naira	6.00	6000.00	18,000	
Fish feed	Naira	6.00	2500.00	7,500	
Land rent 1/-	m ²	0.20	20000.00	2,000	
Fish-rice net	Naira	6.00	5000.00	15,000	
Bowl Plastic	Naira	12.00	1500.00	9,000	
Twine	Naira	48.00	200.00	4,800	
Transportation	Naira	100.00	100.00	5,000	
Labor	Naira	6.00	12000.00	36,000	
Irrigation (Water recycling)	m ²	4.80	2.39	6	
Interest on Operation Capital	Naira	287305.73	0.18	25,858	
Pre-Variable Cost (P-VC)	Naira	2000.00		322,163	

It is also worth noting that no fertilizer, insecticide, fungicide or herbicide was used. Other expensive cost components were machinery, fish-rice net to prevent predatory insects including birds, transportation and labor. The total P-VC was N322,163 (Table 27). The total harvesting and marketing costs (H&MC) was N50,591 while the total variable costs (TVC) was N372,754 (Table 28).

Table 28: Harvesting and Marketing cost of integrated rice-fish production system on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labor	Each	12	2500	30,000	
Grading	Kg	823.65	10	8,237	
Packaging	Kg	823.65	5	4,118	
Plastic bags	Each	823.65	5	4,118	
Drying (smoking)	Kg	823.65	5	4,118	
Fish Middlemen Commission	Kg	823.65	0	0	
Total Harvest and Marketing (H&MC)	Naira			50,591	
Total Variable Costs (TVC)	Naira			372754	

Total fixed costs (TFC) included machinery, water supply overhead and management was N95,981.

Total fixed cost (TC), which is the sum of TVC plus TC was N468,735 (Table 29).

Table 29: Fixed cost of integrated rice-fish production system on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Annual Fixed Cost	Unit	Quantity	Price	Total	Yours
Machinery	m ²	1.00	133961.60	66,981	
Water Supply	m ²	1.00	5.55	6.00	
Overhead and Management	Naira	322163.24	0.18	28,995	
Total Fixed Costs (TFC)	Naira			95,981	
Total budgeted cost per acre (TC)				468,735	

Break-even (BE) analysis is very important in analyzing financial project or enterprise budget. BE analysis tells the farmer or investor the minimum output whereby they are not losing money. BE point (BE-P) refers to when total cost (TC) and total revenue (TR) are equal. In other words, it means there is no loss or gain for the enterprise or business, i.e., it is when the farmer has reached the level of production at which the costs of production equals the revenues for a product. BE-P is calculated by dividing the total fixed costs (TFC) associated with production by the revenue (R) per individual unit minus the variable costs (VC) per unit (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*,

2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022). For instance, the BE P-VC was N371.58, the BE FC was N110.70 and the BE TC was N540.64 respectively. The BE yield was 669.62 Kg (Table 30).

Table 30: Break-Even Analysis of integrated rice-fish production system on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Description	Total
BE Preharvest Variable Cost (P-VC) (Naira)	371.58
BE Harvest and Marketing Cost (H&MC) (Naira)	58.35
BE Fixed Costs (FC) (Naira)	110.70
BE Total Cost (TC) (Naira)	540.64
BE Rice Yield (Kg)	669.62

The risk-rated returns over cash flow were calculated 7 scenarios thus, “Best” and “Worst” expected 7 percent of the time, “Optimistic” and “Pessimistic” expected 16 percent and 31 percent of the time and “Expected” also called “Median” expected 50 percent of the time. In order words, if ten farmers adopted the integrated rice in a rice-fish production system, we assume that at least five of them would achieve the “Expected” yield, price or profit margin. The “Expected” returns and the net profit for rice was N138,164. “All things being equal” is an economic terminology which simply means that the farmer followed all the recommendations provided by experts and there were no natural calamities such as excessive rain, flooding, dry spell or some situation that disrupted production, the farmer or community is capable of obtaining between N261,658 to N179,329 “best” to “optimistic” profit for rice alone on an integrated rice in a rice-fish production system. On the other hand, the farmer or community may equally experience the pessimistic or worst-case scenario of N97,000 to N14,671 on rice production in a rice-fish production system (Table 31).

Table 31: Risk-Rated Returns over Cash flow costs of integrated rice-fish production system on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (N)	261,658	220,493	179329	138,164	97,000	55,835	14,671
Chances (%)	7%	16%	31%	50%			
Chances (%)				50%	31%	16%	7%
Chances for Profit		95%	Net Profit (Naira)				138,164

It is worth mentioning here that, this is one of the major advantages amongst other of adopting the integrated fish-rice production system in the Kebbi State, Northwest Nigeria, because the farmer or community are spreading their production risks. If one, say rice fails, the farmer or community still has fish to make up for the loss, whereas in the conventional system where only rice or fish is cultivated at a given time, any failure translates to a total loss. In our study, the farmer or community has 95 percent chances of obtaining profit on rice production not counting fish production (Table 31).

The sensitivity risk-rated analysis shows five yields scenario, starting from 694 to 1,040 kg. The goal is for the farmer or community to strive for rice higher yields as the “best” case-scenario can fetch from N119,092 to N404,228. On the other hand, the pessimistic and worst-case scenario can fetch from -N11,827 to as low as -N77,286. The chances of obtaining profit ranged from 63 percent to 99 percent. These scenarios also explain why the farmer-2-farmer and the trainer-2-trainer and extension services are a necessary and sufficient conditions for success and sustainability, especially that this technology is new in Nigeria (Table 32).

Table 32: Yield and Price Sensitivity Risk-Rated Returns over Cash Flow Cost of integrated rice-fish production system on 2,000 m² plot in Kebbi State, Northwest Region, Nigeria, 2023

Yield (kg) /Price	Best	Optimistic		Expected (867 kg)	Pessimistic		Worst	Returns	Chances Of Profit (%)
694	119092	86362	53632	20,903	-11827	-44557	-77286	20,903	63
780	190374	153427	116480	79,534	42587	5640	-31307	79,534	86
867	261658	220493	179329	138,164	97000	55835	14671	138,164	95
954	332943	287560	242178	196,795	151413	106030	60648	196,795	98
1,040	404228	354627	305027	255,426	205826	156225	106624	255,426	99

The fixed cost calculation includes cost of the equipment or implement, the salvage value, the life-span, depreciation, interest rate, taxes and insurance. Some of these parameters may not exist in the Kebbi State or the entire region but for sound economic analysis, we have to include them. The fixed costs (FC) items included but not limited to such things as pond construction, machetes, spades, digger axle, shovel etc., (Table 33).

Table 33: Annual Fixed Cost Calculation of integrated rice-fish production system on 2,000 m² plot in Kebbi State, Northwest Region, Nigeria, 2023

Descriptions	% of time for This crop	Cost	Salvage Value	Yrs. of Life	Depr.	Int.	Tax&Ins	FC/m2.
Pond construction	33%	320000	64000	15	5632	11405	887	17924
Machetes	33%	24000	4800	2	3168	855	67	4090
Spade	33%	18000	3600	3	1584	642	50	2275
DiggerAxle	33%	30000	6000	5	1584	1069	83	2736
Shovel	33%	18000	3600	3	1584	642	50	2275
Hoe	33%	18000	3600	4	1188	642	50	1879
Weighning Scale	33%	30000	6000	5	1584	1069	83	2736
Plastic Baskets	50%	30000	6000	3	4000	1620	126	5746
Drag net	100%	210000	42000	8	21000	22680	1764	45444
Sprayer (napsack)	0%	0	0	0	0	0	0	0
Plastic bins (2) (harve	50%	36000	7200	2	7200	1944	151	9295
Miscellaneous	100%	0	0	1	0	0	0	0
Installation	100%	0	0	15	0	0	0	0
Total		734000	146800		48524	42567	3311	94402
Interest on Investment (Ave. Inv. X Int. Rate)					79272.00			
Taxes and Insurance (Ave. Inv. X .014)					6165.60			
Total Annual Fixed Costs					#####			
Total Annual Fixed Costs Per Cycle					<u>66980.80</u>			

Note: The total Annual fixed costs and total annual fixed costs per cycle are the same.

This study shows the net profit for producing rice in an integrated rice in rice-fish farming system in Kebbi State, Northwest, Nigeria is N138,164 while the net profit of producing fish in an integrated fish-rice farming system in the region is N1,401,109 on 2,000 m² size farm. The combined total net profit is N1,539,273. This is expected under normal circumstances, i.e., “all things being equal”. Rice profit margin ranges from the best of N261,658 to the worst of N14,671 whereas fish profit margins range from the best of N1,848,389 to the worst of N953,828 respectively. Overall, implementing an integrated fish-rice production system in Kebbi State or the Northwestern Region of Nigeria is a profitable venture with a net profit of N1,539,273, with 97 percent chances of obtaining profits, “all things being equal” (Table 34).

Table 34: Summary: Profitability of integrated fish-rice production system on 2,000 m² plot in Kebbi State, Northwest Nigeria, 2023

Description	Best	Optimistic		Expected	Pessimistic		Worst
Fish Profit (N)	1,848,389	1,699,296	1,550,202	1,401,109	1,252,015	1,102,922	953,828
Rice Profits (N)	261,658	220,493	179,329	138164	97,000	55,835	14,671
Net Profits Levels	2,110,047	1,919,789	1,729,531	1,539,273	1,349,015	1,158,757	968,499
Chances for Profit (%)	97%		Net Profit (Naira)				1,401,109

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Appendices:

A. Financial Analysis of Integrated Rice-Fish Production System on 330 m² experimental plot at the University of Ibadan, Nigeria.

