Guidelines on development and management of aquaculture systems and new culture fish species bulking techniques

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Introduction

Fish farming began in many countries in Africa at the beginning of the 20th century. In the 1920s, tilapia were successfully produced in ponds in Kenya (FAO, 2005; Hecht *et al.,* 2006), aquaculture for food production was later introduced across Africa between the 1940s and 1950s (Brummett et *al.,* 2008). The objectives were to improve nutrition in rural areas, improve the income of the people in these areas, and diversify to reduce crop failure risks and create more jobs. As a result, many fish farming stations were built by the governments in the 1950s with about 300,000 ponds producing fish, in the whole of Africa at the end of the decade (Satia, 1989). It was at this point (early 1960s) that FAO, in partnership with governments, donor countries, national and international research bodies and NGOs began to take control of the development of aquaculture in the region (Hecht *et al* 2006). Efforts were focused on primary research and development, to understand and communicate practical techniques for a range of mostly indigenous species (Adeleke et al 2021). The development of aquaculture in the region was highly connected with the aid of financial and technical donors, worth about US$500 million from the early 1970s to early 1990s (Hecht *et al* 2006). Aquaculture for food production was later introduced across Africa between the 1940s and 1950s (Brummett *et al* 2008). The objectives were to improve nutrition in rural areas, improve the income of the people in these areas, and diversify to reduce crop failure risks and create more

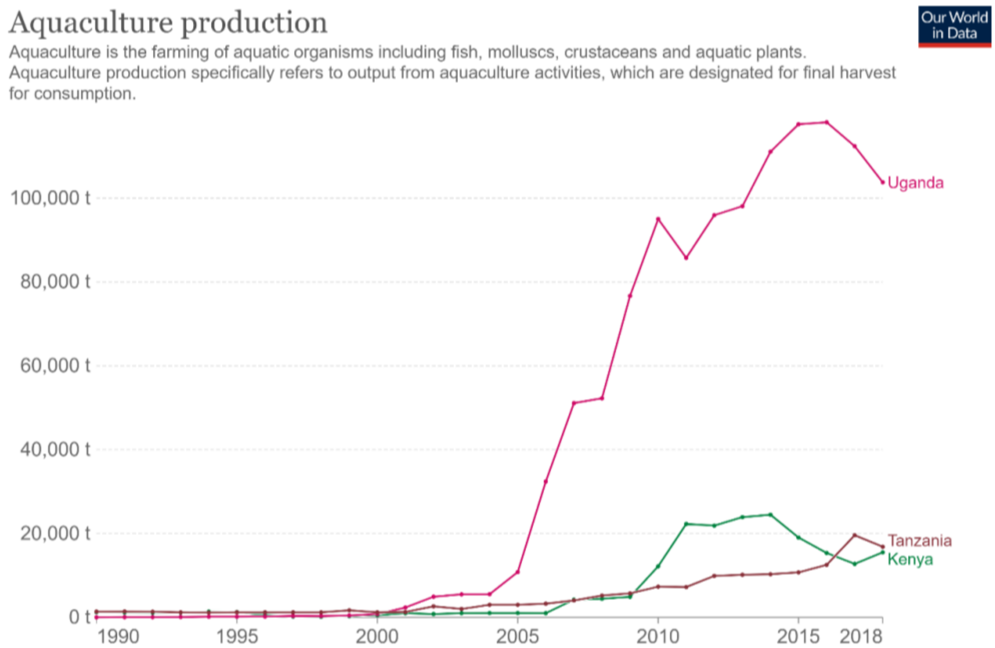

Figure 1. Aquaculture Production in Kenya, Uganda, and Tanzania (Ritchie & Roser, 2021).

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Most of the production (78,9%) comes from inland freshwater systems and is dominated by the culture of indigenous and abundant species of tilapia and African catfish. Marine fish farming contributes only 1% to the total production quantity, although it is emerging as a promising subsector (FAO, 2016; 2018). During the last twenty years, the introduction of tanks and cages together with the improvement of the current production systems induced the rise of the farmed quantities (Figure 1)(Satia, 2017). Models project

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an increase in demand for aquatic foods in the Sub-Saharan region and along with the necessity to reduce imports (of such foods) require aquaculture to produce an additional 5.0 million tonnes by 2030 and 10.6 million tonnes by 2050 (Ragasa *et al.,* 2022).

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Aquaculture Production by Country

Uganda

Aquaculture in Uganda started in 1941 with the introduction of carp into the lakes by the colonial authorities (Adeleke *et al.,* 2021) and later in 1953 with the establishment of the Kajjansi experimental station. Early fish farming was primarily practised to provide fish to supplement the family's diet and was done in small backyard ponds, based on fertilization, and feeding with whatever was left from the kitchen (Bolman *et al.,* 2018). Despite its long history the sector largely remained at small-scale, subsistence level with an insignificant contribution to national fish production till the early 2000s (Bolman *et al.,* 2018). In 1959-1960 the Food and Agriculture Organisation (FAO) supported a comparative study on common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*), resulting in the endorsement of carp. According to the Department of Fisheries Resources, 11,000 ponds were constructed by 1968, all focussing on subsistence farming (Bolman *et al.,* 2018). Between approximately 1970 and 2000, as technical knowledge and inputs started to lack, many farmers abandoned fish farming. Therefore from 11,000 ponds in 1968, there were 4,500 ponds left after 30 years with a production of 285 tonnes (Bolman *et al.,* 2018). From the late 1990s the government of Uganda, together with development partners, introduced strategic interventions to boost aquaculture. African catfish and Nile tilapia were the species that were chosen for these

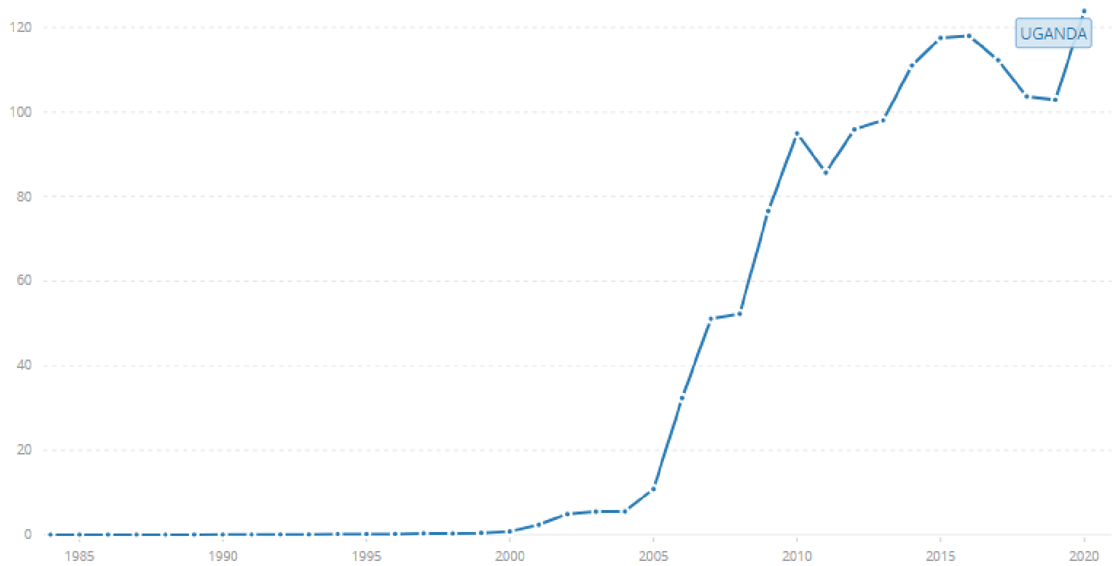

Figure 2. Aquaculture production in Uganda since 1985 (adapted from FAO 2022).

efforts, instead of carp (Bolman *et al.,* 2018). As carp tolerate lower temperatures, they

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are popular in high-altitude areas of the country where temperatures fall to less than 19°C, whereas tilapia and catfish are indigenous and have local and regional markets.

Catfish culture was made possible at that time by the adoption of its induced spawning technologies by a private hatchery. It can be considered that the Ugandan aquaculture sector has two periods: the strong public intervention period (1953–2000) focused on subsistence farming and the strong private involvement period (2000–2018) focused on commercial small-scale farms (Bolman *et al.,* 2018). The Government's Plan for Modernisation of Agriculture (PMA) and the National Fisheries Policy (NFP) introduced new rules for private licenses and foreign investment having as a result the first commercial fish farms to emerge. The first private hatchery was established in 1999, making an alternative source of fingerlings and fry.

Figure 3. A medium-scale pond-farm in Uganda (Dutch Ministry of Foreign Affairs 2021).

The turning point, however, occurred in 2006 with the introduction of cage culture in Lake Victoria (Figure 2) (Bolman *et al.,* 2018). Until then, the cost of industrially manufactured feed pellets remained one of the major constraints to the development of the sector. The feed manufacturers required a sufficient and sustained demand for fish feed to warrant the high investment costs as it would not be economically viable for them to invest in machinery, without knowing if their feeds would be bought. On the other hand, the farmers could not initiate trade without having high-quality feeds from the industries. This changed with the kick-off of cage culture and the support from the US FISH project. Poultry feed manufacturing firms (NUVITA and Ugachick) started producing pelleted (sinking) fish feed (Bolman *et al.,* 2018). As cage culture was increasing, very high-quality feeds were needed to support this growth. This led to the importation of fish feeds

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from several countries outside East Africa including Mauritius, Israel, Brazil, Vietnam and others (Bolman *et al.,* 2018).

Production numbers

By 2005, between 20,000 and 30,000 ponds were operated by approximately 7,000 farmers with an estimated total production of 1,500–5,500 tonnes. The average surface of a pond was 200-500m^2, with 50-200m^2 for subsistence farmers and up to 7,000m^2 for small-scale commercial farmers (Bolman *et al.,* 2018). Production has been estimated at 1,800kg/ha/year in the period 2003-2005. By 2010, 25,000 ponds were recorded with a production of 95,000 tonnes. In 2015, it was estimated by the National Fisheries Resources Research Institute (NaFIRRI) that there were 2,135 cages in the different lakes of Uganda, with 28 farmers and a production of 1,349 tonnes per annum (Bolman *et al.,* 2018). Over the past years, significant growth in cage farming has occurred. In 2018 the production from cages increased to 14,000 tonnes, in 2020 34,000 tonnes and by the year 2025, it is expected to reach 98,000 tonnes. The estimated growth of cage farming runs at a rate of 46% (Dutch Ministry of Foreign Affairs, 2022). Total production in Uganda in 2020 amounted to 123,897 tonnes. (FAO, 2022).

Figure 4. A farm in Uganda using tanks (Dutch Ministry of Foreign Affairs 2022).

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The main species being produced in Uganda are Nile tilapia and African catfish. Until recently, tilapia used to be the most cultured species, but catfish surpassed it (Adeleke *et al.,* 2021). Catfish show a rapid growth rate and ability to feed on organic matter available in households while tilapia have a preferred taste, easy reproduction, and growth performance. Therefore, catfish is now predominant in some aquatic systems, especially those linked with swamps, and widely accepted amongst Ugandan farmers. Other farmed species in particular parts of the country include common carp (especially in systems where low temperatures occur). Carp production encounters problems with the insufficient production of fingerlings and unstable government policies (Adeleke *et al.,* 2021)

Culture systems

Figure 5. Cages in Lake Victoria, Uganda (Dutch Ministry of Foreign Affairs 2022).

Pond culture is the most common aquaculture production type used in Uganda. Pond culture occurs throughout the country, except for the "cattle belt", where beef farming is dominant and fish farming is not practiced (Bolman *et al.*, 2018). The government promoted small-scale aquaculture production by provisioning feed and fry inputs to farmers. As mentioned earlier, Uganda is estimated to have 25,000 ponds, covering 10,000 hectares (Figure 3). Previously subsistence farmers, that represented 99% of fish farmers, had ponds ranging anywhere from 50m² - 200m² (FAO, 2013), however with the commercialization of farming, pond surface increased to a current average of 500m² per fishpond (Rutaisire *et al.,* 2017; Adeleke *et al.,* 2021). 20-30% of smallholder subsistence ponds have successfully transformed into profitable small-scale producers through

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developments in management and scale of production (Figure 5). Almost 2,000 small-scale commercial farmers are believed to exist, who own nearly 5,000 ponds, with an average pond size of 1,500m²/pond. (FAO, 2013).

Decreasing the size of farms is common in some areas due to limited land availability. Wasteland and land with low cost, including gullies and ditches that can support fishponds, may be appropriate for fish farming (Adeleke *et al.,* 2021). The development of aquaculture parks in areas with wetlands lakes and rivers, as proposed by the government, maybe the anticipated solution, however, the permit fees are beyond the affordability of many small farmers.

Tank systems were first introduced in the early 1990s, for the farming of European eel (*Anguilla Anguilla*) on private farms (Adeleke *et al.,* 2021). Recently, circular and rectangular tanks are used for broodstock management and reproduction of catfish (Rutaisire *et al.,* 2017) (Figure 4). Tank systems are also used in tilapia and catfish on-growing production with the use of bore water.

Cage culture systems in Uganda started in 2006 in Lake Victoria and Kyoga to boost aquaculture production (Figure 5)(Adeleke *et al.,* 2021). The most commonly used cage system is the low volume with high-density cages of 8m^3 and a stocking density of 200-400/m^3 depending on the depth and the flow rate (Rutaisire *et al.,* 2017).

Hatcheries

Currently, Uganda has nearly 100 hatcheries, but around 50 are adequate establishments with the capacity to produce fish seed of good quality for supply and distribution. Moreover, only a handful are large-scale commercial ventures. The hatcheries produce primarily Nile tilapia, some other hatcheries produce African catfish as well and only a few produce carp. For most farmers, there is a reasonable availability of seed, and the quality is fair, but there may be exceptions, specifically for those farmers who are operating in remote areas. Factors that often limit hatchery production are inadequate or inappropriate equipment, quality water supplies, lack of genetic programs and the restricted availability of specialized hatchery feeds (Bolman *et al.,* 2018).

