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ASSESSING THE FEASIBILITY OF A SELECTIVE BREEDING PROGRAMME FOR AFRICAN CATFISH IN NIGERIA

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ABSTRACT

African catfish (*Clarias gariepinus*) is an important aquaculture species in Africa. However, this species has not yet been improved by selective breeding in Nigeria. This project assessed the viability of developing and maintaining a Nigerian selective breeding programme and broodstock bank for African catfish. Farmer's perceptions of a programme were evaluated via questionnaires and a potential pilot breeding programme to facilitate implementing future selective breeding was outlined. The questionnaire showed a very positive response. Of 88 respondents 97% indicated willingness to participate in a breeding programme. Most respondents (98%) have experience in selective breeding. Furthermore, many (97%) are willing to serve as multiplication centres to produce selectively improved fingerlings and nearly all (99%) are willing to grow these. Willingness to support the programme was indicated through the purchase of fingerling (86%), feed supply (21%), provisioning of personnel (14%) or infrastructure (11%) and direct financial support (9%). A small pilot breeding programme is proposed. Specifically, a synthetic population with large genetic variation could result from crossings within and between four wild populations. Families could be raised as family units until individuals are tagged. Thereafter, individuals can be pooled in tanks to minimise environmental effects. Pedigrees can be recorded to track co-ancestry. The selection can follow a combination of between- and within- family selection, each based on animal-model-derived best linear unbiased predictors for both mass-at-slaughter and familial survival rate; this latter may negatively covary with cannibalism rate. Allocation of mating pairs among selected individuals could ideally follow optimal contribution selection theory, optimising genetic gain while controlling inbreeding.

TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Fish is a major source of protein for humans. In 2020, fish provided 3.3 billion people worldwide with almost 20% of their average per capita intake of animal protein. In 2017, fish accounted for about 17% of total animal protein, and 7% of all protein, consumed globally (FAO, 2020). However, most fishing areas are experiencing declines in fishing yield and there is a low likelihood that substantial future increases will be possible (FAO, 2020). An alternative to secure future availability of fish is to increase aquaculture production. Currently, aquaculture is a leading source of aquatic food, contributing an estimated 114.5 million tonnes of animal protein to the world food intake (FAO, 2020). In 2018, inland aquaculture produced 51.3 million tonnes of aquatic animals, and accounted thus for 62.5% of the world's farmed food fish production (FAO, 2020).

Africa currently contributes roughly 17% to the world aquaculture production, and Nigeria is one of the major aquaculture countries on the continent. Nigeria produces 40.5% of the fish cultured in Sub-Saharan Africa at approximately 307,000 metric tonnes per year, ranking 20th in global aquaculture fish production (FAO, 2020). One of the reasons may be that Nigeria has both a long coastline bordering the Atlantic Ocean and an extensive network of inland river systems (Oluwatobi, *et al.*, 2017). In the past, development of the Nigerian aquaculture industry was strongly supported by the government. In recent years, investment in aquaculture in Nigeria has transitioned towards more private investment (FAO, 2017). Most of the production of fish feed and fingerlings and grow-out facilities are privately owned and operated. Nigerian commercial fish culture is dominated by two major groups, namely two catfishes (*Clarias* and *Heterobranchus* species and their hybrids) as well as several tilapia species.

The African catfish (*C. gariepinus*) is highly suitable for aquaculture. It is omnivorous, accepts supplementary feeds, has a high disease resistance, grows rapidly, shows ease of adaptability to culture systems, and tolerates relatively poor water quality. These traits make the African catfish an excellent choice for fish farmers (El-feky, Essa, Osman, Shalaby, & Moustafa, 2017). Production usually starts with artificial fertilisation to produce fry, which are either produced directly by grow-out farmers, or by specialised hatcheries. The fry are then raised to fingerling size, again directly, by specialised fingerling or grow-out farms. The fingerlings are usually raised using commercial feed until reaching table size (~500g), which may take 4-6 months. African catfish is consumed fresh or after preservation through smoking. Broodstock fish are raised to larger sizes, often weighing over 1kg.

The growth of Nigerian aquaculture can be linked to increasing catfish production. However, presently this growth is challenged by an insufficient supply of high-quality fingerlings (Fawole, *et al.*, 2020). To increase the availability of fry or fingerlings to the industry, the development of protocols for hatchery techniques to enhance fry, and eventually fingerling, production through hypophysation, induced spawning by hormone injection, was a major step (Moehl, Randall, Mulonda, & André, 2006). Nonetheless, the demand for catfish fingerlings by farmers still often exceeds the supply provided by hatcheries. It is likely due to this high demand that many small-scale hatcheries appear to pay little attention to the quality of the fingerlings they produce. Lacking high-quality fingerlings, many small-scale grow out farmers are discouraged from investing in catfish aquaculture. There is no broodstock bank in Nigeria. This hampers sustainable catfish aquaculture via the management of broodstock and thereby the prevention of possible inbreeding of existing broodstock. Many fish hatcheries in Nigeria use catfish of the same or unknown parentage, which may result, or may already have resulted, in inbreeding over several generations which can lead to a reduction in overall production in the aquaculture industry (Olaleye, 2005). Such a reduction may be underlaid by an inbreeding-related lower genetic and thus phenotypic variation or even an inbreeding depression when deleterious recessive alleles express at the homozygous state. Such a deterioration of genetic quality resulting from inappropriate broodstock was observed in Indonesia before 2010 and spurred the establishment of an Indonesian African catfish breeding programme (Imron, Iswanto, Suparapto, & Marnis, 2020).

Previously, the Nigerian government has supported the aquaculture industry by organizing various training programmes along the aquaculture value chain for youth and women. Also, various forms of technical assistance have come to Nigeria from internal and bilateral development partners. Various donor organizations and investors, such as the United Nations Food and Agricultural Organization, the African Union, the European Union, the World Bank, the African Development Bank, and WorldFish, have also worked toward aquaculture development in Nigeria. To increase the quality of fry and fingerlings and develop a broodstock bank for Nigerian aquaculture, a broodstock production and multiplication programme project was initiated in 2017 by the West Africa Agricultural Productivity Programme in collaboration with the federal government, research institutions, and private hatcheries. Within this programme, effects of population crossing on early traits (fertilisation success, hatch rate, survival of fry) and growth thereafter were evaluated, with some between-population crossing showing superior performance for growth (Iwalewa, et al., 2017, Yisa, *et al*., 2017). However, the evaluation was limited to the F1 generation and no breeding programme was implemented.