Table 35: Yields and Prices of integrated rice-fish production in system on 330 m² plot at the University of Ibadan, Nigeria, 2023

Description	Best	Optimistic	Actual	Pessimistic	Worst
Rice Yield (Kg)	203	186	169	152	135
Rice Price (Naira)	840	770	700	630	560

Table 36: Calculations of Pre-Variable Cost of producing rice with fish on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Pre-Variable Costs Items	Unit	Quantity	Price	Amt/Sq. m
Rice seeds	Kg	20.00	1500.00	30000.00
Fertilizer	Kg	0.00	5000.00	0.00
Land prep (22 x 15 m)	Sq. m	330.00	10.00	1650.00
Lime	Sq. m	15.00	200.00	1500.00
Insecticide	Sq. m	0.00	2500.00	0.00
Fungicide	Sq. m	0.00	2800.00	0.00
Herbicide	Sq. m	0.00	3000.00	0.00
Machinery (fuel, lubricant and maintenance)	Naira	1.00	6000.00	3000.00
Fish feed	Naira	1.00	2500.00	1250.00
Land rent 1/-	Sq. m	0.03	20000.00	330.00
Fish-rice net	Naira	1.00	5000.00	2500.00
Bowl plastic	Naira	2.00	1500.00	1500.00
Twine	Naira	8.00	200.00	800.00
Transportation	Naira	100.00	100.00	5000.00
Labor	Naira	1.00	12000.00	6000.00
Irrigation (Water recycling)	Sq. m	0.08	9.34	0.37
Interest on Operation Capital	Naira	52030.37	0.18	4682.73
Pre-Variable Cost	Naira			58,213.11

Table 37: Harvesting and Marketing cost of integrated rice-fish production system on 330 m² at UI, Ibadan, Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labor	Each	2.00	2500	5,000	
Hauling and Processing	Each	168.3	20	3,366	
Grading	Each	168.3	10	1,683	
Packaging	Kg	168.3	5	842	
Plastic bags	Each	168.3	5	842	
Total Harvest and Marketing (H&MC)	Naira			11,732	
Total Variable Costs (TVC)	Naira			69,945	

Table 38: Fixed Costs of integrated rice-fish production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Machinery	Sq. m	1.00	181.07	90.53	
Water Supply	Sq. m	1.00	57.67	28.83	
Overhead and Management	Naira	58213.11	0.15	4365.98	
Total Fixed Costs (TFC)	Naira			4485.35	
Total budgeted cost per acre (TC)	Naira			74430.46	

Table 39: Break-Even (BE) Analysis of integrated rice-fish production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Description	Total
BE Preharvest Variable Cost (P-VC) (Naira)	344.46
BE Harvest and Marketing Cost (H&MC) (Naira)	69.42
BE Fixed Costs (FC) (Naira)	26.54
BE Total Cost (TC) (Naira)	440.42
BE Rice Yield (Kg)	106.33

Table 40: Risk-Rated Returns over Cash Flow costs of integrated rice-fish production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (Naira)	67,926	59,944	51,962	43,979	35,997	28,015	20,033
Chances	7%	16%	31%	50%			
Chances				50%	31%	16%	7%
Chances for Profits		99%	Net Profits (Naira)				43,979

Table 41: Sensitivity Risk-Rated Returns Over Cash Flow Cost of integrated rice-fish production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Price/Yield	Best	Optimistic		Expected (169 Kg)	Pessimistic		Worst	Returns	Chances of Profit (%)
N560	19909	13786	7662	1538	-4402	-10342	-16282	1280	99
N630	42734	35636	28538	21440	14342	7244	146	21440	99
N700	67926	59944	51962	43979	35997	28015	20033	43979	99
N770	95477	86618	77759	68900	60040	51181	42322	68900	99
N840	125773	115939	106105	96271	86505	76739	66972	96200	99

Table 42: Annual Fixed Cost Calculations of integrated rice-fish production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Item	% of time for This crop	Cost	Salvage Value	Life	Depr.	Yrs. of Int.	Tax&Ins	FC/Ac.
Pond construction	33%	320000	64000	15	5632	11405	887	54
Machetes	33%	4000	800	2	528	143	11	2
Spade	33%	3000	600	3	264	107	8	1
DiggerAxle	33%	5000	1000	5	264	178	14	1
Shovel	33%	3000	600	3	264	107	8	1
Hoe	33%	3000	600	4	198	107	8	1
Weighning Scale	33%	15000	3000	5	792	535	42	4
Plastic Baskets	50%	5000	1000	3	667	270	21	3
Drag net	100%	35000	7000	8	3500	3780	294	23
Sprayer (napsack)	0%	0	0	0	0	0	0	0
Plastic bins (2) (harve	50%	6000	1200	2	1200	324	25	5
Miscellaneous	100%	0	0	1	0	0	0	0
Installation	100%	0	0	15	0	0	0	0
Total		399000	79800		13309	16955	1319	96

Interest on Investment (Ave. Inv. X Int. Rate)	43092.00
Taxes and Insurance (Ave. Inv. X .014)	3351.60
Total Annual Fixed Costs	<u>59752.27</u>
Total Annual Fixed Costs Per Acre	<u>181.07</u>

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Table 43: Yields and Prices of integrated fish-rice production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

	Best	Optimistic	Actual	Pessimistic	Worst
Fish Yield (kg)	395	362	329	296	263
Fish Price (Naira)	2400	2200	2000	1800	1600

Table 44: Calculations of Pre-Variable Cost of producing fish with rice on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Description	Unit	Quantity	Price	Amt (Sq. m)
Rice seeds	Kg	0.00	0.00	0.00
Fish seeds (fingerlings)	Each	1650.00	40.00	66000.00
Fertilizer	Kg	0.00	0.00	0.00
Land prep (22 x 15 m)	Sq. m	330.00	10.00	1650.00
Lime	Sq. m	15.00	200.00	1500.00
Insecticide	Sq. m	0.00	2500.00	0.00
Fungicide	Sq. m	0.00	2800.00	0.00
Herbicide	Sq. m	0.00	3000.00	0.00
Machinery (fuel, lubricant and maintenance)	Naira	1.00	6000.00	3000.00
Fish feed	Naira	1.00	2500.00	1250.00
Land rent 1/-	Sq. m	0.03	20000.00	330.00
Fish-rice net	Naira	1.00	5000.00	2500.00
Twine	Naira	8.00	200.00	800.00
Transportation	Naira	100.00	100.00	5000.00
Labor	Naira	1.00	12000.00	6000.00
Irrigation (Water recycling)	Sq. m	0.08	3083.40	123.34
Interest on Operation Capital.	Naira	88153.34	0.18	6170.73
Pre-Variable Cost	Naira	330.00		94,324.07

Table 45: Harvesting and Marketing cost of integrated fish-rice production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labor	Each	2.00	2500	5,000	
Hauling and Processing	Each	312.55	20	6,251	
Grading	Each	312.55	10	3,126	
Packaging	Kg	312.55	5	1,563	
Plastic bags	Each	312.55	5	1,563	
Drying (smoking)	Kg	312.55	5	1,563	
Fish Middlemen and Commission	Naira	312.55	0	0	
Total Harvest and Marketing (H&MC)	Naira			19,065	
Total Variable Costs (TVC)	Naira			113,389	

Table 46: Fixed Costs of integrated fish-rice production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Machinery	m2	1.00	31024.27	12,410	
Water Supply	m2	1.00	12496.39	4,999	
Overhead and Management	\$	94324.07	0.15	7,074	
Total Fixed Costs (TFC)	Naira			24,483	
Total budgeted cost per acre (TC)	Naira			137,871	

Table 47: Break-Even (BE) Analysis of integrated fish-rice production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Description	Total
BE Preharvest Variable Cost (P-VC) (Naira)	286.70
BE Harvest and Marketing Cost (H&MC) (Naira)	57.95
BE Fixed Costs (FC) (Naira)	74.42
BE Total Cost (TC) (Naira)	419.06
BE Fish Yield (Kg)	306.00

Table 48: Risk-Rated Returns over Cash Flow costs of integrated fish-rice production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (Naira)	673,575	627,649	581,722	535,796	489,870	443,944	398,017
Chances (%)	7%	16%	31%	50%			
Chances (%)				50%	31%	16%	7%
CHANCES FOR PROFIT		99%	NET PROFIT (Naira)				535,796

Table 49: Sensitivity Risk-Rated Returns Over Cash Flow Cost of integrated fish-rice production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Price/Yield	Best	Optimistic		Expected	Pessimistic		Worst	Net Returns	Chances of Profit (%)
N1600	527197	485606	444016	402425	360834	319243	277652	402425	99
N1800	599288	555600	511912	468225	424537	380849	337161	468225	99
N2000	671803	625877	579951	535,796	488098	442172	396246	535,796	99
N2200	744685	696398	648111	599825	551538	503251	454965	599825	99
N2400	817880	767129	716377	665625	614873	564121	513369	665625	99

Table 50: Annual Fixed Cost Calculations of integrated fish-rice production system on 330 m² plot in 330 m2 plot at the University of Ibadan (UI), Nigeria, 2023

Item	% of time for		Salvage Value	Life	Depr.	Yrs. of		FC/Ac.
	This crop	Cost				Int.	Tax&Ins	
Pond construction	33%	320000	64000	15	5632	3802	887	10321
Machetes	33%	4000	800	2	528	48	11	587
Spade	33%	3000	600	3	264	36	8	308
DiggerAxle	33%	5000	1000	5	264	59	14	337
Shovel	33%	3000	600	3	264	36	8	308
Hoe	33%	3000	600	4	198	36	8	242
Weighning Scale	33%	15000	3000	5	792	178	42	1012
Plastic Baskets	50%	5000	1000	3	667	90	21	778
Drag net	100%	35000	7000	8	3500	1260	294	5054
	0%	0	0	0	0	0	0	0
Plastic bins (2) (harve	50%	6000	1200	2	1200	108	25	1333
Miscellaneous	100%	0	0	1	0	0	0	0
Installation	100%	0	0	15	0	0	0	0
Total		399000	79800		13309	5652	1319	20279

Interest on Investment (Ave. Inv. X Int. Rate) 14364.00

Taxes and Insurance (Ave. Inv. X .014) 3351.60

Total Annual Fixed Costs 31024.27

Total Annual Fixed Costs Per Acre 31024.27

Table 51: Summary: Profitability of integrated fish-rice production system on 330 m² plot at the University of Ibadan (UI), Nigeria, 2023

Description	Best	Optimistic		Expected	Pessimistic		Worst
Rice Returns	67,926	59,944	51,962	43,979	35,997	28,015	20,033
Fish Returns	673,575	627,649	581,722	535,796	489,870	443,944	398,017
Total Profit	741,501	687,593	633,684	579,775	525,867	471,959	418,050
Chances for Profit		99%	Net Profit (Naira)				579,775

B. Financial Analysis of Integrated Fish-Rice Production System on 330 m² experimental plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria

Table 52: Yields and Prices of integrated rice-fish production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	Best	Optimistic	Actual	Pessimistic	Worst
Rice Yield (Kg)	176	161	146	131	116
Rice Price (Naira)	840	770	700	630	560