Fish feeding

Uganda has several fish feed factories producing between 20,000 to 30,000 tonnes of feed per year mainly for the cage culture. The biggest producers are Ugachick, Novel Feeds and Sabra and Sons Ltd. There are a few other smaller feed mills, including the

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Ugandan-Chinese feed mill (supported by the governments of the two countries) at Kajjansi (Bolman *et al.,* 2018). There are also some small privately-owned mills that have been set up to support fish farmers. Ugachick supplies feeds also to neighbouring countries such as Kenya, however, the produced amount is not enough for both domestic and regional markets. It is estimated that 85-90% of all small-scale fish farmers make their own feed (Bolman *et al.,* 2018). The factories are geographically distributed unevenly, and their production is inadequate to meet the demand. Moreover, the lack of government regulation and control and the quality standards of fish feed constitute a limiting factor in the development of aquaculture.

Kenya

Pond culture was introduced in the early 1920s starting with different species of tilapia followed by common carp and the African catfish. In 1948, the colonial government established the Sagana and Kiganjo fish farms to produce fingerlings for warm and cold-water fish species. It was the establishment of these stations that enhanced interest in rural fish farming. A campaign by the Fisheries Department for diets containing more fish in the 1960s increased rural pond fish farming in many parts of the country. It is estimated that Nyanza and Western provinces alone had over 30,000 fishponds by the early 1970s. However, the high number of fish ponds over the years did not produce the anticipated amounts of fish due to low output from the ponds. Fish farming did not make much progress and in many cases even declined, resulting in their abandonment (Aloo *et al.,* 2017). There are areas in Kenya that receive adequate rainfall and others with underground water sources (along with rivers, streams, springs, and dams) and soils with good water retention capacity that can provide many thousands of tonnes if aquaculture is practised in a sustainable way. Moreover, the climatic conditions in these areas are also favourable for fish growth throughout the year.

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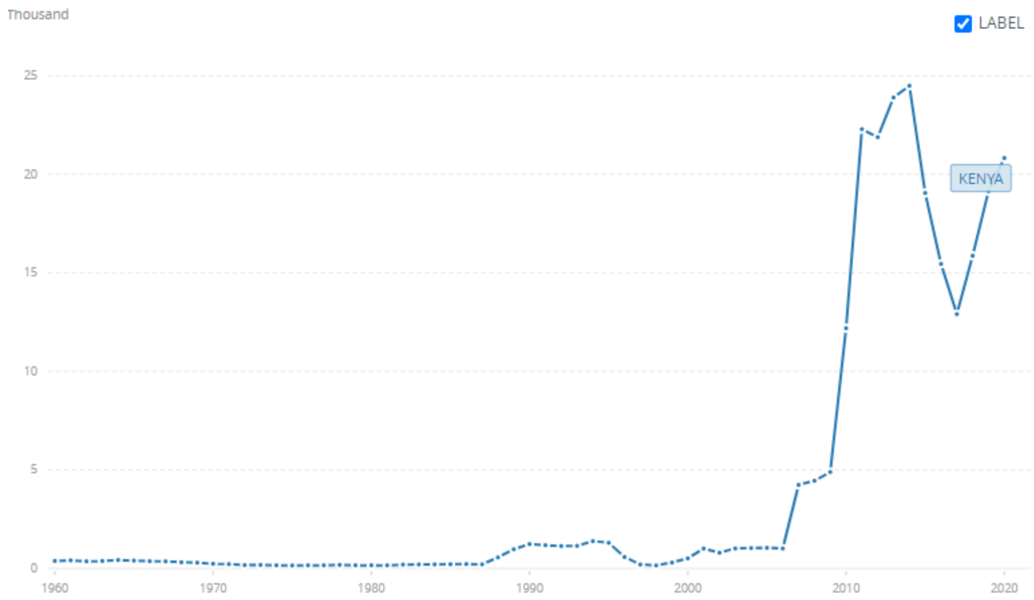

Figure 6. The aquaculture production (tonnes) in Kenya since 1960 (FAO 2022).

Unfortunately, many farmers still consider aquaculture as a risky business, producing small amounts of fish with a poor economic return on cash and labour investments. Lack of experience in fish husbandry and lack of knowledge of new technologies needed for pond fish production are the main reasons. Aquaculture production in Kenya was 1,000 tonnes in the 1990s and until the middle 2000s (FAO, 2022). As the total national fish production reached around 160,000 tonnes on average (per year), aquaculture production represented a contribution of less than 1% (Aloo *et al.,* 2017). There was, however, a momentous rise in aquaculture fish production from 2007 as shown in Figure 6. This rise in production raised the contribution of aquaculture to national fish production to about 3%. This increase was due to the entrance of a few commercial fish farmers. However, this growth in production did not come without challenges: lack of sufficient sources of fish seed and commercial feeds.

Among the government efforts to promote aquaculture was the formation of the Ministry of Livestock and Fisheries Development in 2002, and later the formation of a fully-fledged Ministry of Fisheries Development in 2008, with a focus on aquaculture (Aloo *et al.,* 2017). These interventions led the Ministry of Fisheries Development through the Economic Stimulus Programme to re-structure the allocation of the national economy at the grassroots level. During the first phase of the programme in 2009 - 2010, 28,000 ponds were constructed in 140 constituencies across the country. Moreover, clusters of farmers (at the village or constituency level) were supplied with fish seed, feed, and

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fertilizers. As the pace of the first phase of the programme was very encouraging, the government allocated additional funds for its continuation (Aloo *et al.,* 2017).

The most farmed fish species in Kenya are the Nile tilapia, representing about 70% of farmed fish, followed by the African catfish, with about 21% of aquaculture production.

Figure 7. Ponds in Bukani, Kenya (Odenke et al 2022).

Other farmed species are black bass, Koi carp and goldfish, but their overall contribution is minimal (Aloo *et al.,* 2017). As in the case of Uganda, common carp (6%), rainbow trout (1%) and jipe tilapia (*Oreochromis jipe*) can be found in areas where temperatures do not exceed 19ºC. What is promising, is the fact that a lot of research has been directed toward the culture of indigenous tilapiine species: Singidia tilapia (*Oreochromis esculentus),* Victoria tilapia (*Oreochromis variabilis),* blue spotted tilapia (*Oreochromis leucostictus)* and tilapia jipe *(Oreochromis jipe),* either for commercial or for research reasons (Munguti *et al.,* 2021).

Production numbers

With a total of 146,000 ponds and 6,000 cages, Kenya's annual aquaculture production is estimated at 24,000 MT but has enormous potential for growth through the adoption of sustainable technologies and policies. For the year 2020 when the last formal information was given, the production reached 20,831 tonnes (FAO, 2022). Freshwater production is by far larger than marine production. Kenya has 1.4 million hectares of land suitable for aquaculture, with the capacity to produce 14 million tonnes (Odenke *et al.,* 2022). Despite the massive potential for aquaculture production, the contribution of the

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sub-sector to the gross domestic product (GDP) of Kenya is still very small. Today, Kenya does not export any aquaculture goods. Nonetheless, public interest in aquaculture has been on an upward trajectory since 2015, when most farmers realized the potential of fish production from the government-funded ESP project (Munguti *et al.,* 2021). It is expected that the number of fish farmers will increase to 52% by 2025. With the current productivity, there is already a significant gap between the projected fish demand and production, which is expected to hit 553,000 MT by 2030 (Odenke *et al.,* 2022). If nothing extraordinary happens, this deficit will be covered by imports. Around 80,000 people are working directly or indirectly in the aquaculture sector (Munguti *et al.,* 2021).

Culture systems

The Kenyan aquaculture sub-sector is mainly characterized by small-scale production systems, which are largely for subsistence purposes. The small-scale farmers are facing numerous problems just like the rest farmers in Sub-Saharan Africa: difficulties in

Figure 8. Raceways in Mombasa, Kenya (FAO 1982).

accessing quality seed and feeds and access to markets for their fish. Sub-Saharan Africa is experiencing major changes in farmland ownership patterns. The number of small-scale farms with small surface area is declining everywhere except Kenya. The farmers tend to use more land to increase their yield. Medium-scale farms control roughly 20% of total farmland in Kenya, 32% in Ghana, 39% in Tanzania, and over 50% in

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Zambia. The number of such farms is also growing very rapidly, except in Kenya (Odenke *et al.,* 2022).

Figure 9. A RAS in Machakos, Kenya (hollandaqua.nl).

Tilapia farming is mainly carried out in monoculture systems. A survey conducted in Western Kenya targeting 1000 farmers, indicated that a high proportion of farmers (74%) cultured Nile tilapia and African catfish in monoculture systems, while 26% of farmers carried out polyculture of the two species (Opiyo *et al.,* 2018). Production from the extensive system in water collectors such as dams ranges between 500-1,500 kg /ha/year contributing to 10% of farmed fishes in Kenya. The main system adopted in Kenya is semi-intensive farming in ponds (Figure 7). Apart from the fertilization of the ponds, feeding is done using supplementary feeds formulated on farm or purchased from cottage fish feed production industries (Opiyo *et al.,* 2018).

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Most smallholder farmers have a minimum of 1 pond to a maximum of 6 ponds. Large scale operators possess a pond surface area of 4,000–80,000 m^2 and more than 13 ponds while medium scale operators own 601–3999 m^2 and 5–12 ponds (Opiyo *et al.,* 2018). Small-scale farmers use their own individual labour to produce fish mainly for household consumption and whatever is left is sold to neighbours. It takes 6 months (sometimes more) to produce fish that weigh between 250 and 300 gr from the ponds. If the temperature is lower than 25 °C in a system when harvesting at the end of the 6^{th} month the fish will be smaller.

Figure 10. A Cage farm in Mulukoba Beach in Kenya (Odenke et al 2022).

Raceway tanks are mainly used in rainbow trout production, being practiced in the Mount Kenya region (Figure 8) (Opiyo *et al.,* 2018). According to Kenya's State Department of Fisheries, the amount of trout produced from raceways in 2014 was 241 tonnes and valued at $1,430,000 US. Production in these systems ranges between 10,000-80,000 kg/ha/year. The system requires high-quality feed which is expensive, and this is the main reason that a few farmers can afford it.

In the last years, Recirculating Aquaculture Systems (RAS) have been implemented to support fish production in Kenya (Figure 9). They are mainly tank-based systems used for culturing tilapias and catfish. There are 8 farms in Kenya operating recirculating systems in the form of hatcheries or grow-out farms (Opiyo *et al.,* 2018). Fish are stocked

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at a considerably high density of 5-20 fish/m^3 under controlled conditions. The expected production reaches 200 tonnes/ha/year. As the initial capital investment is high, the system is not very common in the country. Investment in RAS for Nile tilapia production and intensive catfish production is carried out in peri-urban areas near towns (Opiyo *et al.,* 2018).

Cage culture is expanding fast in Lake Victoria. It started in 2013 when cage trials were conducted successfully at Dunga beach by Kenya Marine and Fisheries Research Institute (KMFRI) and Dunga Beach Cooperative Society (Figure 10) (Opiyo *et al.,* 2018). Stocking density ranges from 60 to 250 fish/m^3, while the size of the cage ranges from 8 to 125/m^3. In just a year the number of cages doubled from 1663 cages in 2016 to 3398 in 2017 (Opiyo *et al.,* 2018). Nile tilapia is the only fish that is being farmed in cages, producing 12 million kg of fish every cycle (about 8 months in a year). There are currently, 43 enterprises that operate cages with over 4,000 cages stocked with more than 3 million tilapia fingerlings (Opiyo *et al.,* 2018). There is a huge potential in cage farming, to increase production and support economic growth around the Lake Victoria region.

Hatcheries

The majority of Kenyan hatcheries are owned by private fish farmers (82%) and a few by governmental institutions. They are located in regions of the country with high aquaculture activities and their number has increased from 21 in 2009 to 147 in 2012 and 127 in 2015 (Nyonje *et al.,* 2018). The initial broodstock for this boom of new hatcheries originated from the wild stock of Lake Victoria and Kyoga. The broodstock were domesticated and cross bred with broodstock from the governmental hatcheries. Their main production is Nile tilapia and African catfish fingerlings. Their output reaches 23 million tilapia fingerlings and 2 million catfish fingerlings. Mixed-sex tilapia fingerlings accounted for 90.4% of the total amount of produced fingerlings and only 9.6% were monosex populations. The largest hatchery is the National Aquaculture Research Development and Training Centre (NARDTC) in Sagana and the largest private hatchery is Dominion Fish Farm. The usual broodstock management tactic is to use fish for 3 years and then replace it from government-authenticated sources. In 2018, Nyonje *et al.,* estimated that the stock of broodstock in the Kenyan hatcheries consists of 388,085 tilapias (180-400gr) and 42,502 catfish (0.6-2kg).

A number of challenges are being encountered: high mortalities during larvae phase, inadequate supply of hatchery inputs and equipment, inadequate rearing facilities, high

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cost of larval fish feed and inadequate technical advice. All of these contribute to the supply of low-quality seed to fish farmers. Therefore, there must be better collaboration between the private hatcheries so as to monitor and ensure quality parameters. Production must be optimized in order to reduce cost with the use of monosex populations (male tilapia) and finally, more geneticists must be trained in order to help fish breeding programs (Nyonje *et al.,* 2018).