Despite previous efforts, Nigeria has a shortage of good quality, selectively bred, fingerlings and lacks a broodstock bank for cultured fish species, including African catfish. Sustainability has been a major problem for some aquaculture initiatives. To allow for the continuation of previous efforts and ensure success, perspectives of stakeholders in the aquaculture value chain should be taken into consideration, along with an assessment of their willingness to participate in the establishment and operation of a broodstock programme. This may be especially important because private farmers are key players in the aquaculture industry in Nigeria. The partnership between the government and the private sector can reduce the governmental capital costs and help to bridge the gap between infrastructure and service needs and governmental financial capacity.

To that end, this project seeks to assess the feasibility and sustainability of developing and maintaining a Nigerian selective breeding programme that also acts as a broodstock bank for African catfish. The final goal of such a programme is to provide better fingerlings and broodstock to farmers, and thereby increase aquaculture production and secure fish food availability. The current project focuses on logistic and equipment requirements and farmer acceptance of such a programme to move closer to future successful implementation of a selective breeding programme in Nigeria. However, an assessment of logistics and equipment is only possible when the size and specifics of a breeding programme have been decided upon. Thus, the current project will also elaborate on some of the science and methods associated with initiating a breeding programme and apply these to African catfish production in Nigeria.

1.1 Statement of problem

Demand for catfish fingerling in Nigeria frequently surpasses hatchery supply (Adewunmi, 2015). Although there are several federal and state-owned hatcheries, most of them are in a state of disrepair or produce below capacity. Most catfish fingerling and broodstock production originates from private small-scale operators and a few large commercial farms, creating an opportunity for additional private investment in fingerling and broodstock production. Most private farmers do not keep records of their own broodstock and breeding pairs on their farms. Many fish hatcheries are unconcerned with the source of the broodstock they use, and no documentation is made of individual breeding pairs. Lack of record keeping of broodstock source, age, and family line, combined with the resulting practice of mating highly related catfish parents, is risking a lower genetic and phenotypic variation for production traits in subsequent generations and inbreeding depression over multiple generations and thereby a decrease in total productivity (Ibiwoye & Thorarensen, 2017). Availability of high-quality catfish broodstock and fingerling in large quantities is critical to the development and sustainability of Nigeria's growing catfish industry (Adeleke, Robertson-Andersson, Moodley, & Taylor, 2021).

1.2 Research objective

The overall objective of this project is to design a model for a viable selective breeding programme for *C. gariepinus*. This will support the long-term goal to establish hatcheries that serve as multiplication centres across the Nigerian agroecological regions relevant to catfish aquaculture. To achieve this overall objective, the project will focus on the following specific tasks:

- Deliver questionnaires to assess stakeholder’s (grow-out farmers and multiplier hatcheries) perception on the establishment of a broodstock bank that performs selective breeding in *C. gariepinus*.
- Design a small-scale pilot breeding programme to determine key parameters required for selective breeding and thereby facilitate a future implementation of the practices necessary for a pedigree-based selective breeding programme.

2 LITERATURE REVIEW

Modern animal breeding practices, including the development and application of quantitative genetics to animal production, started at the beginning of the last century (Lhorente *et. al.*, 2019). Genetic improvement is a cost-effective and efficient way to increase fish production (Gjedrem *et al.*, 2012). Genetic improvement in aquaculture species, however, lags far behind those practised in plants and farm animals. This may be because less is known about the management and control of the complete, often complex, reproductive cycle of aquaculture animals in captivity when compared to land-based animals (Gjedrem & Baranski 2010). However, control of the complete life cycle is an essential requirement to establish any formal breeding programme (Rye, Gjerde, & Gjerde, 2010). The first family-based breeding programme started in 1975 with crossing of wild salmon strains in Norway (Gjedrem, 2010). Since then, at least 35 fish species have genetically been improved around the world, including Atlantic salmon (*Salmo salar*) rainbow trout (*Oncorhynchus mykiss*), tilapia (*Oreochromis niloticus*), coho salmon *(Oncorhynchus kisutch*) and common carp (*Cyprinus carpio*) (Gjedrem, 2010). Globally, there has been an enormous increase in the number of aquaculture breeding programmes of other groups and in 2010 up to 104 programmes in 20 species were reported (Neira, 2010; Rye, Gjerde, & Gjerde, 2010). These species were preliminary fish (82.6%), molluscs (8.2%) and crustaceans (8.2%). Sixty-two of the breeding programmes are situated in developed countries (Rye, Gjerde, & Gjerde, 2010), and forty-two were established in developing countries (Neira 2010).

2.1 Establishment of a base population

When starting a breeding programme, one of the first steps is to create a population with a large genetic variation. The population with a large genetic diversity serves to increase the long-term genetic responses to selection, while allowing for minimum inbreeding. Ignoring the low frequency of new mutations, the genetic diversity of the base population is the only source of genetic variation upon which the selective breeding will act, unless new individuals with a different genetic background are added at later generations.

Different strategies exist for building strong base populations:

- If only wild animals are accessible, broodstock should be chosen from at least four genetically diverse strains or populations.
- In a situation where farm broodstock are available but there is no record of the pedigree, it is better to include other farm strains or wild populations in the breeding programme to minimise inbreeding (here, effects due to crossbreeding as described below may play a role initially).
- If known pedigree broodstock is available, the existing level of inbreeding and effective population numbers should be determined to assess whether additions from other farms or wild populations are required. In lack of pedigrees, existing inbreeding can be estimated by employing costly genomic methods (Gjedrem & Baranski, 2010).

The first mating following the collection of broodstock from various strains can be at random within strains. In the second generation, a synthetic population with high genetic diversity can be formed by crossing between strains (Gjedrem & Baranski, 2010)

For example, in the case of the Norwegian breeding programme for Atlantic salmon, which initiated in 1975, the base generation was selected from eight to twenty-four river strains. For each strain, the aim was to use four males (sires) and 12 females (dams) to produce four paternal half-sibling groups and a total of 12 families. The synthetic base population was then formed by random mating within and between strains. Progeny from this base population were selected for body mass at harvest both across and within families. For subsequent generations, random mating of only selected breeders was carried out with attention paid to not mate closely related animals i.e., full or half siblings (Gjedrem, 2010).

In the Genetic Improvement of Farm Tilapia (GIFT) programme began in 1998 and was carried out in the Philippines, the process used for selection of the base population was different. The base population came from five geographic locations (Egypt, Ghana, Senegal, Kenya, and the Philippines). Eight unrelated strains were used, consisting of four wild strains from Africa and four from the Philippines. The first mating was done within strains, whereas for the second mating, a completer 8 x 8 diallel cross was made to produce 64 crosses (Bentsen, et al., 2017)

In a selective breeding programme for rohu carp *(Labeo rohit*a) that was performed between 1992 and 2003 in India at CIFA (Central Institute of Freshwater Aquaculture), the base population originated from a local farm stock and six river strains. Mating was then performed randomly both between and within strains (Gjerde, et al., 2019).