Table 53: Calculations of Pre-Variable Cost of producing rice with fish on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Rice seeds	Kg	20.00	1500.00	30,000	
Fish (fingerlings)	Each	0.00	0.00	0.00	
Fertilizer	Kg	0.00	5000.00	0.00	
Land prep (22 x 15 m)	Sq. m	330.00	10.00	1,650	
Lime	Sq. m	15.00	200.00	1,500	
Insecticide	Sq. m	0.00	2500.00	0.00	
Fungicide	Sq. m	0.00	2800.00	0.00	
Herbicide	Sq. m	0.00	3000.00	0.00	
Machinery (fuel, lub and maintenance)	Naira	1.00	6000.00	3,000	
Fish feed	Naira	1.00	2500.00	1,250	
Land rent	Sq. m	0.03	20000.00	330	
Fish-rice net	Naira	1.00	5000.00	2,500	
Twine	Naira	8.00	200.00	800	
Transportation	Naira	100.00	100.00	5,000	
Labor	Naira	0.00	0.00	0.00	
Irrigation (Water recycling)	Sq. m	0.03	50000.00	825	
Interest on Operation Capital	Naira	46855.00	0.18	4,217	
Pre-Variable Cost (P-VC)	Naira	330.00		52,572	

Table 54: Harvesting and Marketing cost of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Northwestern Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labor	Each	2.00	1500	3,000	
Hauling and Processing	Each	138.7	20	2,774	
Grading	Each	138.7	10	1,387	
Packaging	Kg	138.7	5	694	
Plastic bags	Each	138.7	5	694	
Total Harvest and Marketing (H&MC)	Naira			8,548	
Total Variable Costs (TVC)	Naira			61,120	

Table 55: Fixed Costs of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University Sokoto (UDUS), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Machinery	Sq m	1.00	131.91	66	
Water Supply	Sq m	1.00	42.73	21	
Overhead and Management	Naira	52571.95	0.15	3,943	
Total Fixed Costs	Naira			4030.22	
Total budgeted cost per SQ. M	Naira			65150.17	

Table 56: Break-Even (BE) Analysis of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University Sokoto (UDUS), Nigeria, 2023.

Description	Total
BE Pre-harvest Variable Cost (P-VC) (Naira)	360.08
BE Harvest and Marketing Cost (H&MC) (Naira)	58.55
BE Fixed Costs (FC) (Naira)	27.60
BE Total Cost (TC) (Naira)	446.23
BE Rice Yield (Kg)	93.07

Table 57: Risk-Rated Returns over Cash Flow costs of integrated rice-fish production system on 330 m² plot at the Usmanu Danfodiyo University Sokoto (UDUS), Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (Naira)	58,105	51,086	44,068	37,050	30,032	23,013	15,995
Chances (%)	7%	16%	31%	50%			
Chances (%)				50%	31%	16%	7%
CHANCES FOR PROFIT		99%	NET PROFIT (Naira)				37,050

Table 58: Sensitivity Risk-Rated Returns Over Cash Flow Cost of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Price/Yield	Best	Optimistic		Expected (146 Kg)	Pessimistic		Worst	Net Returns	Chances of Profit (%)
N560	17129	11993	6858	1723	-3134	-7990	-12847	-110	99
N630	36150	30013	23876	17738	11829	5920	11	17460	99
N700	58185	51167	44148	37130	30112	23094	16075	37130	99
N770	82266	74477	66689	58900	51112	43323	35534	58900	99
N840	108434	99879	91325	82770	74216	65661	57107	82770	99

Table 59: Annual Fixed Cost Calculations of integrated fish-rice production system on 330 m² plot in 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	% of time for		Salvage		Life	Depr.	Yrs. of		FC/Ac.
	This crop	Cost	Value				Int.	Tax&Ins	
Pond construction	33%	200000	40000	15		3520	7128	554	34
Machetes	33%	4000	800	2		528	143	11	2
Spade	33%	3000	600	3		264	107	8	1
DiggerAxle	33%	5000	1000	4		330	178	14	2
Shovel	33%	3000	600	3		264	107	8	1
Hoe	33%	3000	600	4		198	107	8	1
Weighning Scale	33%	15000	3000	5		792	535	42	4
Plastic Baskets	50%	3000	600	3		400	162	13	2
Drag net	100%	40000	8000	8		4000	4320	336	26
Sprayer (napsack)	0%	0	0	0		0	0	0	0
Plastic bins (2) (harv	50%	3500	700	2		700	189	15	3
Miscellaneous	100%	0	0	1		0	0	0	0
Installation	100%	0	0	15		0	0	0	0
Total		279500	55900			10996	12975	1009	76

Interest on Investment (Ave. Inv. X Int. Rate) 30186.00
Taxes and Insurance (Ave. Inv. X .014) 2347.80

Total Annual Fixed Costs 43529.80
Total Annual Fixed Costs Per Acre 131.91

Usmanu Danfodiyo University Fish-Rice Experimental Research Financial Analysis of Integrated Rice-Fish Production System

Tabl 60: Yields and Prices of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

	Best	Optimistic	Actual	Pessimistic	Worst
Fish Yield (kg)	460	422	384	346	308
Fish Price (Naira)	2400	2200	2000	1800	1600

Table 61: Calculations of Pre-Variable Cost of producing fish with rice on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Rice seeds	Kg	0.00	0.00	0.00	
Fish seeds (fingerlings)	Each	1650.00	40.00	66,000	
Fertilizer	Kg	0.00	0.00	0.00	
Land prep (22 x 15 m)	Sq.m	330.00	8.00	1,320	
Lime	Sq.m	15.00	250.00	1,875	
Insecticide	Sq.m	0.00	2500.00	0.00	
Fungicide	Sq.m	0.00	2800.00	0.00	
Herbicide	Sq.m	0.00	3000.00	0.00	
Machinery (fuel, lub and maintenance)	Naira	1.00	7000.00	3,500	
Fish feed	Naira	1.00	2500.00	1,250	
Land rent	Sq.m	0.03	10000.00	165	
Fish-rice net	Naira	1.00	7500.00	3,750	
Bowl Plastic	Naira	2.00	2000.00	2,000	
Twine	Naira	8.00	300.00	1,200	
Transportation	Naira	100.00	100.00	5,000	
Labor	Naira	1.00	8000.00	4,000	
Irrigation (Water recycling)	Sq.m	0.03	50000.00	825	
Interest on Operation Capital	Naira	88885.00	0.18	8,000	
Pre-Variable Cost (P-VC)	Naira	330.00		98,885	

Table 62: Harvesting and Marketing cost of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Hand harvest labor	Each	2	1500	3,000	
Hauling and Processing	Each	364.8	20	7,296	
Grading	Each	364.8	10	3,648	
Packaging	Kg	364.8	10	3,648	
Plastic bags	Each	364.8	10	3,648	
Drying (smoking)	Kg	364.8	5	1,824	
Fish Middlemen and Commission	Naira	364.8	0	0	
Total Harvest and Marketing (H&MC)	Naira			23,064	
Total Variable Costs (TVC)	Naira			121,948.65	

Table 63: Fixed Costs of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	Unit	Quantity	Price	Total	Yours
Machinery	Sq. m	1.00	43529.80	21,765	
Water Supply	Sq. m	1.00	42.73	21	
Overhead and Management	Naira	98884.65	0.18	8,900	
Total Fixed Costs (TFC)	Naira			30,686	
Total budgeted cost per acre (TC)	Naira			152,634.53	

Table 64: Break-Even (BE) Analysis of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	Total
BE Preharvest Variable Cost (P-VC) (Naira)	257.51
BE Harvest and Marketing Cost (H&MC) (Naira)	60.06
BE Fixed Costs (FC) (Naira)	79.91
BE Total Cost (TC) (Naira)	397.49
BE Fish Yield (Kg)	76.32

Table 65: Risk-Rated Returns over Cash Flow costs of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

	Best	Optimistic		Expected	Pessimistic		Worst
Returns (Naira)	775,047	721,820	668,365	615,365	562,138	508,911	455,684
Chances (%)	7%	16%	31%	50%			
Chances (%)				50%	31%	16%	7%
CHANCES FOR PROFIT		99%	NET PROFIT (Naira)				615,365

Table 66: Sensitivity Risk-Rated Returns Over Cash Flow Cost of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Price/Yield	Best	Optimistic		Expected (384 kg)	Pessimistic		Worst	Net Returns	Chances of Profit %
N1600	500026	457224	414423	371621	328819	286017	243215	371621	99
N1800	646302	598075	549848	501621	453394	405167	356940	501621	99
N2000	775047	721820	668593	615365	562138	508911	455684	615365	99
N2200	984371	925321	866271	807221	748171	689121	630071	8807221	99
N2400	1176178	111176	1047273	982821	918368	853916	789463	982821	99

Table 67: Annual Fixed Cost Calculations of integrated fish-rice production system on 330 m² plot in 330 m2 plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	% of time for		Salvage		Depr.	Yrs. of		
	This crop	Cost	Value	Life		Int.	Tax&Ins	FC/Ac.
Pond construction	33%	200000	40000	15	3520	7128	554	11202
Machetes	33%	4000	800	2	528	143	11	682
Spade	33%	3000	600	3	264	107	8	379
DiggerAxle	33%	5000	1000	4	330	178	14	522
Shovel	33%	3000	600	3	264	107	8	379
Hoe	33%	3000	600	4	198	107	8	313
Weighning Scale	33%	15000	3000	5	792	535	42	1368
Plastic Baskets	50%	3000	600	3	400	162	13	575
Drag net	100%	40000	8000	8	4000	4320	336	8656
Sprayer (napsack)	0%	0	0	0	0	0	0	0
Plastic bins (2) (harve	50%	3500	700	2	700	189	15	904
Miscellaneous	100%	0	0	1	0	0	0	0
Installation	100%	0	0	15	0	0	0	0
Total		279500	55900		10996	12975	1009	24980

Interest on Investment (Ave. Inv. X Int. Rate)	30186.00
Taxes and Insurance (Ave. Inv. X .014)	2347.80
Total Annual Fixed Costs	<u>43529.80</u>
Total Annual Fixed Costs Per Cycle	<u>43529.80</u>

Table 68: Summary: Profitability of integrated fish-rice production system on 330 m² plot at the Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria, 2023