Fish feeding

More than 90% of farmers practice semi-intensive fish farming while the intensive system is practised by only 3% due to the high cost of electricity and non-availability of cheaper quality feeds. In the semi-intensive systems, ponds are fertilized with animal manure and supplementary feed in the form of cereal bran (wheat, rice, maize) and low protein formulated feeds are given to supplement natural foods (Opiyo *et al.,* 2018). Fish farms in Kenya are in most cases integrated with either crop or livestock production (Vegetables, bananas, goats, cattle, and chicken). Various feeds are used by fish farmers in Kenya, ranging from mash to farm-made pellets, pressed pellets (made by local companies) and extruded floating feeds. Extruded floating feeds are mainly imported from other countries. As feeds are expensive, some farmers have been using pig pellets and poultry feed to feed fish. Some of these livestock feeds are supplemented with antibiotics, probiotics, and growth promoters, which farmers could be introducing to fish without knowing how and why (Opiyo *et al.,* 2018). Since fish and pigs (or any other terrestrial animal) have different dietary requirements, the use of pig or poultry feed for fish is not recommended. Reasonably, fish get nutrients in proportions, which are limited, leading to wastage of feed, poor growth and occurrence of deformities and nutritional diseases.

Commercial fish feeds in Kenya, usually contain 24–30% and 30–40% crude protein for tilapia and catfish respectively (Opiyo *et al.,* 2018). These feeds are too expensive for some farmers such that, most farmers use locally formulated mixed feeds. The feeds are made by mixing either dried freshwater shrimp (*Caridina niloticus*), commonly known as 'Ochonga', with rice bran or maize bran with Omena (*Rastrineobola argentea*) meal. This practice is also inadequate to formulate balanced diets required by the fish, and it leads to poor growth and nutritional deficiencies. Other feed materials and ingredients available locally and commonly used by fish farmers in Kenya are; terrestrial plants (grasses, leaves (e.g. cassava) and seeds of leguminous shrubs and trees vegetables);

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aquatic plants (water hyacinth, water lettuce, duckweed); small terrestrial animals (earthworms, termites); aquatic animals (trash fish, bycatch fish); rice (broken, bran, hulls); wheat (middling, germ, bran); maize (gluten feed, germ, gluten meal); seed cakes (mustard, coconut, groundnut, cotton, sunflower, soybean); brewers waste; slaughterhouse wastes: offal and blood (Opiyo *et al.,* 2018).

Tanzania

Fish farming started with experimental ponds in the 1950s, stocked with tilapia fingerlings from Lake Victoria and the Pangani river. It was a governmental effort with the fingerlings provided by the government to private farms in public water reservoirs. By the 1960s Tanzania had around 10,000 ponds with a surface area of 1,000ha (Shoko *et al.,* 2011). Poor technology and bad management led to the abandonment of many of these ponds, however, during the 1970s and 80s, several aquaculture projects were developed through various donors. Once again though, in the 1990s as these projects failed to show their full potential, they were abandoned by the donors. In Figure 11, aquaculture production can be seen with an increase in the late 80s, without any increase afterwards

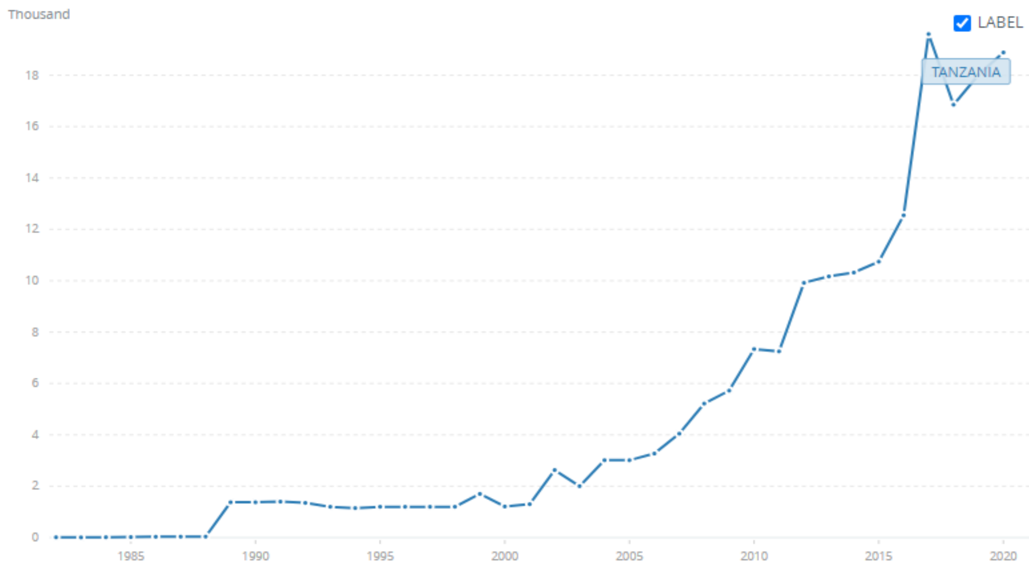

Figure 11. Aquaculture production (in thousands of tonnes) in Tanzania the last 40 years (FAO 2022).

until 2001. From the middle of the 1990s and early 2000s, finfish, crab, shrimp, and pearl oysters started being farmed. All of these gave an increase in the aquaculture-produced tonnage. Although freshwater farming started earlier in Tanzania than mariculture, mariculture grew faster. Tanzania is among the Sub-Saharan countries where aquaculture experienced good growth during the 2000s (Shoko *et al.,* 2011).

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Production numbers

Inland aquaculture of tilapia and catfish has increased substantially in the last decade, whereby the number of earth ponds increased from 14,750 in 2008 to 18,200 in 2010 and 21,300 ponds in 2015 producing 3,118 tonnes/year (Rukanda, 2018). Rapid growth seems to have taken place in two years, as the Ministry of Livestock and Fisheries (MFL) estimated the production to be 10,000 tonnes in 2017. The first cage culture experiments in the lakes started in Lake Victoria and Lake Kumba and research is done in Lake Tanganyika and Lake Nyasa. Van der Heijden and Shoko (2018) reported 106 cages in total in Lake Victoria. New developments in the aquaculture sector have also included the establishment of 10 privately owned and five public hatcheries for tilapia, catfish, and marine species (Figure 12). Marine aquaculture in Tanzania consists mainly of seaweed, finfish (milkfish), and shellfish farming, which includes culturing pearl oysters, fattening crab and commercial shrimp farming (Rukanda, 2018). For the year 2020, when the last formal information was given, the production reached 18,885 tonnes (FAO, 2022), with 90% of it coming from freshwater: 27,979 earthen ponds, 431 cages and one RAS farm (Peart *et al.,* 2022).

The sector is still characterized by the limited number and quality of aquaculture inputs (seeds and feeds), low technology, limited knowledge and low level of investment. The main freshwater fish species cultured include Nile tilapia and African catfish. Most of the farms are situated in Ruvuma, Mbeya, Iringa, Arusha, and Kilimanjaro regions where the number of ponds exceeds 1000 in each region (Rukanda, 2018). Most of these farms are extensive culture systems. The rapid growth has been shown also in urban and neighbouring areas like Dar Es Salaam and Coast, where people are investing in semi-intensive culture systems, hatcheries, and feed production (Van der Heijden & Shoko, 2018).

Culture systems

Farming in small ponds of 150-300m^2 is the dominant freshwater fish farming system in Tanzania. Approximately 61% of farmers own only 1-3 ponds and are farming in an extensive way (Van der Heijden & Shoko, 2018). Most farmers harvest 6 to 12 months after stocking. Recently, medium, and larger-scale farms started to operate, some of them with a relatively high capital cost. Wetengere (2010) distinguished the farmers into the following categories:

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- Operating ponds over 100 m^2 size: feeding at least once/day, trying to maintain green water colour, their target are big fish for the urban market, frequent partial harvest and at least once/year total harvest, 15% of the farmers belong to this category with a productivity of 4-6 ton/ha/year (Figure 13).

- Operating ponds of all sizes: irregular fertilizing, feeding, and harvesting (depending on availability of inputs), 65% of the farmers surveyed belong to this category with a productivity of 1.5-3 ton/ha/year.

- Operating ponds of all sizes but with no feeding or fertilizing: clear pond water and irregular, partial harvests of insignificant and often only small fish, 20% of the farmers belong to this category with ponds being in a bad shape.

45% of the farmers harvest over 2 tonnes/farm during the year, 13% of farmers harvested 1-2 tonnes/farm and the rest (24%) harvest less than 1 tonne/farm (Shoko *et al.,* 2018). Reliable data on the production and productivity of small-scale fish farms is hard to come by because the owners seldom keep detailed records of purchase of inputs or harvest results. Fish farming, as in the rest of East Africa and the Sub-Saharan countries, is for most small-scale rural farmers a part-time activity besides crop farming and other income-generating activities.

Figure 12. The hatchery of Ruvu Fish Farm in Miswe, Tanzania.

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About 40% of the fish farmers surveyed, were practising monoculture of Nile tilapia, 21% were practicing monoculture of African catfish, while 39% farmed both Nile tilapia and African catfish in monoculture or polyculture. The majority (70.4%) of Nile tilapia farmers still practice mixed sex while only 29.6% practice mono-sex culture (Shoko *et al.,* 2018). Unfortunately, most farmers (76.1%) still are not aware of the importance of culturing mono-sex populations. They still believe that using mixed sex is the best traditional farming system, as it will give them more fish when they reproduce naturally in their ponds.

Shoko *et al.* (2018), also showed that 68.7% of farmers experienced mass mortalities

Figure 13. The on-growing ponds of Ruvu Fish Farm, in Miswe, Tanzania.

during stocking. Mortalities were also recorded during the transportation of broodstock and fingerlings. Unfortunately, these mortalities are associated with a lack of aeration on the farms or during fish transportation, as the majority of farmers do not use aeration when transporting fish, either because they do not know or because they cannot afford to. Only 43% of farms use aeration in their aqua farms and during transportation. Farmers are not familiar with good pond management as well, concerning the stocking density. They stock mixed sex of Nile tilapia at a stocking density of 6 to 10 fish/m^2 (Shoko *et al.,* 2018). Most farmers lack all the basic inputs needed to operate even a small-scale commercial fish farm:

- Capital to hire labour to build more and better ponds

- Harvest equipment (net, weighing scale)

- Adequate amounts of fertilizer

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- Feed and fingerlings of good quality

- Preferably all-male populations.

When compared with neighbouring countries, cage farming (in Lake Victoria especially) is at a higher level in terms of management and numbers. There were about 106 square cages in the Tanzanian part of Lake Victoria with varying sizes) in 2018 (Van der Heijden & Shoko, 2018) and 460 in 2021 (Msikula, 2021). Cage fish farming in Lake Victoria, in the part of Tanzania, has been allowed only if experimental trials are conducted in order to show that the environmental impact is going to be minimum (Ng'Wigulu, 2021). This impact may include eutrophication, poor water quality due to faecal matter and excretory, and diseases and parasites spread due to escaped fish from cages interacting with wild fishes.

Hatcheries

There were 15 registered hatcheries producing fingerlings in 2016, both privately and government owned. 12 of these produced tilapia and catfish, and two were designated for marine *spp*. (Rukanda, 2018). There is a demand for 30,000,000 fingerlings countrywide as estimated by the Department of Fisheries Development (Van der Heijden & Shoko, 2018). 80% of the hatcheries are privately owned and 20% are governmental (Shoko *et al.,* 2018). The majority (70%) of hatchery operators produce tilapia fingerlings and 30% produce African catfish fingerlings. The private hatcheries studied had separate

Figure 14. Small-scale farming in ponds in Tanzania (https://www.permaculturenews.org/).

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seed production and grow-out facilities (Figure 14). The climatic conditions (especially temperature) favour an all-year production of fingerlings. Hatcheries produce both monosex and mixed-sex Tilapia fingerlings. Hatcheries sell mostly fry or fingerlings (1-5gr, normally at the age of 30-50 days post-hatching) due to high demand (Van der Heijden & Shoko, 2018).

Tilapia and African catfish hatchery operators obtain broodstock from different sources, without being able to certify their quality. Shoko *et al.* (2018), reported that 40% of tilapia hatchery operators obtain broodstock from the wild, 30% from other hatcheries and 30% from grow-out farms (either their own or other ones'). At the same time, these percentages were for the catfish operators: 60% from the wild, 20% from other hatcheries and 20% from grow-out farms. Each hatchery is believed to have 1,000-10,000 tilapia broodfish and 500-6,000 catfish broodstock.

According to Shoko *et al.* (2018), the majority (50%) of tilapia hatcheries produce between 2,000,000-5,000,000 fingerlings/year, 20% of produce between 10,000,000-25,000,000 fingerlings/year. Respectively, 40% of catfish hatcheries produce 1,000,000-2,000,000 fingerlings/year, 20% produce 2,000,000-3,000,000/year and 10% only around 100,000 fingerlings/year. The remaining 30% of both tilapia and African catfish hatchery operators had no records of the seeds produced. The fingerlings are mostly sold directly to fish farmers (about 99%) (Van der Heijden & Shoko, 2018).

Fish feeding

Aquaculture is practiced in peri-urban and rural areas and is dominated by the culture of Nile tilapia in earthen ponds (van der Heijden & Shoko, 2018). The culture of Nile tilapia under small-scale production system is unprofitable due to low productivity. The low productivity is mainly due to poor quality feeds which are used to feed the cultured fish. In Tanzania, farmers use rice polishing, maize bran and kitchen leftovers to feed the cultured fish (Kaliba *et al.,* 2006). These feeds are of low quality, and fish reared on these feeds are unable to meet their maintenance and production requirements, especially for protein. This prolongs the time taken to reach market weight and consequently leads to production of small sized fish (less than 250 g) at harvest (8 - 12 months) and hence, low profitability of fish farming.

Studies have shown that with good quality feeds it is possible to achieve high yields of 10,000 kg/ha/year and fish can attain market weight in less than 6 months (Jauncey,

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1998). To realize this high yield, pond cultured fish need to be fed with concentrate diets containing 30 – 40% protein. The nutritive value of fish diet depends on quality of the protein ingredients used in diet formulation. In commercial fish feeds, fishmeal and soybean meal are used as the main sources of protein due to their high protein content and balanced essential amino acid profile. However, fishmeal and soybean meal are both costly and scarcely available due to high demand for their use in poultry and other livestock as well as for human consumption. Their inclusion in fish diets increases the cost of feeds, this in turn, makes fish farming to be expensive. In aquaculture, over 50% of the variable costs associated with the farming operation are expended on feed (Pillay & Kutty, 2005). Therefore, identification of alternative cheap and locally available feed ingredients is one of the solutions to the problem of low productivity and for sustainable tilapia farming.