The genetic stock improvement programme of silver barb (*Barbodes gonionotus*) was initiated in 1996 at Bangladesh Fisheries Research Institute. It began with three geographical distinct farm stocks from Indonesia, Thailand, and Bangladesh, and a mass selection technique was carried out through the seventh generation (Rahman, Sarder, Nishat, Islam, & Kohinoor, 2021).

2.2 Approaches to breeding programmes

In various breeding programmes around the world, selective breeding, and crossbreeding (also called "hybridisation") are the two traditional approaches that have been used for thousands of years to improve all major crops and livestock grown by farmers.

Selective breeding

Selective breeding aims to improve specific traits of a population by selecting and mating only the best performing individuals for the selected traits (biggest, heaviest, most desirable colour, etc.) in the hopes that the offspring of the select brood fish will inherit the desired characteristics. Selective breeding programmes provide the opportunity for ongoing genetic gain that can be permanent, with gains passed on across generations. This happens if the selected traits have a genetic variation within the population and selection affects the genetic values underlying the traits. The genetic advantages gained in a breeding nucleus can be amplified and manifested in the thousands, or millions of progenies produced.

Crossbreeding

Crossbreeding is a method that aims to mate combinations between divergent populations to result in superior progeny, known as hybrid vigour (aka heterosis). Even though crossbreeding is a tried-and-true strategy to enhance traits, the results of crossbreeding are usually difficult to predict. Hence, producing superior progeny via crossbreeding is not guaranteed. Many population or strain combinations must be tested until hybrid vigour is established. To date, much of the breeding work in aquaculture has been devoted to hybridisation among especially tilapia species to produce all-male hybrids for grow-out. A disadvantage of crossbreeding is that all the crossbred lines must be maintained separately, and the hybrid lines must be re-created for every new cohort. Further, hybrid vigour may in many cases require that one or both lines are inbred, and the hybrid vigour may then be viewed as recovery from inbreeding depression. Therefore, this approach will not be further pursued here for African catfish.

2.3 Broodstock sourcing and management

Healthy brood fish are a prerequisite for all breeding programmes, as healthy eggs and milt are required to produce offspring. Broodstock sourcing is thus one of the most important elements of the hatchery production system. Broodstock management refers to all the steps taken by farmers to allow a captive group of animals to go through reproductive maturation and spawning to produce fertilised eggs (Mylonas, Fostier, & Zanuy, 2010). The management involves the care and physical handling of brood fish during production and management of the genetic integrity of the brood fish, such as minimisation of inbreeding (De Silva, Ingram, & Wilkinson, 2015). Because Nigerian farmers already have experience in successfully growing this species, this aspect of a breeding programme will not be further explored here, except for issues of inbreeding, which are covered separately.

2.4 Broodstock husbandry

Poor hatchery management practices such as inadequate transportation, rough handling, poor cleaning, overcrowding, misuse of chemicals, and poor water quality are all stressors that can have a negative impact on fish breeding (Bromage, 1995; Schreck, Olla, & Davis, 1997; Adebayo, 2006; Okanlawon, (2010). A stressful reproductive environment reduces broodfish reproductive performance (Gebregeziabhear & Ameha, 2015; Adebayo, 2006; Ayinla, 1991). Therefore, fish husbandry practices that minimise stress, and which are often specific to each species, are of great advantage to the success and sustainability of a broodstock bank and selective breeding programme. As Nigerian farmers already have experience in successfully growing this species, this aspect of a breeding programme will not be further explored here.

2.5 Broodstock feed and feeding regime

Broodstock require high-quality feed, since adequate broodstock nutrition is required to enhance reproductive performance of cultured species. Dietary composition influences parameters relevant to breeding, such as weight gain and proximate composition of brood fish, quantity and quality of eggs and larval viability (Migaud, et al., 2013). The quality of the dietary protein also affects ovary size and viability of the eggs produced (Sarih, et al., 2020). A good broodfish feeding regime not only leads to successful spawning, but also confers a superior health and growth potential of the progeny. Like for the previous points, Nigerian farmers already have experience in successfully growing this species, and this aspect of a breeding programme will not be further deepened here.

2.6 Record keeping

Record keeping is an important aspect of any aquaculture venture. Many fish hatcheries in Nigeria source brood fish from other farms and are not aware of the primary source. Some farms have no documentation on individual breeding pairs. Record keeping for effective broodstock management requires the identification of all families and individuals. Identification can be reached by keeping families or individuals separate, or by tagging families or individuals.

2.7 Control of inbreeding

The mating of closely related individuals or organisms through common ancestry can have a negative impact on fitness, survival, growth rate, the frequency of deformities, and genetic variance (Gjedrem, Robinson, & Rye, 2012). Fish have distinct reproductive characteristics that allow for phenotyping many offspring per parent, which in turn allows for accurate estimation of breeding values and high selection intensities that result in high selection responses for a given heritability of a trait. However, high selection intensities may result in rapid inbreeding. Inbreeding can jeopardize further genetic improvement by reducing genetic variance in the population, reducing fitness and performance, and producing highly variable selection responses (Falconer & Mackay, 1996). Measures for restricting inbreeding are therefore of paramount importance in any breeding programme.

Inbreeding is described by the inbreeding coefficient (F). For an individual, it is expressed as the quantity of inbreeding that has accumulated starting at a certain point in the individual's ancestry. The inbreeding coefficient is the probability that two alleles at any locus in an individual are identical by descent (i.e., both alleles can be traced back to a single common origin). The inbreeding coefficient can be estimated based on pedigree information.

2.8 Effective breeding number

Effective breeding number (N_e) indicates the genetic stability or genetic health of the population. N_e is inversely related to inbreeding and to genetic drift. The effective breeding number is determined by the number of male and female brood fish that produce viable offspring, the sex ratio of the brood fish that spawned, the variance of family size, and the mating system that is used.

The effective breeding number can be calculated using the equation:

$$N_e = \frac{4(\text{Number of males})\ (\text{Number of females})}{\text{Number of males} + \text{Number of females}}$$

Long-term inbreeding and loss of genetic variability because of genetic drift may affect performance and hinder genetic progress. A sufficiently large and genetically diverse breeding population with appropriate family structure is therefore fundamental when establishing and running a selective breeding programme. The effective population size is negatively related to the selection intensity and thus may limit the applied selection intensity in the long term.