Description	Best	Optimistic		Expected	Pessimistic		Worst
Rice Returns	58,105	51,086	44,068	37,050	30,032	23,013	15,995
Fish Returns	775,047	721,820	668,593	615,365	562,138	508,911	455,684
Total Profit	833,152	772,906	712,661	652,415	592,170	531,924	471,679
Chances for Profit		99%	Net Profit (Naira)				652,415

Technical Report: Socio-economic contribution

Analysing End-Market Prospects for Agricultural Output and Identifying Risk Factors

The evaluation of potential end-market opportunities for agricultural output involves a comprehensive assessment of avenues where farm products can be effectively distributed and utilized. A critical aspect of this process is the identification and understanding of associated risk factors. This step is vital for informed decision-making and the formulation of robust risk management strategies. Diversifying the array of end-market possibilities holds the potential to mitigate risks and reduce susceptibility to market fluctuations in any singular sector. Below are prime end-market opportunities tailored to the integrated rice-fish production technology:

1. **Direct Consumer Engagement and Retail:** Exploring opportunities within the retail and consumer segment entails directly offering fish and rice to customers through a multitude of avenues, including farmers' markets, roadside stands, online platforms, and Community-Supported Agriculture (CSA) initiatives operating within the demonstration site locales. However, this avenue is not without its challenges. Variability in demand due to seasonality and consumer preferences can lead to market instability. Oversupply concerns might arise from market saturation, and the need for swift sales to prevent spoilage underscores the perishable nature of the products. Fluctuations in prices, influenced by competition and external factors such as weather conditions and supply-demand dynamics on local, regional, and global scales, can further contribute to market uncertainties.
2. **Wholesale Markets:** The wholesale market option involves bulk sales of rice and fish produce to wholesalers, distributors, or retailers. However, this route comes with its set of complexities. Negotiating prices with larger buyers who wield more bargaining power can be challenging. Adherence to specific grading and packaging requirements dictated by stringent quality standards is essential. Concerns also emerge from the possibility of delayed or defaulted payments, potentially disrupting the cash flow for rice-fish farmers. Furthermore, a heavy reliance on a few prominent buyers can lead to the risk of market concentration.
3. **Food Processing and Manufacturing:** The supply of finished rice and fish products to food processing and manufacturing entities, including eateries and food service establishments, constitutes a viable avenue. Nonetheless, this path isn't devoid of uncertainties. Contracts and the quantity-price dynamics they entail introduce potential risks. Striving to meet exacting quality and consistency benchmarks is crucial to avoid contract termination. Fluctuations in demand due to seasonal shifts can impact the need for both raw materials and processed products. The risk of market concentration is a looming concern, tied to the dependence on a select group of key processors.
4. **Global Export Ventures:** Targeting foreign markets for export purposes is a promising route for farmers engaged in large-scale rice and fish production. Yet, this avenue demands meticulous attention to quality control and the intricate logistics of long-distance shipments. Currency exchange rate fluctuations can exert significant influence on export prices and overall profitability. Furthermore, navigating international trade regulations, tariffs, and sanitary/phytosanitary standards while manoeuvring through the complexities of political instability and trade disputes adds another layer of risk to the equation.
5. **Government and Institutional Supply Channels:** The provisioning of rice and fish products to government institutions like schools, hospitals, and correctional facilities offers a distinct

market opportunity. Implementing mechanisms such as buy-back arrangements or establishing future market contracts can help ensure a steady supply of products. Nevertheless, this avenue involves navigating complex procurement processes and adhering to specific contractual requisites. Budget constraints within the public sector can exert downward pressure on prices, and the reliance on governmental policies and funding for agricultural initiatives adds a layer of risk.

A comprehensive evaluation of end-market prospects for agricultural output requires a keen understanding of the diverse opportunities available. This analysis is incomplete without the identification of risk factors, which are integral to making informed choices and establishing effective risk management strategies. By exploring a range of market avenues and diversifying distribution strategies, farmers can strategically manage risk exposure and enhance the overall resilience of their agricultural endeavours.

Survey and assess economic and profitability margins, consumer preference, and willingness to pay (WTP) for local integrated agriculture-aquaculture products.

To determine profitability margins for the newly introduced integrated rice operation in a rice-fish production system in Nigeria, it was absolutely important to identify all the cost components such as pre-variable costs (P-VC), harvesting and marketing costs (H&MC), total variable cost (TVC), total fixed costs (TFC) and total cost of production (TC) for all the six location sites in the study areas, i.e. Ebonyi and Kebbi States respectively (Table 1).

The P-VC for Onicha in Ebonyi State was N51,072 while the TC of production was N62,569 on a 330 m² size research plot. On the other hand, The P-VC for Wawu-Jaji in Kebbi State was N103,850 while the TC of production was N118,598 on a 2,000m² size research plot. Additional details are illustrated in Table 1.

Table 1: Summary of Rice Costs for different sites in the integrated rice-fish production system in Nigeria, 2023

Site Location	m ²	P-VC	H&MC	TVC	TFC	TC
Ikwo Pond, Ebonyi State	330	51,072	7,090	58,162	3,916	62,078
Onicha Pond, Ebonyi State	330	51,072	7,660	58,732	3,837	62,569
Wawu-Jaji Pond, Kebbi State	2,000	103,850	6,950	110,800	7,798	118,598
Kimba Pond, Kebbi State	2,000	102,585	19,720	122,305	7,803	130,109
University of Ibadan, Oyo State	330	58,213	11,722	69,945	4,485	74,430
Usmanu DanFodiyo University, Sokoto Sokoto State	330	52,572	8,548	61,120	4,030	65,150

Source: Calculation was based on primary/field data obtained during the study.

Furthermore, to determine profitability margins for the newly introduced integrated fish operation in a fish-rice production system in Nigeria, it was also absolutely important to identify all the cost components such as pre-variable costs (P-VC), harvesting and marketing costs (H&MC), total variable

cost (TVC), total fixed costs (TFC) and total cost of production (TC) for all the six locations sites in the study areas, i.e. Ebonyi and Kebbi States respectively (Table 2).

Table 2: Summary of Fish Costs for different sites in the integrated fish-rice production system in Nigeria, 2023

Site Location	m ²	P-VC	H&MC	TVC	TFC	TC
Ikwo Pond, Ebonyi State	330	92,815	8,301	101,116	8,439	109,555
Onicha Pond, Ebonyi State	330	91812	10,900	102,711	53,284	155,996
Wawu-Jaji Pond, Kebbi State	2,000	210,217	41,926	252,144	63,921	316,065
Kimba Pond, Kebbi State	2,000	228,410	30,574	258,984	65,578	324,562
University of Ibadan, Oyo State	330	94,324	19,065	113,389	24,483	134,871
Usmanu DanFodiyo University, Sokoto Sokoto State	330	98,885	23,064	121,948	30,686	152,635

The P-VC for Ikwo in Ebonyi State was N92,815 while the TC of production was N109,555 on a 330 m² size research plot. On the other hand, The P-VC for Kimba in Kebbi State was N228,410 while the TC of production was N324,562 on a 2,000m² size research plot. Additional details are illustrated in Table 2.

The economic investigation of introducing an integrated rice-fish production system in Ebonyi and Kebbi States of Nigeria, respectively, included a break-even (BE) analysis which is very important in analyzing the financial viability of a project. BE analysis tells the farmer or investor the minimum output, whereby they are not losing money. BE point (BE-P) refers to when total cost (TC) and total revenue (TR) are equal. In other words, it means there is no loss or gain for the enterprise or business, i.e., when the farmer has reached the production level at which the production costs equal the revenues for a product. BE-P is calculated by dividing the total fixed costs (TFC) associated with production by the total revenue (TR) per individual unit minus the total variable costs (TVC) per unit (Fonsah, Kunwar and Diaz-Perez, 2022; Fonsah *et al.*, 2018; Kaninda *et al.*, 2020; Kunwar and Fonsah, 2022).

We successfully summarized the BE point for fish in a rice-fish production system for selected critical economic parameters such as the pre-variable cost (P-VC), harvesting and marketing cost (H&MC), total fixed cost (TFC), total cost (TC) and yields (Table 3). A comparison of these selected parameters was conducted for the different integrated fish-rice research sites, i.e., Ikwo, Onicha, Kimba, Wawu, the University of Ibadan (UI) and Usmanu Danfodiyo University, Sokoto (UDUS) respectively. For instance, the P-VC of the Ikwo site in Ebonyi State was N749 compared to N281 for the Wawu site in Kebbi State (Table 3).

Table 3: Summary Break-Even (BE) Analysis of integrated fish on a fish-rice production system in Nigeria, 2023

Description	Ikwo	Onicha	Kimba	Wawu	UI	UDUS
BE P-VC ¹	749	669	354	281	287	258
BE H&MC ²	67	79	47	56	58	60
BE TFC ³	68	389	102	85	74	80
BE TC ⁴	884	1,130	503	422	419	397
BE Yields (Kg) ⁵	55	78	162	158	306	76

¹ Break-even Pre-Variable Costs; ² Break-even Harvesting and Marketing Costs; ³ Break-even Total Fixed Costs;

⁴ Break-even Total Costs; ⁵Break-even Yields (kg).

A similar break-even (BE) analysis was conducted for rice in a rice-fish production system in both Ebonyi and Kebbi states. For instance, the BE total cost (BE-TC) for Onicha, Ebonyi State, Southeast Nigeria, was N894 compared to N1,284 for Wawu, Northwest Nigeria (Table 4). It is worth noting here that the plot sizes were different. The plots in Ebonyi state were 330 m² while the ones in Kebbi state were 2,000m². The two controlled research sites, i.e., the University of Ibadan (UI) and the Usmanu Danfodiyo University, Sokoto (UDUS), were also 330m², respectively (Table 4).

Table 4: Summary Break-Even (BE) Analysis of integrated rice on a rice-fish production system in Nigeria, 2023

Description	Ikwo	Onicha	Kimba	Wawu	UI	UDUS
BE P-VC ¹	925	729	233	1,124	344	360
BE H&MC ²	128	109	45	75	69	59
BE TFC ³	71	55	18	84	27	28
BE TC ⁴	1125	894	296	1,284	440	446
BE Yields (Kg) ⁵	87	89	186	169	106	93

¹ Break-even Pre-Variable Costs; ² Break-even Harvesting and Marketing Costs; ³ Break-even Total Fixed Costs;

⁴ Break-even Total Costs; ⁵Break-even Yields (kg)

This study also captured the net profit for each research site in both Ebonyi State, Southeast region and Kebbi State, Northwest region of Nigeria. A risk-rated model was used to determine the profit margins for fish and rice separately, and a summary of both was calculated for each site. Two sites in Ebonyi state and one from Kebbi state experienced a negative return for rice production. The reasons

included late planting and flooding. Ikwo local government municipality in Ebonyi state obtained a net profit of N135,445 for fish and -N23,578 for rice, thus a net profit of N111,867 despite the negative rice return. This also depicts the importance of integrated fish-rice farming. For instance, if the three sites with negative rice return did not adopt the integrate system, they would have lost their total investment on rice monoculture production (Table 5).