Tunisia

With its 1300 km coastline and 110 000 ha of coastal lagoons, Tunisia offers important resources of marine and continental fauna. Fisheries and aquaculture play a key role in the Tunisian economy providing national and foreign food supplies and offering several employment opportunities in addition to international exchange earnings. Indeed, this sector provides an average annual production of 125,000 tonnes with an average growth rate of about 4% (between 2010 and 2019) and funds almost 10% of agricultural GDP. It contributes to self-sufficiency and food security by an average annual contribution of 13 kg / person / year. It also provides direct and indirect employment for more than 100,000 people, including about 60,000 fishermen and represents the 3rd largest agricultural export.

Overview of Aquaculture sector in Tunisia

I. History

Like the Mediterranean countries and with the scarcity of wild resources due to pollution, overexploitation and illegal fishing, Tunisia has committed to develop the aquaculture sector since the 1960s. This very old activity that dates back to Roman times has been initiated by private investors by breeding the Mediterranean mussel *Mytilus galloprovincialis* and the Pacific oyster *Crassostrea gigas* on fixed tables in Bizerte (Northern Tunisia). The supply of mussel seed is done locally by collection in the lagoon of Bizerte while oyster is imported from France, Italy etc. Shellfish farms were transferred to the National Office of Fisheries (ONP), which continued these activities and initiated the construction of ponds in the lagoons of Monastir and Tunis (Northern and Eastern

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Tunisia). Together with INSTOP (National Scientific and Technical Institute of Oceanography and Fisheries, INSTM currently), established the rearing of fry from various species (common carp, mullets) in dam reservoirs and their exploitation by fishing. At the beginning of the 1980s, one of the first private hatcheries for sea bass *Dicentrarchus labrax* and sea bream *Sparus aurata* in the Mediterranean was set up by investors in the south of the country. During the decade of the 1990s, aquaculture was practised through fish farming in inland freshwater in extensive mode with limited private achievements, mainly in the breeding of sea bass, sea bream and shellfish farming in the lagoon of Bizerte (fixed tables and floating channels).

Since 2003, a new aquaculture activity has emerged, making an exceptional leap forward in the adoption of new farming techniques: the rearing of bluefin tuna *Thunnus thynnus* which ensures a weight gain of more than 20% in a few months, as well as allowing the sale of this product in the international market. The tuna, originating from the fishery and destined for fattening, is transferred alive to floating cages in the open sea. They are kept and reared in captivity for a few months before being sold fresh at relatively higher prices.

Floating and submersible cage farming of sea bass and sea bream has been increased remarkably during the last few years. Fry and feed are mainly supplied through imports from France and Italy.

Regarding inland aquaculture, the first attempts to introduce freshwater species were made during the 1960s. These attempts included:

- The introduction and breeding of the common carp in northern Tunisia in 1965 in order to constitute a nursery of fish fry and to stock them in the dam reservoirs.

- The establishment of two research stations in southern Tunisia, where carp and tilapia breeding tests were undertaken in 1966.

- In 1973, the development of four ponds fed by a brackish water source in the south of the country for the realization of tests in the breeding of mullets.

At the beginning of the 1990's, as part of a Tunisian-German cooperation project entitled "use of dams for aquaculture", freshwater fish were introduced on a large scale in a reservoir located in the north, which constitutes the largest reserve of drinking water in Tunisia. This project laid the foundations for the fishing activity in the Tunisian dams.

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Within this project, stockings with mullet fry collected from the natural environment and the introduction of new species such as zander, carp, catfish and black bass, have been performed.

In 1994, the Ministry of Agriculture promulgated a decree (JORT, 1994a) to regulate and supervise this activity. In 1999, the experimental tilapia breeding station was created in southern Tunisia by the National Institute of Marine Sciences and Technologies, in order to make better use of geothermal water resources, to make the exploitation of existing agricultural project infrastructures profitable and to diversify and increase aquaculture production. On the same grounds, the Boumhal station was created (Northern Tunisia) for reproduction tests of Chinese carps (herbivorous, bighead and silver) in 2000.

A cooperation project between The General Direction of Fisheries and Aquaculture/ United Nations Development Programme was implemented in 2004 for the development of continental fish farming in Tunisia in inland waters including dam reservoirs and geothermal sources. Finally, the "Safeguarding and socio-economic development of environmental resources in the north-western region of Tunisia" project, was carried out within the framework of Tunisian-Italian cooperation (GIPP / COSPE).

II. Production numbers

The aquaculture production in Tunisia has increased from 4,000 tonnes in 2009 to 26,000 tonnes in 2021 (Figure 15), which represents a contribution of 17% in the national production and a production value of 105.3 million US$ (25% of the total value of fisheries and aquaculture products (DGPA, 2021)).

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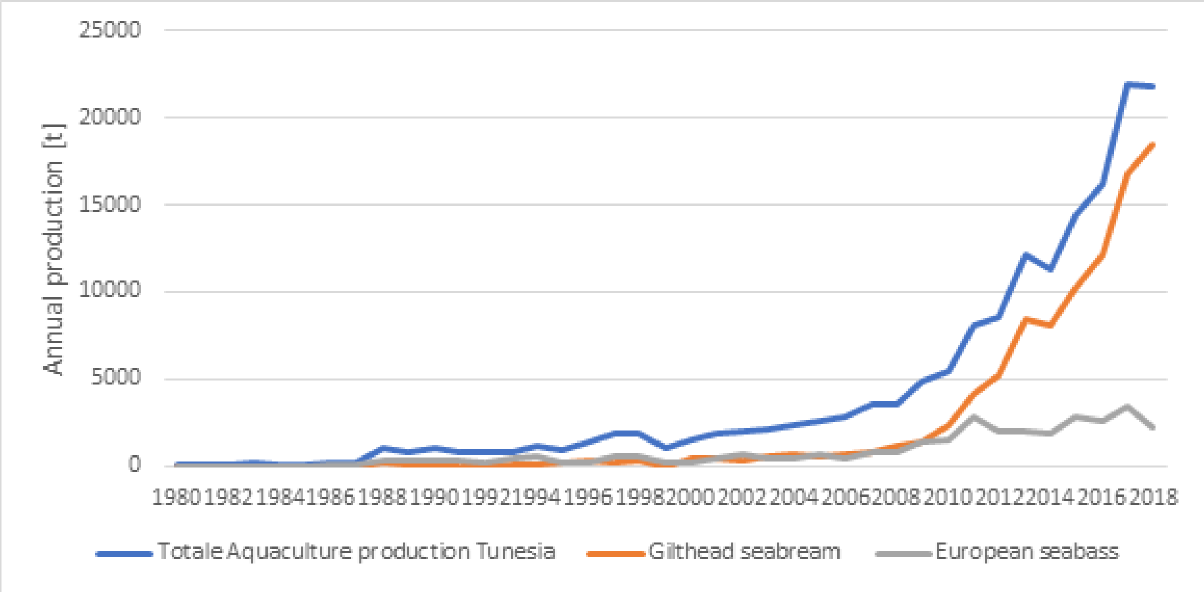
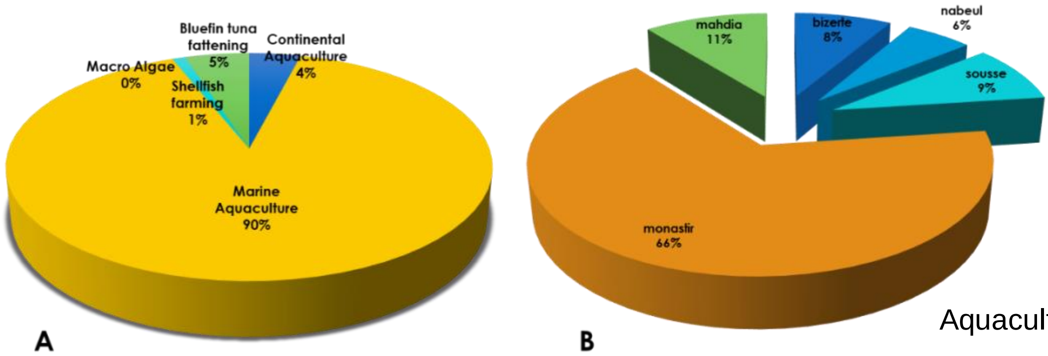


Figure 15. Aquaculture production in Tunisia.

Marine fish farming represents the most productive sector with 90% of the production (23,000 tonnes during the year 2021) and is recording an annual growth rate of 21% (2007-2020). The Bluefin tuna flattening contributes to 5% of the aquaculture production followed by inland aquaculture (4%) (Figure 16A). The largest farm production is noted in eastern Tunisia (Monastir governorate) with 66% of total aquaculture production (Figure 16B)



Aquaculture

Figure 16. Distribution of production by type of farming; B: Distribution of farm production by governorate.

productive projects are distributed mainly on marine fish farming with 23 projects and a total production of 23,000 tonnes during the year 2021. Shellfish farming with a production of 169 tonnes was provided by 5 farms (1% of national aquaculture

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production) while algae-culture provided 12 tonnes: 7 farms of spirulina culture with a production of about 9 tonnes of dry spirulina and 1 farm of *Ulva* and *Gracilaria* culture with a production of 3 tonnes (DGPA, 2021). As for inland aquaculture, it has recorded an average production over the ten years of about 1000 tonnes, with approximatively 1.3 billion US$ of the total value of aquaculture (Table 1).

Table 1. Aquaculture productive projects in Tunisia (2021).

FIELD	FARMING TECHNIQUE	Species			No. of productive projects	Production 2021 (T)
Marine Pisciculture	RACEWAY POND	*Sparus aurata*	*Dicentrarchus labrax*	*Argyrosomus regius*	2	23618
	FLOATING CAGE				21	
Bluefin tuna fattening	FLOATING CAGE	*Thunnus Thynnus*			3	1318
SHELLFISH FARMING	Floating/ Fixed systems	*Crassostrea gigas*	*Mytillus galloprovincialis*		5	169
SHRIMP FARMING	RACEWAY POND	*Penaeus vannamei*			1	1
MACRO ALGAE	FLOATING LINES	*Gracilaria sp+ Ulva lactuca*			1	3
CONTINENTAL AQUACULTURE	Extensive breeding: Seeding of dams and lakes	Mullets, Carps, Zander, Catfish, Eel, Black bass...			32	891
	Raceway	*Oreochromis niloticus*			4	26
	Raceway	*Spirulina sp*			7	9

According to FAO (2020), Tunisia's aquaculture products are sold on the local as well as on the international markets. From the beginning of their activities and first installations, the sea bass and sea bream aquaculture products were exported with attractive prices. Tunisia exports its marine aquaculture products mainly to countries of the Gulf region (Emirates, Qatar, Jordan and Saudi Arabia) and Russia, followed by neighbouring and African countries (Algeria, Morocco, Libya and South Africa) together with USA and Canada, and thirdly to European countries around the Mediterranean Sea (Italy, France and Spain). However, in recent years, due to competition with other farmed products from countries surrounding the Mediterranean, the Tunisian aquaculture producers have been looking into other potential markets. Parallel to the European market, the Tunisian aquaculture products are sold into the large Tunisian tourism sector directly to hotels and tourist restaurants. The rest is sold on the wholesale markets in Tunis, Sousse and Sfax.

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This fish is then transported to the retail markets in towns and villages under statutory health and hygiene conditions.

Figure 17. Intensive fish farming in raceways.

Today, the local markets are the main destination of the most important part of the Tunisian production of sea bass and sea bream, estimated to contribute to 80 and 93% of the total quantity produced from each farm. It should be pointed out that the selling prices for these fish are supposed to be more beneficial to the producers on the Tunisian market than on the European market. Nevertheless, the average selling price of European seabass and gilthead seabream from farm on the national market is about 10.6 and 9.7 Tunisian dinars (approximately 3.62 US$/kg and 3.31 US$/kg in 2020), respectively, whereas the same product on the European market was sold for around 13.1 Tunisian dinars (approximately 4.57 US$ in 2020).

Shellfish (mussels and oysters) is mainly destinated to the export after purging in the licensed purging centres according to current legislation and European directives. According to the FAO (2020) value of the produced mussels is around DT 4.3/kg (appr. 1.49 US$ in 2020) and for the oysters around DT 12.7/kg (approximately 4.38US% in 2020). Table 1 presents an overview of main issues which have to be kept in mind to understand the current situation of the Tunisian marine aquaculture sector.

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Freshwater fish is currently being sold entirely on local markets, mainly on the wholesale markets in larger towns such as Tunis, Sousse and Sfax or on the markets of small towns and villages close to the dam lakes. There is no special demand for this type of product, except in the off-season for marine fish, when there is a demand for mullet or pike-perch which are also very popular. Freshwater fish selling prices are quite low compared with marine fish. Prices vary from 1DT/kg for common carp (approximately 0.34 US$ in 2020), to 2.5DT/kg for pike-perch (approximately 0.87 US$ in 2020) and 3.5DT/kg for mullet (approximately 2.25 US$ in 2020).

III. Culture systems

The farming techniques currently practiced in Tunisia are the following (Cherif et al., 2011; FAO, 2022c)

Intensive farming in raceways

It is practiced in concrete basins of rectangular or circular shape fed by a pumping station of a very important flow (Figure 17). The grow-out is aimed at the production of bass and sea bream from 300 to 350 g. The stock is fed with feed imported from factories located in Europe.

Figure 18. Fish farming in cages.

Farming in cages

Tunisia's geographical location open to the Mediterranean and the extent of its coastline, are assets for the development of this recent aquaculture activity in open sea. Since

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2007, offshore cage culture has experienced significant growth with 25 active companies in 2015 (Figure 18).