2.9 Initiating a selective breeding programme for catfish in Nigeria and the benefits

A selective breeding programme in fish can improve any trait that shows genetic variance. Examples are improvement in growth and feed conversion ratio, increase in survival rate increase in immunity of the offspring and that can translate into better market for production; all of which increase the production efficiency of the farm and in substantial increase in farm profitability (Gjedrem, 2016).

An initial selective breeding programme for catfish may first focus on traits that can directly be determine for individuals kept at the breeding station (rather than on siblings), such as familial and individual growth rates and familial survival rates (a mixture of reduced cannibalism and increased robustness).

Consideration is given to the following:

a) selection of source (river) populations (and individuals within populations) that contribute to the base population,
b) deciding on an effective population size,
c) standardised husbandry practices and trait recording procedures,
d) statistical estimation of the breeding values and selection of breeders,
e) required additional investment in test facilities,
f) assessment whether a market exists for selectively improved fry or fingerlings,
g) contracts with test stations and potential future multipliers and, lastly,
h) possibilities for self-funding of the breeding project past an initial funding period.

2.10 Public private partnership in a selective breeding programme for catfish in Nigeria

It is beneficial to the success of the breeding programme to involve fish farmers early in the process of its initiation. This firstly ensures that needs of fish farmers are properly addressed and secondly secures the trust of fish farmers into, and support for, the programme. Importantly, private farmers hold the facilities that can serve as potential future multipliers for the selective breeding programme. Public–private partnerships (PPPs) create a relationship to allocate the risks to those best able to manage them and to add value to public services by using private sector skills and competence (Weirowski & Hall, 2008). Such beneficial effects are exemplified in several livestock species, which have had successful breeding programmes in the hands of farmer cooperatives around the world, and which were frequently initiated or run with governmental support. Public-private investments in researching and developing genetically improved fish strains have the potential to provide attractive economic returns to the private sector and to meet a public need for improved seed quality (Weirowski & Hall, 2008). Private pioneers have played an essential role in the development of breeds and breeding programmes in several circumstances. For example, the Genetic Improvement of Farmed Tilapia (GIFT) project implemented by WorldFish and its partners in the Philippines and Norway was the first major genetic improvement programme for tropical finfish. This latter is also an example of a public-funded collaboration that evolved into a private-sector collaboration. One of the goals of the here proposed project for the Nigerian catfish sector is such public-private collaboration, which is in line with United Nations Sustainable Development Goals.

3 METHODOLOGY

3.1 Assessing collaborators

Data were collected using questionnaires sent online via email, WhatsApp, and in person by contracted extension agents in Nigeria with target stakeholders in the aquaculture industry, composed of the fish farmers and breeders, fish feed producers, research institutes and academia. The focus was on fish hatcheries and the farmers. Data were stratified based on the agroecological area in Nigeria (Figure 1).

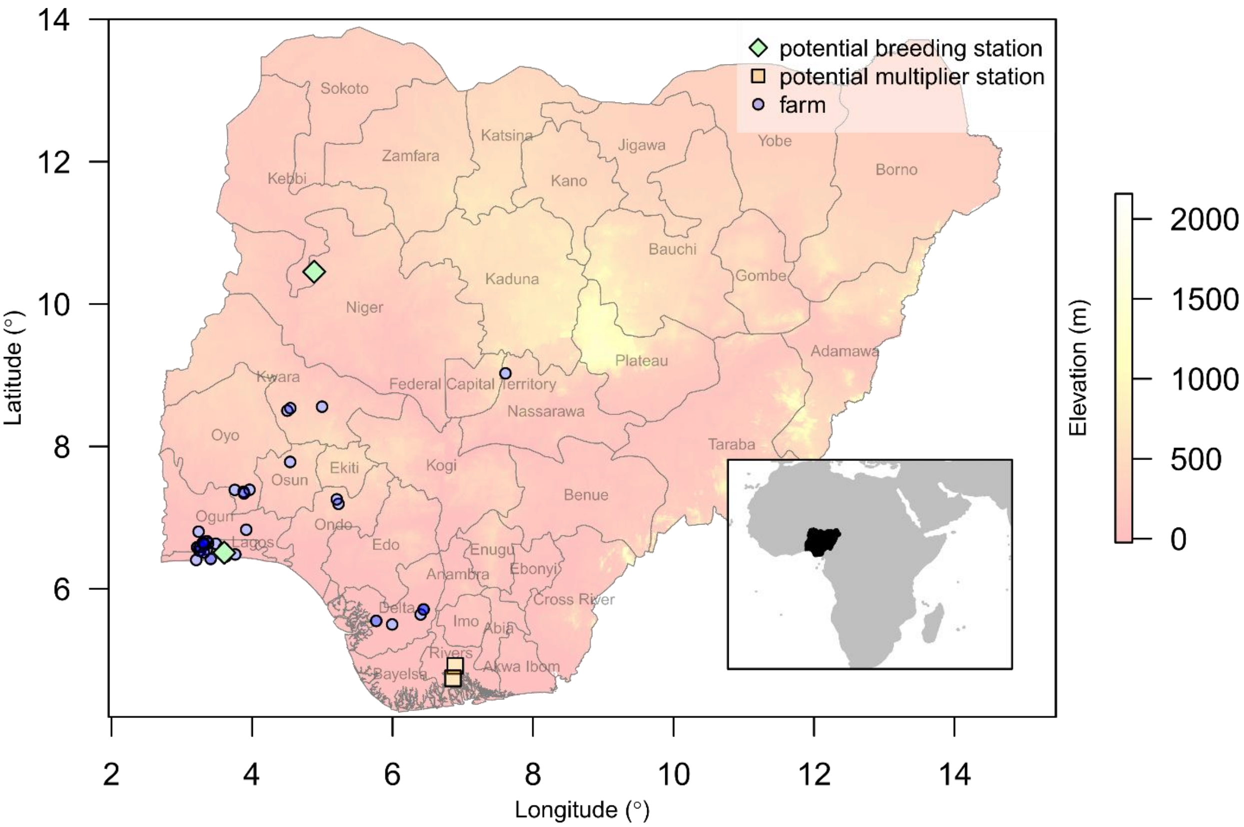


Figure 1. Geographical locations in Nigeria of the potential breeding station (and the broodstock bank), the potential multiplier stations, and the farms participating in the questionnaire.