A similar scenario was observed in Wawu-Jaji, Kebbi State, Northwestern Nigeria. Despite the rice profit of -N53,918, the fish generated a positive return of N1,181,936, thus bringing the net profit of the rice and fish farming system to N1,128,018 on a 2,000 m² size plot (Table 5).

Table 5: Summary of Net Returns for Fish and Rice in an integrated rice-fish production system in Nigeria, 2023

Site Location	Farm size m ²	Fish Net Profit (₦)	Rice Net Profit (₦)	Total Net Profit (₦)
Ikwo Pond, Ebonyi State	330	135,445	-23,578	111,867
Onicha Pond, Ebonyi State	330	120,004	-13,569	106,435
Wawu-Jaji Pond, Kebbi State	2,000	1,181,936	-53,918	1,128,018
Kimba Pond, Kebbi State	2,000	966,438	177,891	1,144,329
University of Ibadan, Oyo State	330	535,796	43,979	579,775
Usmanu DanFodiyo University, Sokoto Sokoto State	330	615,365	37,050	652,415

Source: Data from the demonstration sites. Farmed fish were catfish and planted rice was faro 44 variety.

Our calculations were based on these fish and rice actual yields and prices. However, we examined five case-scenarios, i.e., “Best”, “Optimistic”, “Actual”, “Pessimistic” and “Worst”. The best and worst case-scenarios were obtained 7 percent of the time while we assumed the Expected or Actual case-scenarios were obtained by 50 percent of the time or of the farmers. The optimistic and pessimistic case-scenarios were 10 percent and 20 percent increase or decrease in the prices and yields of fish or rice. For instance, the fish yield for onicha was 138 kg on a 330 m² pond compared to 645 kg in Kimba, Kebbi state, produced on 2,000 m² pond (Table 6).

Table 6: Summary of rice and fish yields for different sites in the integrated rice-fish production system in Nigeria, 2023

Site Location	Farm Size (m ²)	Fish Yields (Kg)	Fish Price (Naira)	Rice Yields (Kg)	Rice Price (Naira)
Ikwo Pond, Ebonyi State	330	124	2,000	55	700
Onicha Pond, Ebonyi State	330	138	2,000	70	700
Wawu-Jaji Pond, Kebbi State	2,000	749	2,000	92	700
Kimba Pond, Kebbi State	2,000	645	2,000	440	700
University of Ibadan, Oyo State	330	356	2,000	169	700
Usmanu DanFodiyo University, Sokoto, Sokoto State	330	384	2,000	146	700

Source: Calculation was based on primary/field data obtained during the study.

The conclusion is that having rice solely may or may not be profitable and since the net returns from rice enterprises alone in our study were not profitable in three sites, in contrast to the sole fish enterprise in all six site locations. Our study shows that despite the negative rice net profit from three of the six sites in our project, total profit was positively encouraging in all six sites, which is one of the advantages of adopting an integrated system to mitigate and reduce production risks.

Willingness to Pay (WTP) and Consumer Preference for Local Rice and Fish

A survey was conducted during the introduction of the integrated fish-rice production system to determine consumers' willingness to pay (WTP) and gauge consumers' behaviours vis-à-vis consuming rice raised simultaneously with fish in the same field. Our findings revealed that Nigerian consumers preferred the local rice to the foreign counterpart. Most (65.45 percent) respondents opined that they eat locally-produced rice three times a week and 19.72 percent of the respondents say they would buy or consume locally-produced rice if readily available in the market. The amount the consumers are willing to pay for 1kg of local rice was less than N2, 000.00, and they are willing to pay NGN 1000–1500 for one MUDU or rubber of local rice. The most locally preferred variety was FARO-44, followed by FARO-52 and FARO-61. Consumers preferred local rice for taste/flavour, availability, sweetness, and cooking. Other reasons adduced by the consumers were finger size, colour and cosmetic appearance, respectively.

The survey further revealed that the most preferred fish consumed by the respondents was local, compared to foreign fish, and they opined that they consume local fish very often and occasionally. Consumers' most preferred local fish was catfish, followed by tilapia, carp, and other local varieties. Most consumers (82.39 percent) are willing to buy local fish if it is readily available in the market rather than foreign fish. The amount the consumers are willing to pay for 1 kg of preferred local fish was between N500 and N1000 for fresh or non-value-added fish, as opined by the majority (59.86 percent) of the consumers, while the reasons given for preferring local fish were taste/flavour, sweetness, availability, cosmetic appearance, fish size, fish length and colour. The N2,000 market price

used for our study was strictly for value-added smoked and packaged fish which also have a longer shelf life and multipurpose use including consumption as a snack. This project has provided smoking kiln to the different site free of charge to be used for value-addition. Farmers are also encouraged to plant more local varieties of rice since it is the preferred rice that commands higher prices, thus, eventually maximizing their rice profitability.

Policy Implications for Adopting an Integrated Rice-Fish Technology

An integrated approach to rice-fish culture technology holds profound policy implications, particularly within rural households. These implications underscore the manifold advantages of fostering such integrated systems, while also emphasizing the multifaceted considerations that policymakers must address to ensure its seamless integration and successful implementation.

Central to these implications is the pivotal role of enhancing food security. By diversifying agricultural practices and augmenting the availability of both rice and fish, vital sources of carbohydrates, proteins, and micronutrients, this technology contributes significantly to ensuring a stable food supply. This is essential for addressing nutritional needs and bolstering the resilience of communities against food-related challenges.

Furthermore, the adoption of this innovative technology actively promotes the principles of sustainable agriculture. Through the judicious utilization of resources, it fosters heightened resource efficiency and concurrently diminishes the reliance on chemical inputs. In effect, this reduces the ecological footprint of agricultural activities and mitigates potential environmental repercussions.

A noteworthy aspect of this integrated approach is its positive impact on rural livelihoods. By creating supplementary income streams, especially in regions constrained by limited land and water resources, it imparts a substantial economic uplift to farmers. This holds the potential to alleviate economic pressures and enhance overall quality of life in these communities.

Policymakers stand to orchestrate instrumental changes that further amplify the benefits of integrated rice-fish culture technology. By crafting policies that incentivize the prudent use of water resources, the integration of rice and fish production optimizes water allocation and minimizes wastage. This aligns seamlessly with broader water conservation goals, contributing to the sustainable management of this finite resource.

In essence, embracing integrated rice-fish culture technology transcends agricultural innovation; it embodies a holistic approach that encompasses food security, sustainable practices, and rural prosperity. By integrating these facets into policy frameworks, governments can usher in a new era of resilient, productive, and ecologically conscious agricultural systems.

Integrated rice-fish culture stands as a promising approach to safeguarding aquatic biodiversity. By establishing intricate ecosystems that accommodate a range of fish species, rice varieties, and aquatic organisms, this practice plays a pivotal role in enhanced biodiversity. To ensure the realization of its benefits, governments should consider substantial investments in research, extension services, and farmer training. Educating farmers on the nuanced advantages, and techniques of integrated rice-fish culture becomes paramount.

Facilitating policy support emerges as a vital component, facilitating the formation of market connections and value chains for both rice and fish products. This, in turn, guarantees equitable access to markets and fair remuneration for farmers' diligent efforts. The holistic implications of integrated

rice-fish culture extend to bolstering climate resilience. The diversification of income streams for farmers coupled with amplified ecosystem services can potentially counteract the adversities posed by climate change.

Effective governance can be demonstrated through the implementation of regulations and benchmarks, thereby ensuring the value of rice and fish products originating from integrated culture systems. Equally crucial is the upskilling of farmers, extension workers, and stakeholders involved. By investing in capacity-building programs, policy makers can elevate the expertise and understanding of those engaged in integrated rice-fish culture.

The trajectory towards successful adoption of integrated rice-fish technology hinges upon strategic allocation of resources. Prioritizing research and development fosters enhanced comprehension, innovation, and optimization of integrated systems. Productivity, sustainability, and environmental implications warrant dedicated attention in these endeavours. The dissemination of practical knowledge and skill refinement, achieved through strengthened extension services, forms the bedrock for effective integration. It is evident that a multi-faceted approach, entailing education, policy backing, capacity enhancement, and research, is imperative for the integration of rice-fish culture into prevailing practices.

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Annex 22: Summary of Outputs (Monitoring, Evaluation and Learning indicators of the project)