Semi-intensive farming

This technique is used by a farm located in southern Tunisia (Ajim Jerba). This farm has earthen ponds of 2.5 ha to 9 ha, designed exclusively for the breeding of sea bream. The rearing is done with pre-grown fry in concrete basins. The fish are fed with a semi-wet feed made on the farm with fresh fish mince, fish meal and soybean meal.

Inland fish farming

Inland fish farming is practiced extensively in dams and intensively in basins fed by geothermal water in the south of the country.

Exploitation of dam reservoirs: 33 dams were in operation in 2014 in the North and centre of the country, for the production of electricity, the supply of drinking water or irrigation, flood control and recharging of groundwater. Intensive fish farming is subject to certain restrictions in reservoirs intended for drinking water supply.

Figure 19. Fish farming in dams.

The water bodies of these reservoirs contain fish species that have a direct commercial value (consumption by humans) or indirectly (fodder fish for carnivorous species) (Figure 19).

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Fish farming in geothermal waters: In Tunisia, the exploitation of geothermal water resources has allowed an agricultural revolution in the South of Tunisia. However, aquaculture in geothermal water remains limited by numerous constraints including water cooling and availability. Currently only 4 projects are active with the production of Nile tilapia *O. niloticus*.

<u>*Shellfish culture*</u>

The Mediterranean mussel *Mytilus galloprovincialis* and the Pacific cupped oyster *Crassostrea gigas* are farmed using breeding tables or floating lines to which they are suspended (Figure 20). These two culture techniques are practiced in the Bizerte Lagoon in the north of the country.

Figure 20. Shellfish farming.

IV. Hatcheries

Hatchery production for marine aquaculture in Tunisia currently comprises 2 private companies, focusing on fingerling production of the Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*). These companies provide juveniles to the privately owned grow-out companies. With an annual total production volume of 25 million fingerlings (*Dicentrachus labrax* and *Sparus aurata*), the reproduction of both species can be considered been established in Tunisia. At the moment, 5 companies have asked for permits or are in different state of preparation to start production in the near future, targeting a total capacity of 190 million fingerlings. The licensing procedure for a marine aquaculture farm in Tunisia requires at least 1 year up to 2 years. Based on the current production numbers of the two mainly targeted species with a total volume of approximately 20.000 tonnes in 2018, and considering this fingerling production sufficient for the future local producers, this capacity would enable extension of the

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Tunisian production to approximately 160,000 tonnes based on these two targeted species (Azaza, 2021).

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V. Fish feeding

Feed production in Tunisia currently comprises 3 companies, with a total production capacity of about 90,000 tonnes/year. The species in focus are Gilthead seabream and European seabass but also feed for other species like meagre, tilapia or shrimps. The current annual national production is significantly under the potential production capacity and therefore, the companies are looking for other international markets to sell their products. It is also assumed that the local producers can easily extend their production in order to provide the required additional feed in the case of increasing finfish mariculture activities in future (Azaza, 2021).

VI. Continental Aquaculture in Tunisia

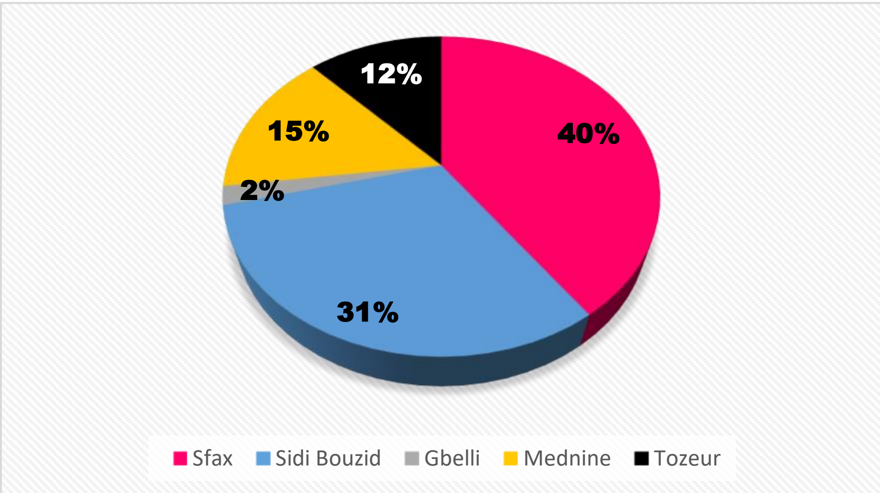

Figure 21. Distribution of Tilapia production by governorate (DGPA, 2021).

Since the beginning of the 1950s, Tunisia had a developed water collection network. The objective being to satisfy the country's needs in drinking water, the maintenance and development of agricultural activity, the recharging of groundwater, and the production of hydroelectric power.

This network is essentially made up of dams and hill lakes and extends over a total area estimated at 20,000 ha holding more than 2 billion m^3 of water spread over ten governorates.

VI.1. Management of freshwater reservoirs

The exercise of the activity of continental aquaculture is dependent on obtaining a fishing permit or authorization of exploitation. Currently, there are:

- 153 fishing authorizations or the equivalent of 307 fishermen in 2021.

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- 4 dams are operated by private promoters (Ghzela, Laabid, Lahjar and Bzirekh).

The length of the boats used must not exceed 6m and they are generally made of wood or resin. The allocation of fishing permits per reservoir is based on the surface area of the dam. The dams are operated in an extensive culture mode. Successful attempts have been made to rear Tilapia in floating cages in few dams during the summer months, but without any follow-up in terms of profitability, which is dependent on the quality produced. The fishing activity in the dams is open during the whole year, except for the months of March and April corresponding to the biological rest period of the ecosystem (DGPA, 2019).

VI.2. Seeding of freshwater reservoirs

The use of freshwater bodies for fish farming began in the late 1960s with the stocking of some dams with endemic species such as barbel and eel. Subsequently, the introduction of mullet fry from 1979 to 1988 by the National Fisheries Office (ONP) allowed an increase in the quantities fished. It was only towards the end of the 1980s that inland fish farming in Tunisia underwent a significant qualitative and quantitative development with the start of the Tunisian-German technical cooperation project on the development of fishing in Tunisia (DGPA, 2019).

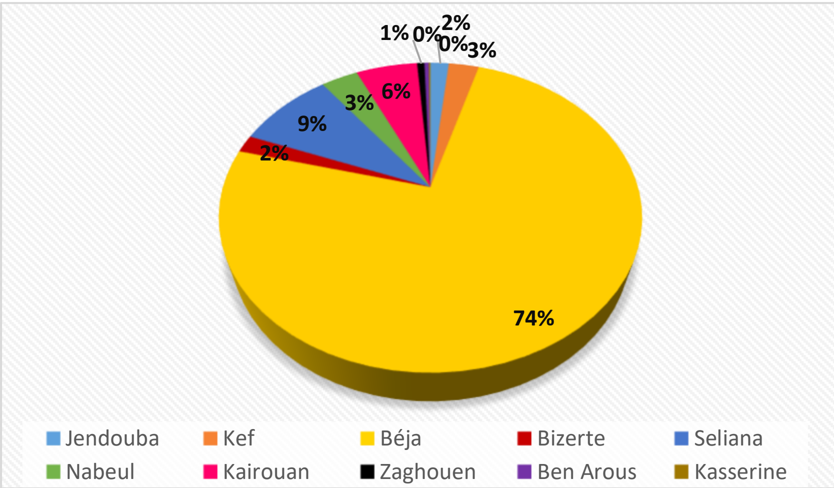

Figure 22. Distribution of inland aquaculture production by governorate (DGPA, 2021).

The national program for the stocking of dams has allowed to increase the number of stocked reservoirs. Currently, Tunisia has 40 plans of fresh water stocked including 22 dams and hill dams and 16 hill lakes spread over several governorates. This program consists in the seeding of fry fished from the natural environment in freshwater reservoirs

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or the transfer of broodstock of certain species such as zander and black bass as well as forage fish (e.g. roach and the common rudd) (DGPA, 2019).

Regarding the breeding of tilapia in basin, the DGPA (Direction Générale de la Pêche et de l'Aquaculture) has granted 7 operating licenses of which 5 projects are productive located in the governorates of Sfax, Sidi Bouzid, Gabes, Kebili, Medenine and Tatouin. Total production reached 26 tonnes in 2021 with a maximum noted in Sfax governorate (Figure 21). The governorate of Beja is the leading provider of freshwater fish with 74% of national production (Figure 22). The Sidi Salem reservoir provides on average of more than 65% of total catches.

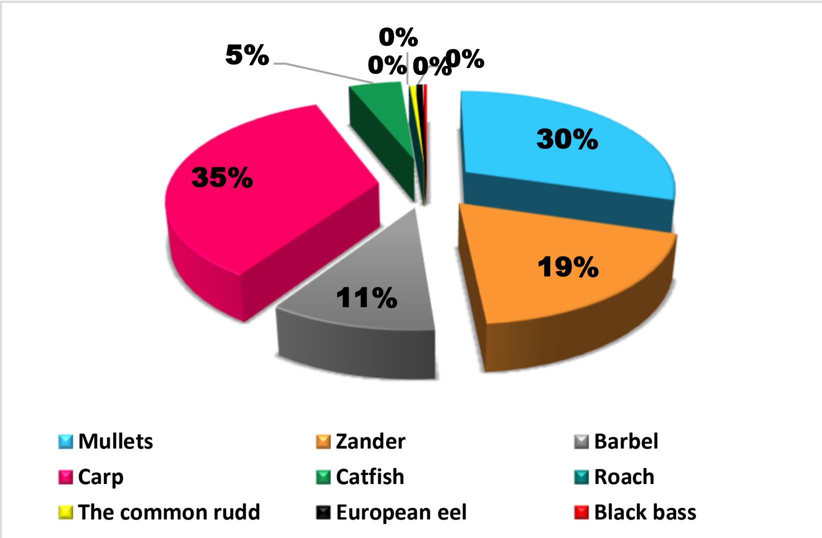

Figure 23. Distribution of continental aquaculture production by species in 2021.

Carps, Mullets and in third place Zander are the most caught species in Tunisia, representing nearly 84% of the freshwater production. The catches of barbel and catfish represent approximately 16% of production (Figure 23) (DGPA, 2021).

Mullet, zander and European eel are considered among the noble freshwater fish. Their selling prices vary respectively between 1.37 and 2.05 US$/kg; 1.03 and 1.37 US$/kg; 2.74 and 4.11 US$/kg. The selling prices of carp, roach and the common rudd are among the lowest. They vary between 0.10US$/kg and 0.34 US$/kg. They are sold at the local level in the regions near the dams.

Conclusion

Tunisian aquaculture sector has been rapidly developing in recent years, mainly based on finfish mariculture of especially sea bream (*Sparrus aurata*) in netcage systems along

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the Tunisian coastal zones. Other mariculture systems such as mussel and oyster cultivation, tuna fattening, and traditional mullet cultivation have been left behind in this development. In order to enable the best possible further development of the Tunisian aquaculture sector, which sets, accordingly to the aquaculture developmental strategy for 2030 a target production of 56,000 tonnes per year, nearly three times of the current production. Therefore, it is essential to combine the listed information and work out the necessary steps in cooperation with all relevant Tunisian stakeholders.

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Aquaculture Systems

Feed Formulation

Local Feed Ingredients (SUA-Tanzania)

One of the main issues facing the aquaculture industry in Tanzania is the lack of high-quality feeds. The feed manufacturing industry in Tanzania is characterized by small-scale plants which produce feeds with limited quality and quantity. Currently, according to the Ministry of Livestock and Fisheries (URT, 2021b), fish feed production is estimated at 540 metric tonnes. This does not meet the estimated demand of 120,000 tonnes/year. Moreover, due to high prices of commercial feeds and feed ingredients, most fish farmers cannot afford to purchase the commercial feeds and, hence, rely on locally available feed ingredients to formulate their feeds (Mmanda *et al.,* 2020). The feed materials mostly used in Kilombero district to formulate diet include agro-processing by-products (rice polishing, maize bran and sunflower seed cake) and leguminous tree leaves (*Leucane leocephala*, *Moringa oleifere*) and aquatic plants (*Azolla pinnata*) (SUA). Studies have revealed that diets formulated using locally available ingredients are cheaper (less than USD 0.5/kg) compared to commercial feeds (USD 1.5 USD/kg) (Shoko *et al.,* 2022). Therefore, to reduce production costs, most farmers either don't use supplementary feeds at all or formulate their own feed using locally available feed ingredients. However, the home-made diets have an imbalance of energy and protein ratio, this is attributed to lack of knowledge for formulation of well-balanced diet. In addition, plant-based ingredients contain high fibre content and anti-nutritional factors which limit nutrients and protein bioavailability (El-Sayed, 1999). In addition to poor availability of essentials amino acids such as methionine, tryptophan and lysine, plant ingredients have poor digestibility and are not palatable (El-Sayed, 1999; Ogunji & Wirth, 2001). The use of these feeds results into lower growth rate and hence, poor yield at harvest. Attempts to replace the fishmeal in fish diets with plant protein sources have resulted in variable success and generally led to reduced feed efficiency and growth (Ogunji & Wirth, 2001). According to De Silva and Anderson (1995), it is not possible to replace fishmeal with a single plant protein source. However, it has been shown that combining different alternative protein sources which possess different limiting amino acids can improve fish growth performance (Ogunji & Wirth, 2001). Therefore, this study intends to assess the effect of replacing fishmeal with sunflower seed cake and *Moringa oleifera* leaf meal on growth

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performance and feed utilization efficiency and determine their optimal inclusion levels in Nile tilapia diets.