Population of farmers in each agroecological area were determined based on records held at the Nigerian state ministry of agriculture and 30% were randomly selected, while the questioned researchers were selected from various institutions. The questionnaire addressed important areas such as the knowledge and experience with catfish farming, experience with selective breeding programmes, personal opinions about the need for a selective breeding programme, willingness to participate in such a breeding programme, and the willingness and ability to support and fund the breeding programme and broodstock band.

3.2 Statistical analysis

Data collected using the questionnaires were described using basic summary statistics. To describe the socio-economic and characteristics of the respondents, data were analysed using descriptive statistics including frequency distributions, percentages and means.

4 RESULTS

4.1 General characteristics of respondents

Responses were received from 88 farms. The responding aquaculture farmers were mostly males (84%) and with average age of 44 years (range: 20-70 years). Twenty-eight of the employees on the respondent's farms had, at a minimum, a secondary school certificate. The respondent's farms are of small to large size (<1 to 5 ha) with an average of 15 tanks (range: 1-200 tanks) and have been in operation between less than a year to over 5 years (Table 1).

Table 1. General characteristics of respondents (N = 88)

Characteristics	**Categories**	**Frequency**	**Percentage**
Sex	Male	76	84
	Female	12	14
Age	20-30	9	10
	31-40	19	22
	41-50	32	37
	51-60	23	27
	61-70	3	3
Staff education level	None	22	14
	Informal	23	15
	Pry	24	15
	Secondary	35	23
	Graduate	26	17
Years in operation	≤ 5	25	28
	> 5	63	72

4.2 Respondents' willingness to participate in and support a future breeding programme

The survey showed a very positive response towards a breeding programme. Specifically, 97% (n = 85) of the 88 respondents indicated a clear willingness to participate in the selective breeding programme. Another 2% (n = 2) were not clear whether they would want to contribute and only 1% (n = 1) responded a clear absence of willingness to participate. Furthermore, 97% of the respondents are willing to serve as multiplication centres to produce fingerling for other farmers and 99% are willing to grow selectively improved fingerlings on their farm. Nearly all respondents (98%) have previous knowledge of selective breeding programmes.

The respondent also indicated interest in supporting a potential selective breeding programme through purchase of fingerling (86%), supply of feed (21%), provision of personnel (14%) provision of infrastructure (11%) and financial support (9%) as seen is Figure 2.

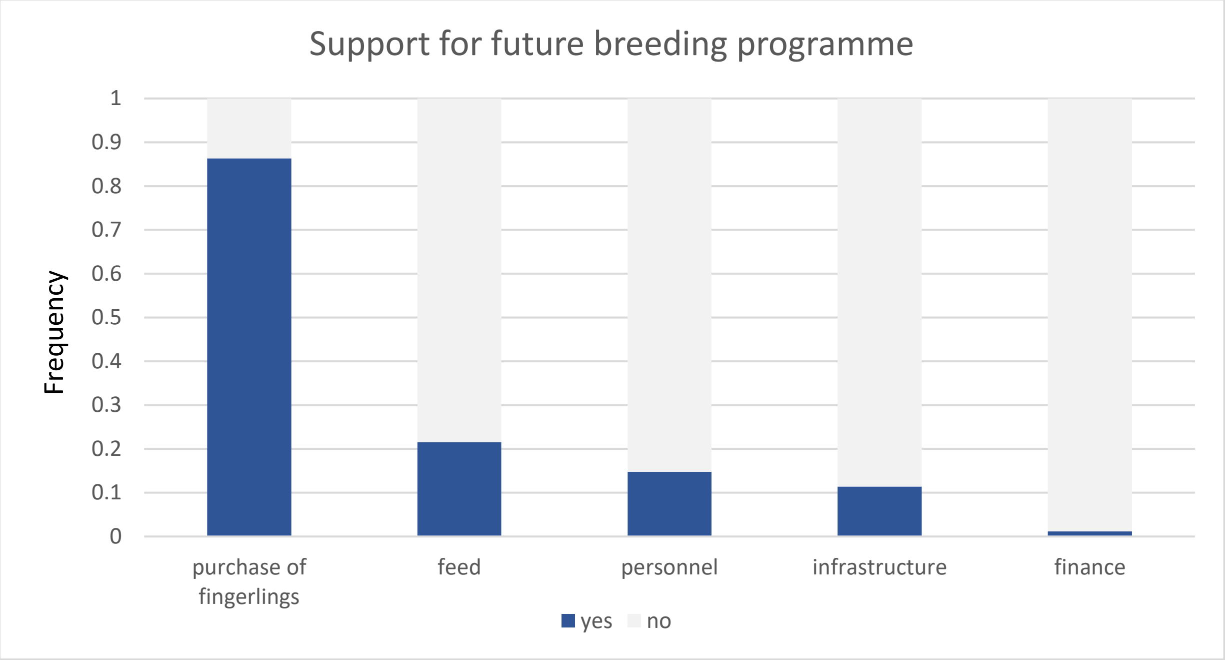


Figure 2. Offers of support by respondent to the proposed selective breeding programme

4.3 Prior experience in selective breeding and previously selected traits

About one in five of the respondents (19%) had prior experience in selective breeding of catfish. Specifically, some had carried out crossbreeding of catfish on their farms with the hope of improving specific traits. Desired traits included higher fecundity, higher body weight or faster growth rate, higher disease resistance, increased hatchability rate, growth efficiency and higher survival rate (Table 2).

Table 2. Traits that were previously improved by selective breeding.

Traits	Frequency	Percentage
Increased hatchability	26	30
Higher disease resistance	24	27
Higher fecundity	22	25
Higher body weight	22	25
Faster growth rate	18	20
Higher growth efficiency	15	19
Higher survival rate	6	7

4.4 Technical requirements and approximate cost of a selective breeding programme

To run a farm effectively, an individual ought to have undergone one form of training or the other, Figure 3, below, shows the various forms of training that the respondents have undergone. It was observed that the respondents have been trained on biosecurity measures (70% of the 88), farm management practices (51% of 88), broodstock management (57% of 88), and fingerling production (10% of 88), to familiarise themselves with the operation of the farm and only one respondent claim to be learning on the job.

Figure 3. Past personnel fish-farming training experience as given by respondents

4.5 Perceive constraints associated with past failures of selective breeding

Challenges in selective breeding identified by respondent were mostly associated with the fish, feed, facilities, and weather condition (Figure 4). For the fish feed (33 out of 88), the respondents further specified contamination of feeds due to inadequate storage - either from the point of sale or at the farm, but also high costs, and low quality. For fish, the mentioned constraints included low quality of broodstock (14 out of 88), inbreeding (7 out of 88), and high mortality rate in fingerlings (5 out of 88). With regards to facilities, lack of infrastructure (15 out of 88), poor water quality (20 out of 88) and non-availability of market for sales of fish (4 out of 88) were mentioned. Lastly, some respondents indicated inadequate finances to run and expand the business (5 out of 88).