Outputs	Indicators	Baseline	Target	Actual Achievement	Means of verification	Lead institution(s) to deliver outputs
Outcome 1: Development of suitable integrated rice-fish production technology through participatory research actions.						
<u>*Output 1.1:</u> Action research is conducted to develop a knowledge base on agroecological wetlands suitable for integrated fish and rice farming.	- Number of wetland identified - Number of stakeholder meetings conducted with communities	0 wetland map 0 stakeholder meeting	1 wetland map 2 stakeholder meeting	- Wetland maps of Ebonyi and Kebbi state produced - Three stakeholder meetings conducted (one each in Kebbi and Ebonyi states; One national workshop in Ibadan)	Survey report on agroecological wetlands Project document	Joint FAO/UI
<u>Output 1.2</u> Farming Systems are analyzed to characterize the prevailing rice-fish farming practices and gather evidence on how to introduce innovative and high performing farming system through appropriate	Number of rice farming systems identified No of needs of farmers for intensification of fish production in rice fields gathered from survey and group discussion Number of research site selected Number of project beneficiary selected,	0 systems 0 needs assessments 0 research sites 0 project beneficiaries 0 farmer field school training	1 system 1 needs assessment 2 research sites 200 project beneficiaries 2 farmer field schools 8. 9.	2 systems 1 need assessment conducted 8 plots sites selected (three each in Kebbi and Ebonyi states, two institutional sites in University of Ibadan and one institutional site in Usmanu Danfodiyo University Sokoto - About 800 beneficiaries	Project annual/quarterly report	UI

management options	30% of which must be women and youths Number of Participatory farmer field school training conducted			Six farmer field schools training conducted		
<u>*Output 1.3:</u> Evidence-based and locally adaptable cost-effective integrated rice-fish system, including market access development are piloted in the target communities	On-farm adaptive research to obtain information on cost of production, rice and fish yield, resource use, and fish performance under different feeding regimes in each system Number of participation farmers, disaggregated to gender and age (youth and adults) Number of hectares under farm diversification process Number of cluster farms established	0 on-farm adaptive research 0 participating farmers 0 hectares under farm diversification 0 farm cluster	2 on-farm adaptive research 6 participating farmers 2 hectares under farm diversification 2 farm clusters	8 on-farm adaptive research 8 participating farmers 10 hectares under farm diversification - 3 farm clusters	Weekly report of on-farm adaptive research Project Documents	Joint UI/FAO
<u>Output 1.4:</u> The promotion and adoption of cost-effective, sustainable and innovative approaches and	Number of farmers (women, men, youth) that take up the technology and applied the farm diversification process	0 farmer technology adoption 0 percent increase	100 farmer technology adoption 5 percent increase 10 percent monetary value increase	108 farmer technology adoption 5 percent increase 10 percent monetary value increase	Report of workshops and trainings Report of review of institutional policies 10.	UI

practices to support agroecologically sound aquaculture operations in rice farms of target communities are evaluated.	Percentage increase in yield of rice of the participating farmers percentage of project participants with increased dietary diversity Percentage increase in the monetary value of sales (rice and fish) of project participants	0 percent monetary value increase				
*Output 1.5: Production technological packages for sustainable integration of rice-fish farming in the participating states through adaptive research are developed.	Number of rice-fish technological package is developed	0 technological package	1 technological package	3 technological package	11. Report on production technological package for rice-fish UI Newsletters Project Report	Joint FAO/UI
Output 1.6: A functional Innovation Platform on IAA system is established.	Number of Innovation platform established Number of participating farmers and other stakeholders disaggregated according to gender and age	0 innovation platform	2 innovation platforms	2 innovation platforms	UI Newsletters FAO Aquaculture Newsletter Project Report	UI
Output 1.7: Capacity building of local stakeholders (training programs for farmers, training of trainers) and	Number of Trainings, workshops, seminars conducted Number of training participants disaggregated according to gender and age	0 trainings 0 training participants 0 communication material	2 trainings 200 training participants 5 communication materials	8 trainings 727 training participants (232 female, 495 male, 54 youth). 5 communication materials	Number of training and workshop participants	UI/UGA

mainstreaming gender roles in rice-fish farming systems based on research and/or survey data of stakeholder needs in rice-fish farming are conducted.	Number of Training/communication material developed					
Outcome 2: Understanding convenient market access approach and nutrition contributions of rice-fish farming products						
<u>Output 2.1</u> Situational analyses of markets before, during and after intervention process are conducted and analyzed.	Number of Market access survey is conducted	0 survey conducted	3 surveys conducted	2 surveys conducted	Survey questionnaire report Analyzed survey data Project Documents UGA Reports	UGA
<u>*Output 2.2</u> Situational analyses of nutrition status, gender and youth involvement before, during and after intervention process. Designed and implemented fish surveys (see Project Document Section 3 for description of surveys)	Number of surveys conducted when administering the food/fish consumption, HDDS, HFIAS, MDD-W survey questionnaires.	0 survey conducted	3 surveys conducted	2 surveys conducted	Survey questionnaire report Analyzed survey data Project Documents	Joint FAO/UI

<u>Output 2.3:</u> Enhanced entrepreneurship or business skill of farmers, especially youths and women and end market opportunities from the farm outputs identified and supported through the project are evaluated.	Number of Entrepreneurship training is conducted Number of new entrepreneurs among the project beneficiaries disaggregated according to gender and age Rice-fish business manual development is initiated	• 0 entrepreneurship training • 0 new entrepreneur	• 1 entrepreneurship training • 10 new entrepreneurs	• 3 entrepreneurship training • 50 new entrepreneurs	Report of entrepreneurship/business evaluation Project Documents	UGA
<u>Output 2.4</u> Partnership between scientists and the development community for improving food production-nutrition linkages to address undernutrition (malnutrition)	Number of partners and other development partners involved in the project The number of organizations (farmer groups, market stakeholders) with increased performance improvement through the project	• 0 partners • 0 number of organizations	• 2 partners • 3 number of organizations	• 3 partners • 6 number of organizations	Reports of joint partner activities Project documents University of Ibadan Newsletters	UI

are strengthened.						
Outcome 3: Capacity development and enhancement of co-learning among all stakeholders (academics, farmers, extension workers and other development partners)						
Output 3.1: Best performing and preferred species suitable for sustainable rice-fish production in the two states (Kebbi and Ebonyi) are identified and evaluated	Number of preferred fish species by consumers Number of best performing fish species	• 0 preferred fish • 0 fish specie	• 1 preferred fish • 1 best performing fish specie	• 2 preferred fish • 2 best performing fish species	Record of fish population studied Project Documents	UI
Output 3.2: Locally available feedstuffs as suitable supplemental feeding for <i>Clarias gariepinus</i> and <i>Oreochromis niloticus</i> are tested	Number of low cost but good quality feed developed Number of locally feedstuff ingredient tested	• 0 feed developed • 0 feed ingredient tested	• 1 feed developed • 2 feed ingredient tested	• 2 feed developed • 3 feed ingredient tested	Project Documents National Agriculture reports	Joint UGA/UI
Output 3.3: Manual for small-scale rural farmers that helps development of an investment and business plan is developed.	Number of business plan developed for rice-fish farming through grower's profitability margins, grower's acceptability and consumer purchasing behavior and Willingness to Pay (WTP) analyses.	• 0 business plan	• 1 business plan	• 1 business plan	Publication of the business manual Project Documents	UGA

<u>*Output 3.4:</u> National conference on rice-fish farming is organized.	Number of National conference on rice-fish farming organized Number of participants and key stakeholders in that attended the National conference disaggregated according to gender and age Number of recommendations and key messages from the National conference	• 0 National conference • 0 National conference attendee • 0 key recommendation	• 1 National conference • 30 National conference attendees • 5 key recommendations	• 1 National conference • 45 National conference attendees • 12 key recommendations	FAO Newsletters Project Documents	Joint UI/FAO
<u>*Output 3.5:</u> Policy brief as an informed guide to influence policies and practices for the inclusion, promotion, and implementation of IAA in future food policy designs and/or national agricultural programs, as a nutrition-sensitive approach are published.	Number of knowledge products produced and published At least four policy brief developed before project completion	• 0 knowledge products	• 2 Knowledge products	• 4 policy brief developed • Seven manuscripts developed for publications	Project Documents UI News Report National Agriculture reports	FAO/UI/UGA

Annex 23: Policy Brief 1: Changing the food production landscape in Nigeria through farm diversification process – modifying rice field for fish production



Policy Brief 1: 2023

Changing the Food Production Landscape in Nigeria through Farm Diversification Process - Modifying Rice Field for Fish Production

Nigeria faces significant challenges related to food insecurity, malnutrition, and limited access to food, particularly in rural communities. A promising solution to address these issues is the integration of agriculture and aquaculture, specifically through rice-fish farming. This approach seeks to transition rice fields into productive, diversified landscapes, benefiting rural communities and contributing to the overall well-being of the population. This approach not only boosts agricultural productivity but also enhances nutrition security and livelihoods. The farm diversification pilot project successfully integrated fish and rice farming in Kebbi and Ebonyi states, resulting in enhanced production of rice and fish, and reported improvement in food security and nutrition status of beneficiary farming families.



KEY FINDINGS

- Integrated rice-fish farming led to increased fish and rice yields, contributing to food security and improved nutrition in communities.
- The integrated system produced higher yields of rice and fish compared to monoculture practices, showcasing its potential for increased productivity.
- The approach had positive socio-economic impacts, creating employment opportunities, especially for youth and women.
- Water and soil quality parameters were maintained within acceptable ranges, demonstrating the environmental sustainability of IAA systems.

The project confirms that integrated rice-fish farming is practicable, environmentally friendly, economically viable, and can significantly contribute to food security and livelihood enhancement in Nigeria. Proper implementation and operational mechanisms are essential to realize these potentials. Additionally, the integrated approach addresses challenges like freshwater scarcity for fish culture and rice production, increased demand for more food, and low productivity, making it a key tool for ensuring food security, youth and women empowerment, and improved livelihoods. To fully utilize the benefits of the system, it's important to establish an effective institutional framework. These will serve as catalysts for maintaining the positive outcomes and results achieved through this integrated project.



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AND FORESTRY

Project Implementation Team

Lead PI: Matthias Halwart, PhD
Food and Agriculture Organization of the United Nations

Lead Co-PI: Xinhua Yuan, PhD
Food and Agriculture Organization of the United Nations

Nigeria PI: Emmanuel K. Ajani, PhD
University of Ibadan

Nigeria Co-PI: Bamidele O. Omitoyin, PhD
University of Ibadan

U.S. PI: Amrit Bant, PhD
University of Georgia

U.S. Co-PI: Esendugue G. Fonsah, PhD
University of Georgia

U.S. Co-PIs: Gary Burtle, PhD
University of Georgia

Project Coordinator: Oluwafemi Ajayi
Food and Agriculture Organization of the United Nations

RECOMMENDATIONS

To fully harness the benefits of integrated agriculture and aquaculture for food security and livelihood enhancement, the following steps are recommended:

- Develop and improve market access and value addition strategies for aquaculture products.
- Improve land tenure systems and develop infrastructure for integrated aquaculture ventures.
- Facilitate easy access to formal credit for prospective investors.
- Create business models to attract youth and women to the sector.
- Increase access to critical inputs and develop a strong legal and institutional framework.
- Foster collaboration between relevant government agencies, research institutions, and private sector stakeholders.

By adopting the recommended policies and strategies, Nigeria can harness the benefits of this innovative approach to ensure a more sustainable and resilient food system for its population.

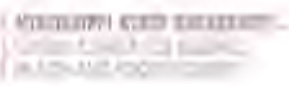
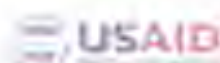
IMPLEMENTATION AND FUTURE OUTLOOK

For successful implementation, collaboration among government agencies, private sector entities, research institutions, and local communities is crucial. With proper policy support and strategic investments, integrated agriculture and aquaculture can significantly contribute to food security, improved nutrition, and enhanced livelihoods in Nigeria. This policy brief emphasizes the potential of integrated agriculture and aquaculture to address food security challenges, boost nutrition, and empower rural communities in Nigeria.