Commercial fish diets are manufactured as either extruded (floating) or pelleted (sinking) feeds. Some fish species such as tilapia prefer floating feeds while others such as catfish prefer sinking feeds (Limbu, 2015; Abdel-Hay *et al.,* 2020). A study of carp by Yaqoob *et al.* (2010), revealed that fish fed floating diet have better growth performance than fish fed sinking pellets. In traditional small-scale fish farms in Africa, typically fish are fed both floating and sinking pellets, depending on the availability and price of each type of feed (Adewumi & Olaleye, 2011). This project will evaluate the suitability of powdery feed, sinking pellets and floating pellets as feed for Nile tilapia and determine the most appropriate diet form that can be used by small-scale farmers in rural areas.

Design and description of the specific pilot system

During the survey which was conducted in April 2022 in 21 villages of Kilombero district, the feed materials used for fish feed formulation were identified. Then, feed samples were collected and analysed for chemical composition. Based on the chemical composition of the locally available feed materials, seven well balanced diets were formulated to contain 30% crude protein. The diets were formulated based on fishmeal, sunflower seed cake and moringa leaf meal as sources of protein and maize bran and rice polishing as energy sources. The energy sources formed 59% of the diet and their inclusion levels were maintained constant in all the seven diets (38% maize bran and 21% rice polishing). The protein sources comprised 40% of the diet, but their inclusion levels varied among the seven diets. All diets contained 1% mineral premix. In addition to the diets formulated using locally available feed materials, a commercial diet (C2) was added and used as the control diet and formed the 8th treatment. The proportions of feed ingredients are shown in Table 2. The contribution of fish meal, sunflower seed cake and moringa leaf meal to protein is presented in Table 3.

Table 2. Promotions of feed ingredients in the formulated diets.

Ingredients	D1	D2	D3	D4	D5	D6	C1
FM	1	1	0.5	0.5	1	0.5	4
MB	3.8	3.8	3.8	3.8	3.8	3.8	3.8
RP	2.1	2.1	2.1	2.1	2.1	2.1	2.1
SSC	1.5	0.75	1.75	0.875	3	3.5	0
MLM	1.5	2.25	1.75	2.625	0	0	0
Mineral	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	10	10	10	10	10	10	10

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Note: ***FM- Fishmeal, MB- Maize bran, RP- Rice polish, SSC- Sunflower Seedcake, MLM- Moringa Leaf Meal, M- Minerals & D- Diets***

Table 3. Percentage contribution of fish meal, Sunflower seed cake and Moring leaf meal as source of protein in formulate feeds.

Protein source	D1	D2	D3	D4	D5	D6	C1
Fishmeal	25	25	12.5	12.5	25	12.5	100
Sunflower Seedcake	37.5	18.75	43.75	21.875	75	87.5	0
Molinga Leaf meal	37.5	56.25	43.75	65.625	0	0	0

The feeding trial started on 28th September 2022 and will last for 120 days; hence, it will be completed on 25th January 2023. The diets were used as experimental treatments. The eight treatments were randomly allocated to 16 plastic tanks which are used as the experimental units. Each treatment was randomly assigned to two plastic tanks. Each tank has a size of 62.5 cm length x 42.5 cm width x 30 cm depth. All tanks are indoor and fitted with a recirculating and aeration systems. All tanks were filled with water and the water is circulated and aerated continuously. Each tank was stocked with Nile tilapia fingerlings at a density of approximately 118 fingerlings/m^3. During the first 30 days of the experiment the fish were fed with respective diets at a feeding level of 7.5% of body weight. After 30 days, the fish were fed at 5% of their body weight and this feeding level will be used up to the end of the experimental period. The fish are fed three times per day at 8.45 am, 12.45 pm and 4.45 pm. Water quality parameters such as water temperature, dissolved oxygen, pH, total alkalinity and turbidity are measured weekly to ensure that they are within the acceptable limits for tilapia growth. Body weight of fish in each tank are measured in bulk and were first measured at the start of the experiment and then measured every two weeks and this will continue up to the end of the experiment. Weight gain, growth rate, specific growth rate, feed conversion ratio as well as gross margin for each treatment will be determined at the end of the experiment and the best diets will be identified.

Following the identification of the best diet in the first experiment, a second experiment will be conducted to determine the most appropriate form of the diet to be used for feeding tilapia. Two diet forms (flakes and pellets) will be evaluated. The best diet from experiment one above will be used to make flakes and pellets. The effects of flakes and pellets on water quality, plankton community and growth performance of Nile tilapia will be assessed. The experiments will be done on-farm in farmers earthen ponds. Nine

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farmers from three villages in Kilombero district will be purposely selected basing on the criterion of having at least two fishponds with the size of 100 - 300m^2. The experimental treatments will be the feed forms (flakes and pellets). Each farmer will have two ponds for the experiment and the treatments will be assigned randomly to the ponds. Two weeks before stocking, all ponds will be fertilized with chicken manure at a rate of 50g/m^2. All ponds will be stocked with sex-reversed Nile tilapia (*Oreochromis niloticus*) at a stocking density of 4 fish/m^2. Feeding will be done twice daily, in the morning (10.00 am) and in the evening (4.00 pm).

Weekly measurements of water quality parameters (water temperature, dissolved oxygen, pH, total alkalinity, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total dissolved solids, and conductivity) will be done in each pond. A random sample of 10% of fish will be sampled from each fishpond for body weight and length measurements, at the start of the experiment, and then every two weeks up to the end of the experiment. Death of fish will be recorded every day. At the end of the experiment, fish will be harvested. Data including yield, growth rate and survival will be computed for fish from all treatments. The best diet and feed form (flake or pellet) will be identified and promoted for use by fish farmers.

Available Results

Results from the survey show that the majority of fish farmers in Kilombero district culture tilapia in earthen ponds while a few farm African catfish either under monoculture or polyculture system in combination with tilapia. Pond water is fertilized with either cattle manure or chicken manure. Most farmers use homemade feeds to feed their fish. The ingredients used for making the feeds are rice polishing, maize bran, fishmeal, sunflower seed cake and human food leftovers. The results in Figure 24 show that the majority of farmers in Kilombero district feed their fish with a mixture of rice polishing and maize bran, followed by those who use rice polishing only as a single ingredient in the diet. There were few farmers who were using either a combination of rice polishing, maize bran and human food leftovers or a mixture of rice polishing, maize bran and fishmeal. From the results, it is evident that most farmers use rice polishing and maize bran, which are both energy sources. Therefore, ingredients for protein sources, of both plant and animal origins, are rarely included in fish diets used by the fish farmers in Kilombero district. This may be due to lack of knowledge on fish nutrition and feed formulation. In addition to lack of knowledge on feed formulation, farmers in Kilombero district have no

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proper knowledge on appropriate feeding regime for fish with different size/age (i.e. fry, fingerlings and grow-out). For proper growth, there is a need to provide each fish category with the right amount of diet, containing appropriate and balanced nutrients in order to meet the requirements for maintenance and growth. The quantity of feed is supposed to match the progressive increase in weight, but farmers in Kilombero district tend to guess the quantity of feed to provide their fish per day. Also, the fish farmers don't follow appropriate feed formulation protocol, hence, the type of feeds they use are not nutritionally balanced. This has resulted in low growth performance and poor yield at harvest. Therefore, there is a need to train fish farmers on proper feeding and formulation of well-balanced diets for fish feeding.

Forms of fish feed used for feeding fish

Results in Figure 25 show that the fish feeds used by most fish farmers in Kilombero district are in powdery form. Very few farmers use pelleted feeds and the majority of farmers are not aware of the existence of pelleted feeds. This may be attributed to the

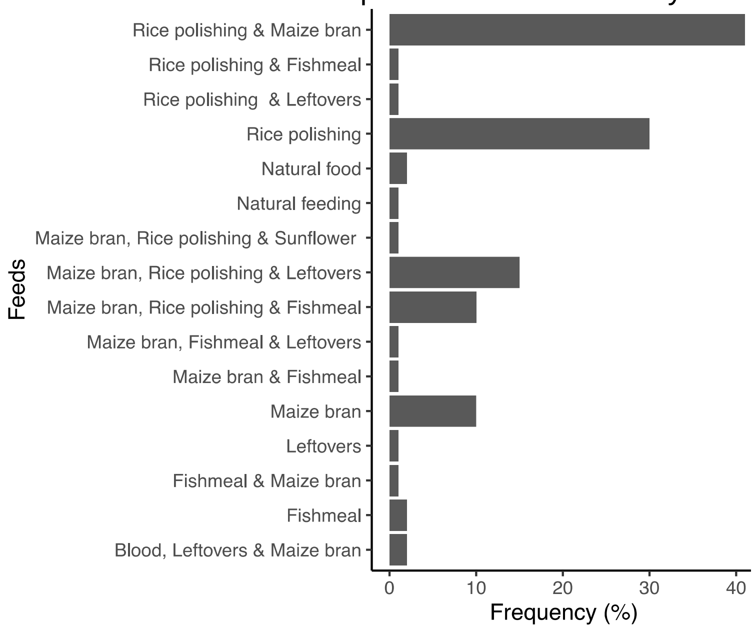

Figure 24. Feeds used for feeding tilapia in Kilombero food hub.

fact that pelleted feeds are commercial feeds either made by feed manufacturing factories located in major cities such as Dar es Salaam or imported from outside the country. The commercial feeds have high price and are not easily available in rural areas. Most small-scale farmers cannot afford to use commercial feeds and thus, they tend to make their own feeds using locally available feed ingredients. Farmers in Kilombero district use powdery feeds of either maize or rice bran or the mixture of the two, because

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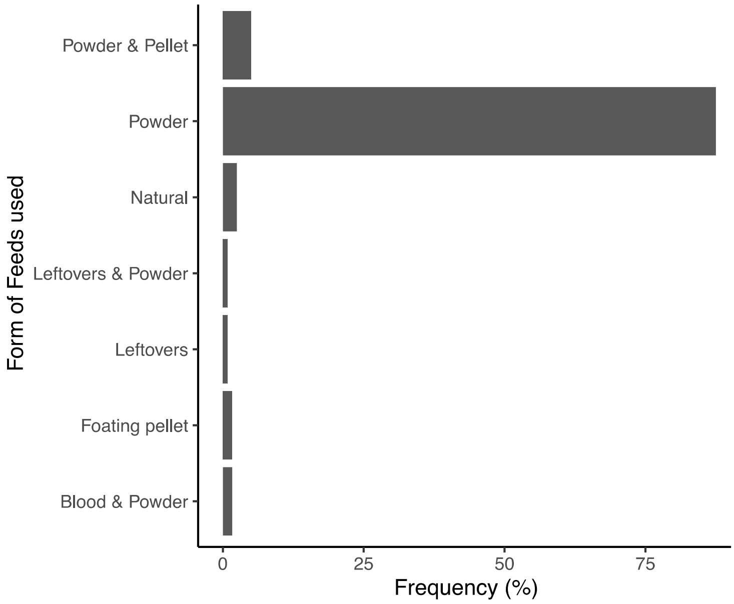

Figure 25. Forms of fish feed used at Kilombero Food-hub.

these ingredients are easy to find and less expensive. However, these homemade feeds are not well balanced in terms of nutrient required to meet the nutritional requirements of fish.

Preliminary results on feeding trial

Figure 26 shows the preliminary results of the feeding experiment conducted to evaluate different diets formulated using locally available feed ingredients in comparison to a commercial diet. The results show that the Nile tilapia fingerlings fed the commercial diet (diet C2) showed higher growth performance than those fed other diets from week seven of the experiment. The fingerlings fed a diet containing fishmeal as the only protein source (diet C1) had lower growth performance compared to those which were fed diets D1, D2, D3 and D4 in which fishmeal was replaced with the combination of sunflower seed cake and moringa leaf meal by either 75 or 87.5%. The fingerlings fed diets D3 and D4 in which fishmeal was substituted with the mixture of sunflower seed cake and moringa leaf meal by 87.5% ranked second in terms of growth performance to those which were fed the commercial diet (C2). On the other hand, the fish which were fed diets D5 and D6 in which fishmeal was replaced with only sunflower seed cake by 75 and 87.5%, respectively, showed the lowest growth performance. Therefore, the preliminary results have clearly demonstrated that the combination of sunflower seed cake and moringa leaf meal can substitute fishmeal in Nile tilapia diets up to 87.5% without compromising the growth performance. This is consistence with the findings of

El-Saidy and Gaber (2003) who reported that protein from plant protein mixtures can completely replace the fishmeal protein in Nile tilapia diets. Based on the preliminary results, sunflower seed cake and moringa leaf meal can be used to replace fishmeal, which is expensive.

Complete results on feeding experiment will be available at the end of February 2023.

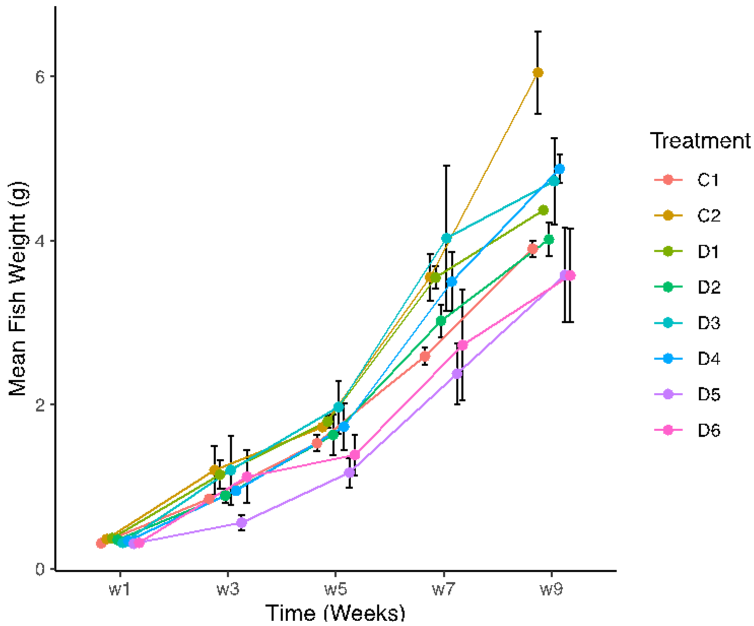

Figure 26. Preliminary growth performance of Nile tilapia fed different formulated diets based on locally available feed ingredients in Kilombero district.