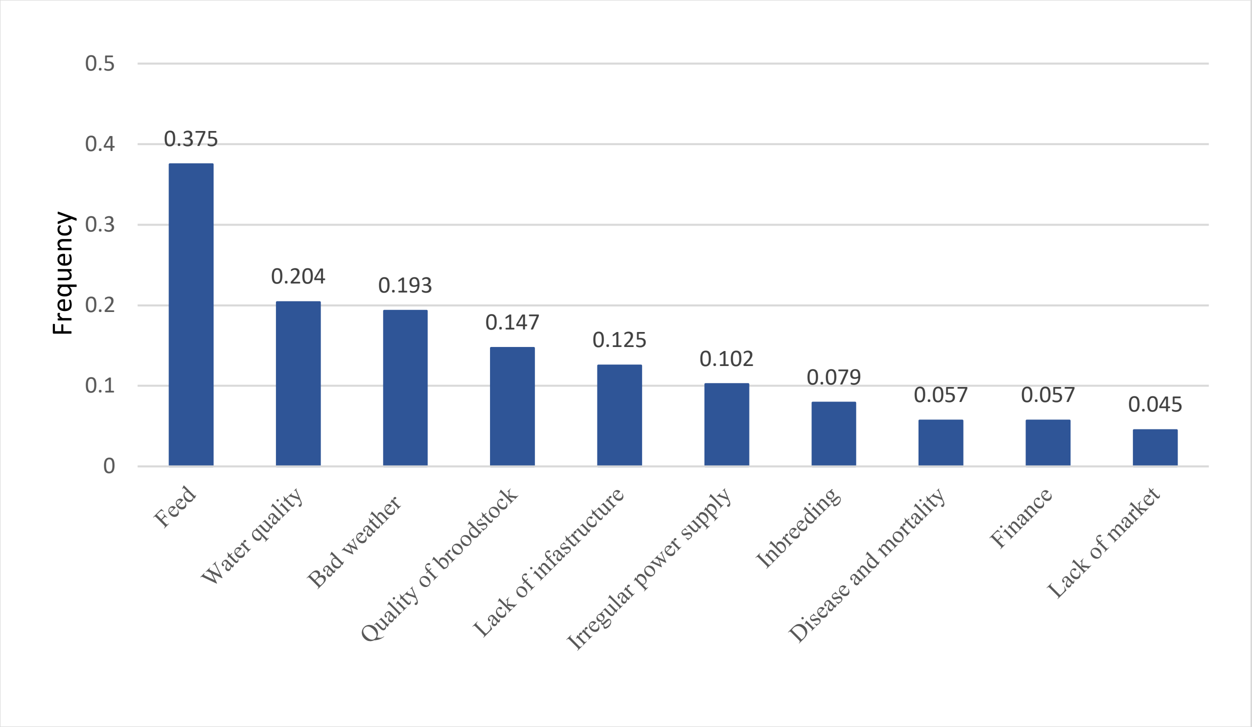


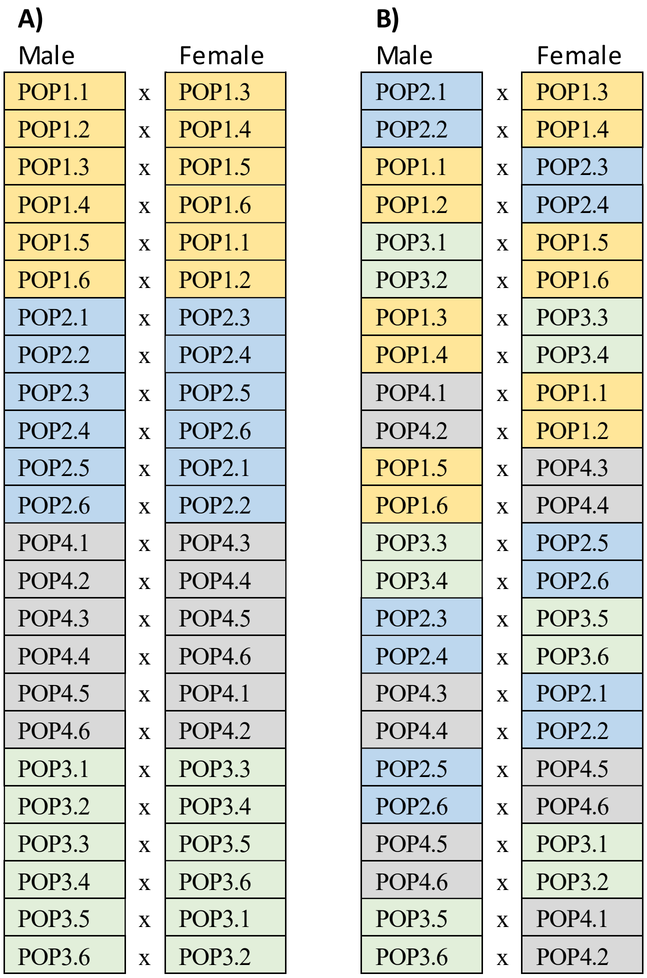
Figure 4. Challenges of past selective breeding as encountered by respondents

4.6 Design and required logistic for a selective breeding programme

Possible locations for a breeding station were identified to be at either the Badore Research Station of the Nigerian Institute for Oceanography and Marine Research (NIOMR), Lagos state, or at the Nigerian Institute for Freshwater Fisheries Research (NIFFR), Kainji Niger State, Nigeria (Figure 1). The reason is that both institutes have mandates to conduct research on aquaculture species in Nigeria. Also, they are located close to most of the production facilities, which voids long transportation of fish, such as from northern to southern Nigeria. The out-stations of either research institutes can also serve as the multiplying centres.

Each founder should be individually tagged dorsally behind the head for re-identification and re-allocation to its source using passive integrated transponder (PIT) tags. All tagged founders should be acclimatized in tanks, mixed by source population, but separate by sex to minimise aggression (Basiita & Rajts, 2021), maintained under standard methods for catfish production (Shourbela, Ashraf, Abd-El-Latif., & Abd-El-Azem, 2014) and fed a commercial diet until reaching maturity.