ABOUT THE FISH INNOVATION LAB

The Fish Innovation Lab supports the United States Agency for International Development's agricultural research and capacity building work under Feed the Future, the U.S. Government's global hunger and food security initiative. Mississippi State University is the program's management entity. The University of Rhode Island, Texas State University, Washington University in St. Louis, and RTI International serve as management partners.

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Integrated Rice-Fish Farming as a Climate-Smart Land Use Strategy in Nigeria

The integration of agriculture and aquaculture (IAA) has emerged as a promising approach to enhance agricultural productivity while mitigating environmental impacts in Nigeria. This policy brief highlights the benefits of adopting IAA practices, as demonstrated in the USAID/Fish Innovation Lab (FIL)-funded project on farm diversification in Kebbi and Ebonyi states, Nigeria.

Integrated agriculture-aquaculture diversifies food systems, reduces waste, increases productivity, and enhances climate resilience. The approach is particularly valuable for small-scale farmers facing climate change challenges and limited resources. This policy brief advocates for the integration of IAA into national agriculture and food policies to address food security and promote sustainable adaptation and mitigation strategies for common agricultural-related environmental issues.



Farmers preparing rice field in preparation for fish stocking

Nigeria's agriculture sector faces the dual challenge of meeting growing food demand and addressing

climate change impacts. Integrated farming systems, such as Integrated Agriculture and Aquaculture (IAA), offer environmentally friendly solutions. The IAA system demonstrated in the USAID/FIL-funded project has effectively increased climate resilience, reduced chemical input dependency, and diversified livelihoods.

Approaches and Results

The IAA model's effectiveness was demonstrated through participatory approaches and three production cycles across agroecological zones in Kebbi and Ebonyi states. Key findings include:

- Water productivity of 6.55kg/m³ under integration.
- Fish assimilate 24-36% of nitrogen inputs.
- Fish feed and waste contribute 60% of nitrogen inputs.
- Fish waste became a valuable resource for nutrient cycling, contributing to improved productivity.
- Rice acting as a major nutrient sink (68%).
- Improved water management, increased outputs, and enhanced resource efficiency.
- Potential for using pond water for irrigation, enhancing resilience to rainfall variability.
- The IAA system showed a reduction in fertilizer and pesticide use and maximized land and water resources, enhancing the overall efficiency of the system.

Adaptation Potentials of the System

IAA improved on-farm water management and efficiency, leading to increased rice and fish outputs. This method enhances climate resilience by enabling

irrigation using pond water during water scarcity. The system's versatility maximizes land use and minimizes input requirements, resulting into:

- Increased outputs of rice and fish compared to monoculture.
- Reduced fertilizer and pesticide dependence.
- Increased resilience to water scarcity.
- Efficient land utilization through multiple production systems.

Mitigation Options of the System

The IAA system offers climate mitigation opportunities. The rice-fish system approach of this project utilizes fish waste and farm by-products as fertilizers and feed. This approach mitigates greenhouse gas emissions and avoids emissions linked to fertilizers and feed production. Proper waste management decreases emissions and enhances sustainability.

- Utilization of IAA waste for low-cost, quality fish feed production.
- Reduction in emissions from waste decomposition.

- Effective waste management leading to reduced GHG emissions.



A rice-fish farm stocked with fish in [Nigeria](#)



A project beneficiary family rice-fish farm recently modified for integrated rice-fish farming in Ebonyi state, [Nigeria](#)

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Conclusion

IAA represents a climate-smart approach by minimizing waste, boosting productivity, and reducing external input dependence. The system's potential to lower greenhouse gas emissions and enhance climate resilience makes it a valuable tool for sustainable land use.

Project Implementation Team

Lead PI: Matthias Halwart, PhD
Food and Agriculture Organization of the United Nations

Lead Co-PI: Xinhua Yuan, PhD
Food and Agriculture Organization of the United Nations

Nigeria PI: Emmanuel K. Ajani, PhD
University of Ibadan

Nigeria Co-PI: Bamidele O. Omitoyin, PhD
University of Ibadan

U.S. PI: Amrit Bart, PhD
University of Georgia

U.S. Co-PI: Esendugue G. Fonsah, PhD
University of Georgia

U.S. Co-PIs: Gary Burtle, PhD
University of Georgia

Project Coordinator: Oluwafemi Ajayi
Food and Agriculture Organization of the United Nations

Recommendations – Policy Implications:

Incorporate IAA in Policies: Consideration to integrate IAA into national agriculture and food policies, with a focus on smallholder farmers. Extension programs should provide training, resources, and finance for IAA implementation.

Support Resource-Poor Farmers: Prioritize resource-poor small-scale farmers' access to IAA training and resources. Facilitate their adoption of suitable IAA practices through targeted support.

Customize Policies: Recognize local contexts and livelihood strategies while formulating national policies to encourage IAA adoption.

Promote IAA Types: Encourage adoption of suitable IAA types, particularly rice-fish and rice field fishery-based systems, as alternatives to conventional aquaculture.

Strengthen Environmental Regulations: Implement robust environmental regulations and enforcement mechanisms to support IAA adoption and minimize environmental impacts.

By embracing IAA practices and integrating them into policies, Nigeria can enhance food security, climate resilience, and sustainable land use, benefiting both farmers and the environment.

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Leveraging Integrated Rice-Fish Farming for Rural Prosperity

The integration of rice-fish culture technology offers a holistic solution to multiple challenges within rural agricultural systems. This policy brief underscores the transformative potential of this approach, highlighting its implications for food security, sustainable agriculture, rural livelihoods, biodiversity conservation, and climate resilience. To fully realize the benefits, policymakers must focus on incentivizing adoption, promoting research and capacity building, facilitating market access, and implementing regulations to ensure the quality and value of integrated rice-fish products.



How Can Rice-Fish Farming Contribute to Rural Prosperity

- **Enhancing Food Security:** Integrated rice-fish culture technology diversifies agricultural practices, ensuring a stable food supply by augmenting both rice and fish production. This addresses nutritional needs and enhances community resilience against food security-related challenges, making it a vital component of food security strategies.
- **Promoting Sustainable Agriculture:** By efficiently utilizing resources and reducing reliance on chemical inputs, integrated systems minimize ecological footprints and mitigate environmental impacts. Policymakers should prioritize policies that encourage resource efficiency and sustainable practices to support the long-term health of agricultural ecosystems.
- **Boosting Rural Livelihoods:** Integrated rice-fish culture creates supplementary income streams for farmers, particularly in regions with limited land and water resources. Policymakers should facilitate market connections, value chains, and training to ensure equitable access to markets and economic uplift for rural communities.
- **Safeguarding Biodiversity:** The intricate ecosystems of integrated rice-fish culture contribute to enhanced biodiversity by accommodating diverse fish species, rice varieties, and aquatic organisms. Investments in research, extension services, and farmer training are necessary to maximize these benefits while conserving aquatic biodiversity.
- **Enhancing Climate Resilience:** The diversified income streams and ecosystem services of integrated systems can counteract the challenges posed by climate change. Policymakers should align policies to bolster climate resilience through capacity building, research, and encouraging practices that contribute to climate adaptation.



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Policy Implications of Rice-Fish Farming for Rural Development

An integrated approach to rice-fish culture technology holds profound policy implications, particularly within rural households. These implications underscore the manifold advantages of fostering such integrated systems, while also emphasizing the multifaceted considerations that policymakers must address to ensure its seamless integration and successful implementation.

Central to these implications is the pivotal role of enhancing food security. By diversifying agricultural practices and augmenting the availability of both rice and fish, vital sources of carbohydrates, proteins, and micronutrients, this technology contributes significantly to ensuring a stable food supply. This is essential for addressing nutritional needs and bolstering the resilience of communities against food-related challenges.

Furthermore, the adoption of this innovative technology actively promotes the principles of sustainable agriculture. Through the judicious utilization of resources, it fosters heightened resource efficiency and concurrently diminishes the reliance on chemical inputs. In effect, this reduces the ecological footprint of agricultural activities and mitigates potential environmental repercussions.

A noteworthy aspect of this integrated approach is its positive impact on rural livelihoods. By creating supplementary income streams, especially in regions constrained by limited land and water resources, it imparts a substantial economic uplift to farmers. This holds the potential to alleviate economic pressures and enhance overall quality of life in these communities.

Policymakers stand to orchestrate instrumental changes that further amplify the benefits of integrated rice-fish culture technology. By crafting policies that incentivize the prudent use of water resources, the integration of rice and fish production optimizes water allocation and minimizes wastage. This aligns seamlessly with broader water conservation goals, contributing to the sustainable management of this finite resource. In essence, embracing integrated rice-fish culture technology transcends agricultural innovation; it embodies a holistic approach that encompasses food security, sustainable practices, and rural prosperity. By integrating these facets into policy frameworks, governments can usher in a new era of resilient, productive, and ecologically conscious agricultural systems.

Integrated rice-fish culture stands as a promising approach to safeguarding aquatic biodiversity. By establishing intricate ecosystems that accommodate a range of fish species, rice varieties, and aquatic organisms, this practice plays a pivotal role in enhanced biodiversity. To ensure the realization of its benefits, governments should consider substantial investments in research, extension services, and farmer training. Educating farmers on the nuanced advantages, and techniques of integrated rice-fish culture becomes paramount.

Facilitating policy support emerges as a vital component, facilitating the formation of market connections and value chains for both rice and fish products. This, in turn, guarantees equitable access to markets and fair remuneration for farmers' diligent efforts. The holistic implications of integrated rice-fish culture extend to bolstering climate resilience. The diversification of income streams for farmers coupled with amplified ecosystem services can potentially counteract the adversities posed by climate change.

Effective governance can be demonstrated through the implementation of regulations and benchmarks, thereby ensuring the value of rice and fish products originating from integrated culture systems. Equally crucial is the upskilling of farmers, extension workers, and stakeholders involved. By investing in capacity-building programs, policy makers can elevate the expertise and understanding of those engaged in integrated rice-fish culture.