Integrated Aqua-Agriculture

Integration of aquaculture and agriculture (NARO - Uganda)

Much as aquaculture has been identified as one of the most plausible options to bridge the gap between the growing fish demand and the decline fish production from capture fisheries, it can pause a big danger to the environment if the effluents are not well managed (Tovor *et al*., 2000 and Lin & Yi, 2003). Increasing demand for fish, has led to the development of several technologies targeted towards intensification with little attention being paid to the effects of aquaculture effluents on the aquatic environment. The few technologies that are currently being championed focus more on extraction technologies whose contribution to increased fish productivity, yield and other food production is very minimal. Integrated aqua-agriculture is one technology with the potential to ensure cleaner production while maximizing the nutrient discharges from aquaculture. At the same time this technology can play a greater contributory role in production of a number of agricultural crops. Nutrient extraction from aquaculture effluent

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waters reportedly leads to increased yield while also taking advantage to produce other foods and vegetables. Wastewater is key to this system because droppings or uneaten feeds from the fish culture systems contain nutrients that can support growth of vegetables. In this study wastewater from a fish production system is used to irrigate the selected vegetables. The objective of the study from NARO is to identify and demonstrate to smallholder farmers the best integrated fish-vegetable models of high potential, value and affordability for increased household food security and incomes while ensuring environmental sustainability (Figure 27).

Specific objectives

1. Determine nutrient (phosphorous and nitrogen) extraction efficiency of the different vegetables used in the fish-vegetable integrated production model.
2. Compare growth performance of African catfish (*Clarias gariepinus*) farmed in fish-vegetable integrated model in relation to the commercially cultured African catfish.
3. Compare crop production yield from fish-vegetable integrated model with production from specialized vegetable gardens.
4. Evaluate the quality of the produce (fish and crops) in terms of nutrients and bio accumulation (heavy metal).
5. Assess the economic viability (cost-benefit analysis) of the two suggested integrations.

Method

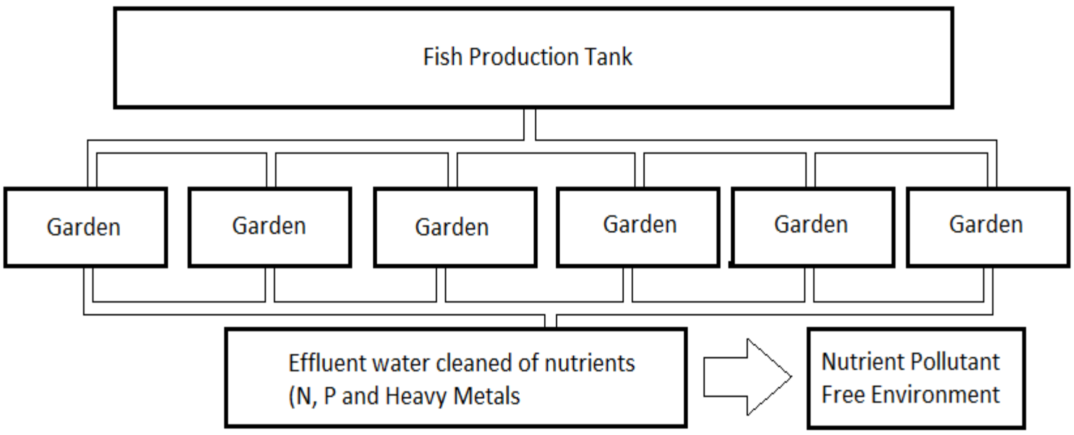

Figure 27. Schematic flow of wastewater used to irrigate the vegetables.

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Wastewater from fish production tanks was used to irrigate and supply nutrients to selected vegetables cultured in vegetable gardens. In this experiment fibreglass tanks ($1m^3$) were used to simulate fish production facilities with vegetables grown in earthen gardens adjacent to these tanks (Figure 28).

Each of these fibreglass tanks was stocked with African catfish (*Clarias gariepinus*) of average weight of 10g at stocking densities of $5kg/m^3$. Another earthen plot was prepared and planted with the same vegetables and irrigated using underground water (Figure

Figure 28. Leaf vegetables irrigated with aquaculture effluents.

29). The irrigation with aquaculture wastewater was done per the schematic flow (Figure 27). A layout of a mini-irrigation system with wastewater from the fish production tanks used to raise vegetables while these vegetables extract nutrients as a cleaner production role (Figure 27 & 28). Six plots of gardens (2.7x10m) were prepared. Three selected types of vegetables were randomly allotted into the two plots in replicates. The vegetables selected for use in these experiments included; tomatoes (*Solanum Lycopersicum*), leafy vegetables–nakati (*Solanum aethipicum*), dodo (*Amaranthasus retroflexus*), Sukuma (*Brassica oleracea*), Beta root (*Beta vulgaris*), cabbage (*Brasica oleracea* (capitatta group)) and spring onions (*Allium fistulosum*). Water parameters (dissolved oxygen, temperature, ammonia-nitrogen, pH) that might cause acute stress to the fish were monitored on a daily basis in each of the fish production tanks. Water quality parameters including; nitrate-nitrogen, nitrite-nitrogen, and orthophosphate were monitored once every week from each of the fish production tanks, from pipes exiting the fish production tanks and from pipes exiting the vegetable production gardens. The average weights of vegetables were taken before planting as the starting weight.

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During growth, the amount of nutrients (N & P) discharged and taken up by the vegetables were measured. The length and weight of the cultured vegetables and fish were measured every seven days. The length and weight of the plants, maturity period, flowering and fruiting stage (in case of tomatoes) every one or two weeks depending on the plant. The total fish and crop harvest as well as nutrients were determined at the end of the culture period. Total yield at harvest (fresh weight-bundles in weight for leafy vegetables and fish production per m^3) was calculated at the end of the production period. In addition to the above, the number of vegetable cycles produced per fish cycle (varies per vegetable type) were determined. The experiment was carried out at the premises of ARDC, in Kajjansi, and lasted for three months.

Available Results

Findings and results are expected to contribute towards generating the outputs below:

1. Report of nutrient (P&N) extraction efficiency of the different produced vegetables in the fish-vegetable integrated model.

2. A write up on the growth performance of African catfish (Clarias gariepnus) culture under the fish-vegetable integrated production model in relation to the African catfish (*Clarias gariepinus*) cultured under mono-species.

3. A report on the comparison of crop yield from fish-vegetable integrated production model in relation to the specialized vegetable production.

4. A report on the evaluation of the quality of the produce (fish and crops) in terms of nutrients and bio accumulation (heavy metal).

5. An assessment report of the economic viability (cost-benefit analysis) of the two suggested integrations.

Figure 29. Leaf vegetable irrigated using underground water from a borehole.

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Technology and production key performance indicators to be gathered:

1. Survival and Growth performance of the fish in the production systems (the specific growth rates; lengths and weight) will be measured

2. Growth performance of the vegetables in the production systems (lengths and weight) will be measured

3. Nutrients (Phosphorous and Nitrogen) extraction efficiency of the different vegetables used in the fish-vegetable integrated production model

4. The crop production yield from fish-vegetable integrated model with production from specialized vegetable gardens.

5. Number of farmers trained on BMPs for integrated fish and vegetable production technology

Risks and Mitigation Measures

Risks	Mitigation
Climate change effects – dry spells and heavy rains	Resistant structures Use of climate resilient strains
Choking of vegetable on excess nutrients	Pre-testing and routine monitoring of nutrient discharges before use in irrigation of vegetables
Fish mortalities due to poor water quality	Regular water quality monitoring in the fish production units to ensure that water quality is maintained within acceptable ranges
Poor management by farmers	Regular training of farmers on guidelines and BMPs on fish cum vegetable productions
Fish predators	Use of predator controls like covering nets; Maintaining the production site clean and clear of any bushes
Crop pest and diseases	Selection of pest and disease-free seedling; Screening and control of access to the vegetable production site

Integration of chickens, vegetables, and aquaculture (SUA - Tanzania)

Currently, human population in Tanzania is 61.7 million and is estimated to reach 129.4 million in 2050 (UN, 2021). About 26.4% of population live under extreme poverty, below one dollar per day (URT, 2022) hence, they cannot meet their basic daily needs. Most of the poor people live in rural areas and depend on agriculture (crop farming, livestock keeping and fish farming) for their household food and income. Improvement of agricultural productivity is the most important and readily available avenue for poverty reduction in rural areas. However, improvement in agricultural productivity is constrained by small size of land holdings of farmers. Over the years the average land holdings of

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smallholder farmers has been declining and at the moment most smallholder farmers own small plots with the size below one hectare (URT, 2021a) and there is limited or no option for expansion. The current ways in which farmers use their land and water are inefficient and cannot anymore meet the human demand for food and income. The situation is further worsened by climate change which makes rainfall to be unpredictable and increases the frequency of drought.

With increasing human population pressure, new ways of farming that integrate many diverse enterprises at the farm level and regenerate the environment need to be developed. Integrated farming system needs to be promoted to efficiently utilize resources, increase agricultural productivity, reduce environmental degradation and make improved production sustainable under smallholder production systems. Integration of various agricultural enterprises i.e., crop farming, livestock keeping, and aquaculture has great potential for increasing income and food security in rural areas. These enterprises not only supplement the income of the farmers but also help in increasing the family labour employment throughout the year (Jayanthi *et al.,* 2009). Numerous examples of integrating aquaculture with crop and animal production exist including fish culture with rice, fruit, ducks, and chicken production and have been practices for many years in Asia (Prein, 2002). According to Al Mamun (2011), the integration of fish production with ducks, geese, chickens, sheep, cattle or pigs results in increased fish production by 2 to 3.9 times. Getu *et al.* (2017) and Debara *et al.* (2021), demonstrated that poultry fish-vegetables integration results into higher revenue compared to monocrop or mono-livestock farming practice. According to Brummet (1999), integrated farms produce almost six times the income generated by the typical smallholder farms. Under integrated system, chicken droppings and feed wastes can be used to fertilize the fishponds and constitute feed for fish and zooplankton. Moreover, chicken manure can be used to fertilize vegetable fields that can also constitute feed for fish. Vegetables can be irrigated by water from the fishponds, this in turn, reduces the need for additional inorganic fertilizer application. Moreover, the multiple use of water makes the farm to be more efficient in terms of the value of production per unit of water used, and more environmentally sustainable (Prinsloo *et al.,* 1999).

Design and description of the specific pilot system

The project will be carried out in two villages of Kilombero district, Tanzania. In each village three farmers will be recruited to participate in the project. The selection of the

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farmers/farmer groups will be based on willingness to participate in the project and ability to construct a fishpond and chicken house. The integrated aquaculture package will be established using the combination of cabbage (*Brassica oleracea*)/spinach (*Spinacia oleracea*)–chicken-tilapia fish production. Each farmer will construct at least one fishpond with the size of 150 - 300 m^2. The ponds will be stocked with Nile Tilapia fingerlings at a stocking density of 4 fish per m^2. The project will provide the farmers with the fingerlings. The ponds will be fertilized with chicken manure at a rate of 50 g DM/m^2 per week. The fish will be fed a concentrate diet identified in experiment one at a rate of 5% of body weight. For rearing of chickens, each farmer will construct a chicken house on the pond embankment depending on the pond size. Each farmer will be provided with approximately 15-20 Sasso chickens aged 30 days old, at a stocking density of 4 birds/m^2. The chickens will be fed with a concentrate diet made from locally available feed materials and formulated to contain 3200 Kcal ME and 18% CP. The chickens will be fed formulated diet based on their body weight and provided with clean water *ad libitum*. All chickens will be vaccinated for Marek's, Gumboro and New castle diseases according to standard vaccination programme. In addition, each farmer will establish 0.25 acre of cabbage or spinach or both depending on the land holding size and preference. The plots will be established one months after stocking of fish and chickens. The cabbage will be planted at spacing of 45 cm from plant to plant and 60 cm from row to row. The spinach will be planted using a spacing of 15 cm from plant to plant and 30 cm from row to row. The cabbage and spinach plots will be fertilized with manure from the chicken house at a rate of 2.5 and 1 kg DM/m^2, respectively, 14 days before planting. The crops will be irrigated with water from the fishponds by gravity.

The fish will be cultured for 180 days. Fish body weights and lengths will be measured at the beginning of the experiment and then after every two weeks up to the end of the experiment. Specific growth rate, condition factor and body weight at harvest (180 days) will be determined. Pond water pH, dissolved oxygen, conductivity, total dissolved solids, salinity and temperature will be measured at weekly intervals. The chickens will be reared for 120 days and they will be measured for body weight at the start of the experiment and then every two weeks up to the end of the experiment. Feed intake, growth rate and final weight gain will be computed. The cabbage will be grown for 90 days and at harvest head weight (kg), head diameter (cm), head length(cm) will be measured, and total head yield (kg/ha) will be computed. Spinach will be grown for 60

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days, but leaf harvesting will be done starting at 30 days of age and continue up to 60 days of age. Leaf yield per ha will be computed.

Available results

Currently there are no results as the experiment has not started. It is expected that the experiment will start in February 2023.