When individuals of the wild source populations have reached maturity, mating should be performed following a design that also ensures a powerful statistical determination of breeding values in the founder generation. A small design may include six breeding pairs from each population that can be crossed within each population and, by re-using the same individuals, between populations, to total 48 families (crossing example in Figure 5). This number is a compromise between what can be relatively cheaply and reliably managed and maintained initially, also without much prior experience of individual record keeping, and what is needed to provide a sufficiently large genetic diversity that allows for selective breeding, while minimising inbreeding. The initial effective population size for this design is $N_e = 48$.



A)

Male		Female
POP1.1	x	POP1.3
POP1.2	x	POP1.4
POP1.3	x	POP1.5
POP1.4	x	POP1.6
POP1.5	x	POP1.1
POP1.6	x	POP1.2
POP2.1	x	POP2.3
POP2.2	x	POP2.4
POP2.3	x	POP2.5
POP2.4	x	POP2.6
POP2.5	x	POP2.1
POP2.6	x	POP2.2
POP4.1	x	POP4.3
POP4.2	x	POP4.4
POP4.3	x	POP4.5
POP4.4	x	POP4.6
POP4.5	x	POP4.1
POP4.6	x	POP4.2
POP3.1	x	POP3.3
POP3.2	x	POP3.4
POP3.3	x	POP3.5
POP3.4	x	POP3.6
POP3.5	x	POP3.1
POP3.6	x	POP3.2

B)

Male		Female
POP2.1	x	POP1.3
POP2.2	x	POP1.4
POP1.1	x	POP2.3
POP1.2	x	POP2.4
POP3.1	x	POP1.5
POP3.2	x	POP1.6
POP1.3	x	POP3.3
POP1.4	x	POP3.4
POP4.1	x	POP1.1
POP4.2	x	POP1.2
POP1.5	x	POP4.3
POP1.6	x	POP4.4
POP3.3	x	POP2.5
POP3.4	x	POP2.6
POP2.3	x	POP3.5
POP2.4	x	POP3.6
POP4.3	x	POP2.1
POP4.4	x	POP2.2
POP2.5	x	POP4.5
POP2.6	x	POP4.6
POP4.5	x	POP3.1
POP4.6	x	POP3.2
POP3.5	x	POP4.1
POP3.6	x	POP4.2

Figure 5. Mating design within (A) and between (B) four wild founder populations, whereby each square represents one individual and crossing is indicated by ‘x’. The same individuals are re-used once for within- and between-population mating

Around the time of sexual maturity, females should be monitored weekly for egg maturation. Following standard procedures, ready-to-spawn females will be selected and injected with hormone (Srimai, et al., 2019). At the end the latency period, eggs should be stripped from each female. Males should be sacrificed, and their gonads extracted and lacerated. The milt can be obtained by squeezing the gonads, which is then mixed with pure saline solution of 0.6% NaCl and kept in a beaker at room temperature. The milt of one male should be used to fertilise egg batches from one female within the same population and one female from another population to create a synthetic population. Likewise, eggs from each female are split into two batches and each batch is fertilised by a male from the same or another population. The fertilised eggs should be incubated separately by family in incubation chambers labelled by family. Unfertilised eggs should be removed to prevent fouling of the water and fungal infections.

For every new generation (cohort) hatched, the same procedures will apply. To allow a selection for improved survival and reduced cannibalism, individual numbers per tank (i.e., family) need to be standardised and tightly monitored. Numbers need to be high enough to have a minimum of 50 individuals at the time of tagging. Also, the number of shooters need to be recorded for every family during the family period. Shooters are unusually large individuals that grow much more rapidly than others for unknown reasons, possibly cannibalism. Family rearing continues until reaching average individual sizes of 5g, which may be expected after about 28 days. At this size, the fish will have a well-developed dorsal muscle that can hold passive integrated transponder (PIT) tags to allow for individual re-identification (Rezk, 2008). For every cohort, 50 individuals for each of the 48 families will be tagged (50 individuals x 48 families = 2400 individuals).

After tagging, the fish from different families should be combined and replicated across several tanks until adulthood and their performance recorded (Tave, 1995). The rationale for combining fish from the different families and replicating the family mix across several tanks is to be able to separate genetic from common environmental effects. Common environmental effects are tank effects that may confound genetic effects in the case of single-family tanks, leading to an inefficient between-family selection. Having fifty individuals per family enables a reliable family mean to estimate as necessary to select the best performing families and allows for within family selection. Theoretically, having more families and more individuals per family, allows for a stronger selection intensity and thus a larger expected genetic gain per generation, while not risking high inbreeding ratios. However, the larger a breeding programme, the higher the technical and logistic demands. The anticipated numbers are a compromise between viable and practically feasible numbers.

Selection should proceed via combining between and within family selection. Survival and shooter rates should be family-specific traits, whereas growth (or mass) is both a family and an individual-specific trait. At a maximum, the best 50% best-performing families of each cohort ought to be kept for individual selection. The family performance is the average of the family breeding index based on equal weights for breeding values for survival and growth (each being the average of the breeding values of both parents). This is a relatively accurate approach already in the first generation because the breeding value of every founder parent is evaluated based on two families (i.e., based on both full and half-sibs). Individual selection should be based on keeping the best two individuals from each sex of each selected family (24 families x 2 individuals x 2 sexes = 96 breeders), which ought to be used to create 48, predominantly full-sib families that make up the next cohort. From here on, breeding values will be estimated based on both parental (or further distant relatives in previous generations or the current generation) and the offspring generation performances, i.e., data within and across generations.

Allocation of mating pairs among the selected individuals should proceed according to optimal contribution selection (OCS) theory (Meuwissen, 1997). OCS is a selection method that restricts inbreeding by setting a restriction on the rate of inbreeding while maximising increase in genetic gain. To practice OCS, breeding values and pedigrees for the breeder candidates are required. Breeding values are required to select mating pairs that improve traits, and the pedigree is required to calculate co-ancestry that allows the control of inbreeding. Breeding values will be obtained using classical animal model estimates for the recorded traits to be improved. The pedigree results from the mating design and individual assignment, possibly via using initial family rearing and later implementing individual tags.

A field /farm trial of the progeny should be conducted for each generation to rule out the tank or location effect**.** On completion of the exercise, information about the new trait will be sent via extension agent, to other farmers, for promotion and advertisement

Other procedures necessary to successfully run the programme do not deviate significantly from previously established procedures. However, keeping many families in unique tanks and data recording for every individual will be much more work-intensive than known standard procedures.