The trajectory towards successful adoption of integrated rice-fish technology hinges upon strategic allocation of resources. Prioritizing research and development fosters enhanced comprehension, innovation, and optimization of integrated systems. Productivity, sustainability, and environmental implications warrant dedicated attention in these endeavours. The dissemination of practical knowledge and skill refinement, achieved through strengthened extension services, forms the bedrock for effective integration. It is evident that a multi-faceted approach, entailing education, policy backing, capacity enhancement, and research, is imperative for the integration of rice-fish culture into prevailing practices.

Project Implementation Team

Lead PI: Matthias Halwart, PhD
Food and Agriculture Organization of the United Nations

Lead Co-PI: Xinhua Yuan, PhD
Food and Agriculture Organization of the United Nations

Nigeria PI: Emmanuel K. Ajani, PhD
University of Ibadan

Nigeria Co-PI: Bamidele O. Omitoyin, PhD
University of Ibadan

U.S. PI: Amrit Bart, PhD
University of Georgia

U.S. Co-PI: Esendugue G. Fonsah, PhD
University of Georgia

U.S. Co-PIs: Gary Burtle, PhD
University of Georgia

Project Coordinator: Oluwafemi Ajayi
Food and Agriculture Organization of the United Nations



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Policy Recommendations for Improving Rural Prosperity through Rice-Fish Farming

Educational Initiatives: Awareness/educational campaigns to educate farmers about the benefits, techniques, and advantages of integrated rice-fish culture technology. This will increase awareness and drive adoption.

Incentivize Adoption: By initiating programmes that provide incentives for farmers to adopt integrated rice-fish culture technology, such as rice seed and fish seed subsidies, grants for rice field modification to include fish farming, and tax benefits.

Resource Allocation: Prioritize funding for research, extension services, and training programs to support successful integration of rice-fish culture into prevailing agricultural practices.



Farmer removing weeds/preparing rice field for rice-fish farming in Myanmar

Market Access and Value Chains:

The goal is to establish connections and value chains in the market for rice and fish products from integrated systems. This aims to ensure fair remuneration for farmers and equitable market access. A survey conducted during the introduction of the integrated fish-rice production system examined consumers' willingness to pay and their preferences for consuming rice and fish from the same field. The results showed that a majority of consumers (82.39%) are inclined to purchase local fish if it's easily accessible, as opposed to foreign alternatives.

Research and Capacity Building: Allocate resources to research and development to optimize integrated systems for productivity, sustainability, and environmental benefits. Invest in capacity-building programs for farmers, extension workers, and stakeholders to ensure effective implementation. Specific capacity-building activities on fish hatcheries (fish seed production- ricefield nurseries) that could be implemented by farmers such as will serve the needs of rural farmers.

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Annex 26: Policy Brief 4: New Development Frontier: Unlocking the potential of rice field fisheries (RFF) in Nigeria



Policy Brief 4: 2023

New Development Frontier: Unlocking the Potential of Rice Field Fisheries (RFF) in Nigeria

Rice Field Fisheries: A Rich Resource

Rice field fisheries encompass the capture, collection, and harvest of fish, as well as other aquatic organisms and plants naturally inhabiting rice field agroecosystems. Nigeria's rain-fed and flooded rice fields serve as essential and productive reservoirs of aquatic life, including fish, frogs, snails, crickets, and more.

Tradition and Innovation in RFF

Research into aquatic biodiversity, carried out under the USAID/FIL project on farm diversification, has illuminated the practice of rice field fisheries in Nigeria. Indigenous utilization of these resources has persisted for over a century, spanning four generations of rice-farming families. This long-standing tradition underscores the historical significance of gathering aquatic products from rice fields for sustenance. However, this practice remains relatively primitive, with substantial untapped potential awaiting exploitation through innovative approaches to rice field fisheries management.

A century of Indigenous management of fish in rice fields in Kebbi State

The indigenous culture of cultivating naturally-occurring fish within rice fields is deeply rooted in Kebbi State and extends back for more than a century. Though precise years are elusive, this practice has persevered through generations, dating back as far as their history of rice cultivation. This historical continuity underscores the profound connection between local heritage and the sustainable exploitation of aquatic resources in rice fields.

Unleashing Opportunities for Sustainable Growth

Rice field fisheries present an unexplored avenue for bolstering food security, safeguarding cultural heritage, and upholding rural livelihoods. To unlock this potential, a holistic strategy is essential. This approach must encompass sustainable management practices, capacity enhancement, research, regulatory frameworks, and community involvement. By fostering collaborative partnerships among stakeholders and harnessing indigenous knowledge, Nigeria can ensure the enduring advantages of rice field fisheries while concurrently protecting its rice field agro-ecosystems from decline.



Children using their hands to catch fish in a rice field



A recently flooded rice field in Nigeria



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Overview of RFF Management in Kebbi

During periods of rainfall or when rice fields become inundated by nearby rivers, fish are drawn into the rice fields. Rather than immediately harvesting or collecting them, farmers often opt to let the fish grow to a larger size, a process that typically spans around three months. In this system, farmers sometimes create dug-out areas within their rice fields to provide ample space for fish to grow.

Upon rice harvesting, farmers excavate holes within the rice field or at water drainage points, where they gather both water and fish. Subsequent to the rice harvest, farmers return to retrieve the fish using nets. This practice recurs annually, mainly during the rainy season, which typically falls between May, June, and July. Harvesting usually occurs around October or November. The fish are allowed to develop naturally in the rice field ecosystem without supplementary feeding.

Diverse aquatic life, including different fish species, snails, and crabs, are observed within these rice field ecosystems. The collection of these aquatic resources contributes to household consumption. In instances where fish attain substantial size, some farmers opt to sell them for economic gain.



A person searching for aquatic animals in a rice field

In Argungu, Kebbi State, a distinct fish species habitually enters rice fields and hibernates within rice fields. This fish remains dormant within the rice fields even as floodwaters recede. These fish emerge when farmers transition to dry-season rice cultivation, proving valuable as a food source in times when other fish are scarce.

Each farming household in the community has access to these aquatic resources within their own plots. A collective respect for individual farm ownership prevents unauthorized harvesting from others' fields. Given the prevalence of rice farming and similar practices, there's a shared understanding that cross-field harvesting is unnecessary.

In Wawa, Kebbi State, a participant shared how he integrated the traditional indigenous approach with the rice-fish integration techniques he learned from the farm diversification project. He dug trenches in his fields, allowing fish to naturally enter during floods or rain. Additionally, he introduced fish seed and cultivated them alongside the naturally entering fish. This combination exemplifies a collaborative fusion of local practices with modern methodologies.

Overview of RFF Approach in Ebonyi State

Contrasting the practices in Kebbi, the system of rice field fisheries (RFF) management in Ebonyi State takes on a different form. In this region, aquatic resources from rice fields are collected as soon as they are spotted. In this setup, there isn't a deliberate effort to cultivate fish for growth to larger sizes.

This practice is open to everyone within the community. Anyone can collect fish, crickets, crabs, and other aquatic organisms found in the rice fields for personal household consumption. The collected resources are primarily intended for domestic use and are not typically sold.

Abundant during the rainy season, these aquatic resources become particularly prevalent. However, some individuals report scarcity during the dry season. In some instances, individuals set hooks in the rice fields, leaving them overnight with the expectation of catching fish.

Core Components of the Rice Field Fisheries System in Nigeria

Floodplain Rice Fields denote submerged rice agro-ecosystems where fish disperse during flooding seasons to feed and breed. These areas serve as habitats for fish and other aquatic animals that can be harvested.

Fish Refuge act as designated areas within the rice field ecosystems that offer protection and sanctuary to fish.



A rice field with a fish refuge



A fishhook placed in a rice field to catch fish overnight

Key Phases and Activities to Promote RFF System:

The strategy below delineates the fundamental components of the Rice Field Fisheries (RFF) system that could be applied to promote the system in Nigeria. It addresses challenges, presents solutions, and outlines the essential phases and activities crucial for its sustainable management. Developing a sustainable RFF management approach involves three distinct phases:

1. Site Identification: Wetland areas and flooded plains

2. Needs Assessment and Action Planning:

- Evaluate available resources ((water (nearby lakes, rivers, dam), fish stock, rainfall pattern, farming seasons) through stakeholder analysis.
- Formulate a practical vision for RFF spanning at least 3 to 5 years.
- Create an action plan to aid communities in realizing the established RFF vision.
- Establish a Monitoring and Evaluation framework to document progress.

3. Intervention and Management Process:

- Raise awareness about RFF.
- Build capacities (practical knowledge of fish management) among stakeholders.
- Enhance water channels for improved RFF conditions.
- Redesign rice field systems (creating fish refuge, enhancing water flows) to support aquatic life.
- Manage fish stocks effectively.
- Regulate aquatic plant growth to balance the agroecosystem.
- Evaluate the level of aquatic resource utilization for individual/home consumption and use.
- Follow up on advancements in livelihood enhancements of farming families.

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Policy Recommendations

Promote Sustainable Management:

- Encourage the adoption of best practices, such as maintaining appropriate water depths and reducing pesticide usage, to safeguard the health of aquatic ecosystems.

Project Implementation Team

Lead PI: Matthias Halwart, PhD
Food and Agriculture Organization of the United Nations

Lead Co-PI: Xinhua Yuan, PhD
Food and Agriculture Organization of the United Nations

Nigeria PI: Emmanuel K. Ajani, PhD
University of Ibadan

Nigeria Co-PI: Bamidele O. Omitoyin, PhD
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U.S. PI: Amrit Bart, PhD
University of Georgia

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University of Georgia

U.S. Co-PIs: Gary Burtle, PhD
University of Georgia

Project Coordinator: Oluwafemi Ajayi
Food and Agriculture Organization of the United Nations

Enhance Capacity Building:

- Implement comprehensive training and awareness initiatives for farmers, highlighting the advantages of allowing fish to grow before harvesting in sustainable RFF practices.
- Collaborate closely with agricultural extension services to disseminate knowledge and techniques that underscore responsible RFF methods.

Prioritize Research and Data Collection:

- Allocate resources for research aimed at comprehending the ecological interactions of RFF and its potential contributions to overall fish production.
- Gather comprehensive data on fish populations, species diversity, and the general health of ecosystems to facilitate informed decision-making based on evidence.

Foster Community Engagement:

- Encourage active participation from local communities in drafting RFF management plans, ensuring that their unique knowledge and needs are integral to the process.
- Establish dedicated platforms for dialogue that brings together government agencies, researchers, and community members to facilitate effective and collaborative resource management.

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