4.7 Benefit and estimated start-up cost of the selective breeding programme

The project is anticipated to provide benefit of increase in genetic level of traits in African catfish, increase in the economic values of the traits and farm, market, or industry output. This will both improve food security in Nigeria and elevate the standard of living of catfish farmers. In addition, it will likely lead to a more sustainable fish production by allowing for raising improved fish stocks more rapidly and economically to slaughter sizes. The husbandry, upbringing of selection candidates and the trait recording, contribute to the cost of the breeding programme are detailed below (Table 3). Further costs emerge from sourcing for brood fish, purchasing hormones for stimulating gonadal development in the female, feeding the fish (i.e., juvenile and broodfish), and staff salaries. Also, initially additional equipment will be needed, such additional tanks to accommodate 48 families, tagging and tag reading equipment and software that associates data records with tags.

Table 3. Estimated start-up cost of the selective breeding programme (year 1-5)

Details of Expenditure	Quantity	Unit Price ($)	Cost ($)
Root blowers and accessories	3	2,500.00	7,500.0
Automatic feeders	15	100.00	1500.0
Water test kit	1	400,000.00	400,000.0
Scoop net different sizes	3	18.00	54.0

Hormones	10	55.13	551.3
Towel	12	0.70	8.4
Fish tags	10 pkt	0.56	5.6
Tag reader	2	126.53	253.1
Procurement of broodfish	500	7.19	95.0
Electricity	608kwh	0.093	56.5
Labour	4	11,534.40/month/5 years	2,768,256.0
Cost of feeding broodfish	50	1.92/per cycle/5 years	384.0
Cost of feeding juvenile	2,400	1.44/per cycle/5 years	172,800.0
Cost of other logistics		48.06/month/5 years	2,306.9
Contingency	10% cost of project		335,377.1
Total			3,689,147.9

4.8 Financing the breeding programme.

Financing the breeding programme will be in four dimensions.

a) For each generation, samples will be sold to the commercial fish farmer that showed their willingness to participate in the breeding programme from the questionnaires sent out (3.1) as (i) direct sales to grow-out farms or as (ii) broodstock to multiplication centre the operation is shown in (Figure 6).

b) Because there is a market for fish from 300-500g, instead of culling the fish that are not continued within the breeding program, this group of fish will be reared for 3 months, smoked, and sold to consumers.

c) Income from training programmes for prospective fish farmers and breeders.

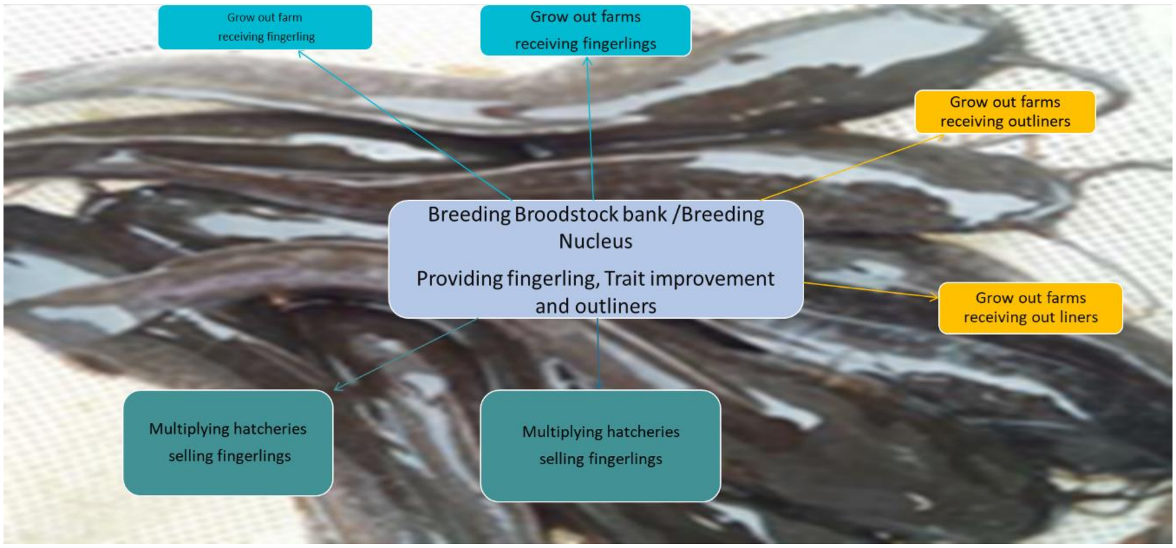


Figure 6 Role of the broodstock bank during the initial first four years of the selective breeding programme (A) breeding nucleus (B) external multiplier hatcheries (C) fish between 300-500g.

5 DISCUSSION

Using online and offline questionnaires, the project assessed the willingness of farmers to participate in a potential selective breeding programme. Support including willingness to purchase fingerlings, supply feed, provision of infrastructure and financial support were offered by the respondents should the breeding programme commence. This result shows how viable it may be to promote public-private partnerships for aquaculture in Nigeria. Most studies in aquaculture have demonstrated that public-private partnerships have been a “win–win”, with both farmers and government benefitting. Financial funding can give publicly funded research agencies access to cutting-edge research tools, materials, and proprietary knowledge public-private investments in researching and developing genetically improved fish strains have the potential to provide attractive economic returns to the private sector and to meet a public need for improved seed quality (Weirowski & Hall, 2008).

Some of the present challenges experienced by respondents were associated with fish traits, feed, facilities, and weather conditions. Constraints include low fecundity, low quality of milt, inbreeding, and high mortality rates in fingerlings. All these latter, the project intents to solved by using four base population originated from river strains to create broodfish for future generation broodstock with selectively improved traits of *Clarias gariepinus*.

6 CONCLUSIONS AND RECOMMENDATIONS

A selective breeding programme should be set up by federal government of Nigeria in public-partnership with farmers who has more years of experience with farming as they show more willingness to participate in the selective breeding program, with an aim to make fingerling and broodstock available to other farmers in the aquaculture industry in Nigeria. For sustainability of the programme, it should be under a hybrid public-private management to ensure continuously maintained and funded into the future if improvement is to continue, since the selective breeding programme is for the greater good and viability of whole aquaculture industry of Nigeria. A strong commitment by the industry and government is needed to continue breeding through good and bad times in the production sector, and the breeding entity itself needs to be profitable.

To run the selective breeding programme, staff (researchers and extension agents) need to be re-trained on hatchery operations and broodstock management. Especially the requirement of knowing family (via early family separation) and individual identification (via tags) at the different stages requires some modifications of existing procedures and training of new skills. These skills include performing the tagging and data recording that are associated with individual tags.

It also suggested that new required equipment be put in place. In deviation from previous procedures to successfully mate and raise catfish that have already been established at either possible station, some new equipment may be necessary. This may encompass additional tanks to accommodate enough families (44), tagging and tag reading equipment, and software associated with tagging and data records.

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