Recirculating Aquaculture Systems

Tanzania (SUA)

In Tanzania, aquaculture is dominated by the culture of Nile tilapia (*Oreochromis niloticus*) in earthen ponds under extensive system (Rukanda & Sigurgeirsson, 2018; Mmanda *et al.,* 2020). The productivity of Nile tilapia under extensive production system is low, characterized by slow growth and small mature weight at harvest ranging from 140 to 380 gr (Chenyambuga *et al.,* 2014). Aquaculture production can be increased by intensifying the production through stocking at high density, feeding good quality feed and providing more aeration to cultured fish. Adoption of intensive production system can increase the productivity from less than 2000 kg/ha/year to 100,000 kg/ha/year and at the same time reduce the water consumption per unit produced to half of that used under the extensive system (Avnimelech *et al.,* 2008). Recirculating Aquaculture System (RAS) is a method for rearing fish or other aquatic organisms by reusing the water in the production units. In RAS water is continuously cleaned through mechanical and biological filtration and then reused. Mechanical filtration removes particulate wastes while biological filtration removes dissolved wastes via biochemical reactions that occur during bacterial metabolism (Bregnballe, 2015). These processes allow water to be cleaned and reused several times prior to discharge and thus, conserve water by reducing the amount of water needed (from an external source) for rearing of fish. In addition to water conservation, RAS allows large fish yields to be obtained in a relatively small area and enable year-round production (Adam *et al.,* 2014). However, the cost of constructing a standard RAS is high as the technique is costly in terms of initial capital investment and its operation needs high energy in terms of electricity. Hence, small-scale fish farmers in developing countries cannot afford it. Moreover, the supply of electricity is not reliable in most developing countries, especially in rural areas. Therefore, this project will develop an efficient, cost-effective and solar powered RAS that can be adopted by smallholder farmers in Tanzania and other developing countries. The cost-effective RAS will use locally available materials such as coconut shells as media in biofilters for removing ammonia and nitrite which. The cost-effective RAS will be promoted for use by small-scale fish farmers in rural areas as well as peri-urban areas.

Design and description of the specific pilot system

Experimental set up

This experiment will start in March 2023, after the feed formulation experiment (feed formulation Exp 1), whereby a demo-solar powered RAS will be constructed and placed at one village in Kilombero food Hub.

The proposed RAS unit is a modification of the simple RAS designed by Mnyoro *et al.* (2022) (Figure 30). This RAS is operated by electricity. However, the supply of electricity is not reliable in Tanzania, especially in rural areas. Therefore, the modification in this experiment will involve using solar rather than electricity as power source. The RAS will consist of a fish rearing tank, solid removal tank, pump station, biofilters and solar panels. In addition, since plastic biofilters are expensive, and not readily available, especially in developing countries, coconut shells will be used as local biofilters. A study by Mnyoro *et al.* (2022), revealed that out of the five locally available media evaluated, coconut shells performed better in removing ammonia and nitrite and showed similar performance as the plastic media. Total Ammonia Nitrogen (TAN) and nitrite are toxic compounds produced from fish excretion and leftover feeds, hence, should be removed in the RAS as quickly as possible.

The fish rearing tank will have a capacity of 1000 litres. Tilapia will be stocked at stocking

density of approximately 0.11 kg/L and reared for six months. Since the stocking density will be high, this will increase the productivity of fish. The specific surface area of the

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biofilter (coconut shells) will be 500m^2/m^3 according to Mnyoro *et al.* (2022). Fish will be fed floating feeds at a feeding level of 5% of their body weight and will be fed four times per day at 8.00 am, 11.00 am, 2.00 pm and 5.00 pm. Water quality parameters (temperature, pH, dissolved oxygen, alkalinity, turbidity, ammonia, nitrite and nitrate) will also be recorded throughout the experimental period. Body weight and length of individual fish in the grow-out tanks will be weighed at the start of the experiment to determine initial weight and length, respectively, and then every two weeks up to the end of the experiment. Mortalities will be recorded every day. At the end of the experiment, fish will be harvested and final weight, growth rate, yield, feed conversion ratio and survival rate will be recorded. The performance of the modified RAS unit in terms of removing ammonia and nitrite from the rearing tank and supporting fish growth and survival will be evaluated.

Available results from the system

This experiment will take place from March to July 2022, after the end of the feeding experiment.

Kenya (DALF)

RAS are one of the new areas of innovation in aquaculture that gains significant importance as it requires limited water resource for greater production and provides environment sustainability. RAS are used for fish production in indoor tank-based systems where water exchange is limited and the use of biofiltration is required to reduce ionized and unionized ammonia level (Timmons *et al*., 2010). RAS are designed in such a way that minimise water consumption, control culture conditions and allow waste streams to be fully managed. They can also provide some degree of biosecurity through measures to isolate the stock from the external environment. This system filters the water through a series of biological and mechanical filtration systems and makes it clean for recycling back through fish culture tanks and more than 90% of the water is re-circulated through the culture units (Sugita *et al*., 2005). In contrast with the conventional method of growing fish outdoors unit, this system rears fish at very high densities in indoor tanks with a "controlled" environment and can facilitate a broad range of species, irrespective of temperature requirements as well as, enable secure production of non-endemic species (Martins *et al*., 2010). The major pre-requisite for RAS is clean water, dissolved oxygen, and optimal temperatures for ensuring proper growth and environment sustainability.

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The basic principle behind the RAS is to re-circulate the water through flow-through fish farm by diverting the water supply through ponds or tanks. However, recirculation implies treatment of some or all of the discharge water and returning this to the fish rearing system. In RAS, a key design parameter is the ratio of recycled water to wastewater (i.e., percentage of recycled water in the fish tank inflow water). The main functional parts of a RAS include:

- Growing tank(s)
- Sump for the removal of the particulates
- Biofilter
- Oxygen supply with U-tube aeration
- Water circulation pump.

Description of the pilot system

Recirculating Aquaculture System (RAS) in Kisumu Food hub

The department of Agriculture Livestock and Fisheries (DALF) in Kisumu County in collaboration with other partners developed a tilapia hatchery in Kisumu, Kenya through the European Union Funded project VicInAqua. It is a RAS using treated municipal wastewater through a technology called Membrane Bio Reactor (MBR) as the main source of water for the system. The hatchery has a capacity to produce 30,000 monosex tilapia fingerlings per month to supply pond aquaculture in the area. The system was designed as a flexible, scalable and modular system which can be adapted to the needs of the client. The plant brings together multiple technologies from different sectors. Energy demands, often one of the largest overheads for any RAS system are met chiefly through renewable energy sources – solar photovoltaic with a capacity of 14.3 kWp (kilo watt peak) and consisting of 52 PV modules mounted on the roof top of the plant building. This has a second advantage of reducing the system's dependence on the national grid, which suffers from frequent blackouts. Monitoring of system parameters, using technology is available in real time online as well as on site, allowing problems to be identified quickly and site staff notified.

RAS Components

The hatchery consists of 3 RAS: One for the holding of broodstock and egg incubation, one system for larval rearing and one nursery system (Table 4).

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Equipment

Table 4. Equipment for different life stages (broodstock, larval rearing and nursery) of fish in RAS.

	Brood stock and Egg incubation		**Larval rearing**		**Nursery**	
Design Parameters:						
Water turnover rate	1 tank turnover per hour		0.5m³/hour		0.5m³/hour	
Flow rate	28,000L/h		8,000l/h max		9,000l/h max	
Water temperature	25⁰c-30⁰c		28⁰c-30⁰c		27⁰c-30⁰c	
Tanks:	**Volume**	**Number**	**Volume**	**Number**	**Volume**	**Number**
Fish Tank	3,000L	6	500L	9	500L	2
Sump/Biofilter	2,000L	1	1,650L	1	1,650L	1
Pumps:	**Flow**	**Number**	**Flow**	**Number**	**Flow**	**Number**
Main pump	30,000L/h	1	18,000L/h	1	18,000L/h	1
DF backwash pump	1,000L/h,5.5 bar	1	3,100L/h,10 bar	1	3,100L/h,10 bar	1
Disinfection:	**Watt**	**Number**	**Watt**	**Number**		
UV	40W	1	80W	1		
Filtration:	**Flow**	**Number**	**Flow**	**Number**	**Flow**	**Number**
Drum filter	Rated 30 m³/h at 40µm	1	Rated m³/h at 20µm	1	Rated 15 m³/h at 40µm	1
Protein Skimmer	10m³/h	1		1		1
Biofilter media	700m²/m³	900L	700m²/m³	300L	700m²/m³	600L
Aeration:	**Flow**	**Number**	**Flow**	**Number**	**Flow**	**Number**
Air pump	160L/min at 2 meters	3	47L/min at 2 meters	1	47L/min at 2 meters	1

RAS A: Brood stock and egg incubation

The system includes 6 breeding tanks with a capacity of 3m³ (2x3x0.6m) each. The egg incubation unit consists of a table with 5 MacDonald jars and 5 hatching trays. The input water for the egg incubation system is filtered through a UV sterilizer. The filtration system for RAS A is designed for a maximum of 10 fish/m³ while feeding 2% of the total biomass.

RAS B: Larval rearing

This system consists of 9 round plastic tanks with a capacity of 500L each, while the filtration system of RAS B is designed for a maximum biomass of 2kg/m³ with a maximum feeding rate of 15% of total biomass.

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RAS C: Nursery

This system consists of 12 round plastic tanks with a capacity of 500L each. The filtration system for RAS B is designed for a maximum biomass of 4kg/m^3 with a maximum feeding rate of 10% of total biomass.

Filtration systems

The system was designed in such a way to minimize energy use. Water from the culture tanks flows by gravity from the main drain of the tank and then overflows into the drum filter collection box and then into the drum-filter. The drum-filter has a mesh of 20 and 40 micron and is backwashed periodically by a pump. From the drum filter water flows into the biofilter where the bio media is kept moving in the water by air flowing through an air-grid. Water is then pumped from the clean partition in the bio-filtration sump, up to the header tank. The header tank is positioned higher than the rest of the system components on a large table. Water from the header tank flows back by gravity to the culture tanks after being aerated using air diffusers connected to an air blower. Emergency oxygen is also supplied to the fish tanks in case of power outage by compressed oxygen tanks connected to dosing cabinets which automatically dose oxygen if the dissolved oxygen concentration falls below a limit set by the operator.

Stocking density

In this RAS an experiment was set up in 9 tanks (200L capacity) with 70 fingerlings stocked with an average weight of 1.76g, at a feeding rate of 20% of body weight. The following data are collected from the experiment: Total weight and length of the fish. Currently the experiment is on-going at the food hub.

General Management

Biosecurity

In order to prevent the disease outbreak/spread in the system, it is important to take note of the following:

The facility is bio-secure. Using the RAS, it is expected that the risk of pathogen spreading is reduced as the water going into the system is disease free and sterilized.

People entering the farm should follow strict bio-security measures (use disinfection footbaths, wash hand thoroughly use alcohol, do not touch anything for visitors).

Between the batches of the system is thoroughly disinfected. Different systems are separated in terms of use of equipment and staff/visitor for bio security measures.

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Contacts with the systems, system water or material in the systems must be kept to only the necessary minimum.

Pest and Rats Control

One of the most important reasons why it is important to control these animals on a farm is because of the health and food safety issues associated with these animals, at the facility rats used to be the major problems but they were eliminated by use of wire mesh on store's window.

Handling of mortalities

From the RAS, any mortality collected is recorded and sampled according to protocol (date, system, and tank) and is normally disposed of immediately in a sanitary manner.

Observe the bottom of the tanks for dead animals.

Tare bucket on scale if mortality needs to be weighted.

Place net into the tank and remove the mortalities taking special attention not to disturb other fish.

Count mortalities from the net into the bucket.

Once all mortalities are removed, record on sheet.

If the mortality appeared to be the result of disease or infection report immediately to manager or a veterinarian and take appropriate actions.

Guidelines for disease treatment

Only use chemicals and veterinary drugs from suppliers that are registered with the authorized authority.

Veterinary drugs, medicated feeds and other chemicals should be labelled in an adequate language, with clear information on: name, active substances, target animal species, storage conditions. Prescribed dosage, route of administration, expire date and withdrawal period.

Veterinary drugs, medicated feeds, chemical and biological substances should be used according to the instructions of the manufacturer and as specified on label.

Substances requiring prescription should be used under adequate supervision by a qualified expert.

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Veterinary drugs need to be stored in a separate room from the standard feeds.

Veterinary drugs, medicated feeds and other chemicals should be stored according to manufacturer's instructions.

Harvesting and transportation

Handling: to minimize the damage of fish during the harvesting and post-harvest handling farmers should do the following:

- Use equipment that has been designed for rapid and efficient handling of aquaculture products without causing mechanical damage. Any scratches on the fish should be avoided.
- Use harvesting areas and equipment for harvesting, catching, sorting, grading, conveying and transporting of products that are smooth and easy to clean.

Harvesting procedures

Harvesting activities should be planned in advance and should be organized timely in order to avoid that fish are exposed to high temperatures for longer periods. Additionally, the manager should ensure that:

- The fish should not be fed one day prior to harvest to reduce their gut contents.
- Only healthy fish that show no clinical sign of disease should be harvested.
- Detailed records need to be maintained during harvesting to allow for proper traceability.
- Do not subject the fish to extremes of heat or cold or sudden variations in DO.
- Slowly cool down the fish using ice when sorting and packing to avoid stress during transport.
- Minimize physical damage and stress during packing and transport by fast and efficient handling.
- Fry is harvested, graded and weighed before packing. Basins, perforators and weighing scale are used for harvesting, grading and weighing respectively. Fish are usually transported life in containers (plastic bags are not available in Kenya due to the plastic ban) and supplied with oxygen (medical grade).

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Feeding

As growth rate in RAS depends totally on formulated feeds, fish feeding is of top importance. Feeding is normally done manually using the pellets feeds ranging from mash to grow out pellets. The first feed is fine powder that floats on the water surface. Small fry normally feeds on 15-20% of their body weight. As the fry grows larger feeds should be given. Feeding rate starts from 20% of body weight for the fry and 2% of body weight for broodstock with 3-5mm pellets. Under FoodLAND project innovation technologies, feed formulation has been adjusted to incorporate Macrophytes (*Lemner minor* and Azolla) as they are readily available for local use by farmers. These plants are used together with other raw materials to formulate a feed that is being tested for use in the recirculating Aquaculture system. Trial for the feeds and data collection are on-going activity with tilapia (*O.niloticus*).

Data collected from plant system

Electricity use: as shown in Figure 31, the plant over the last one year has consumed more power from the grid than the other systems.

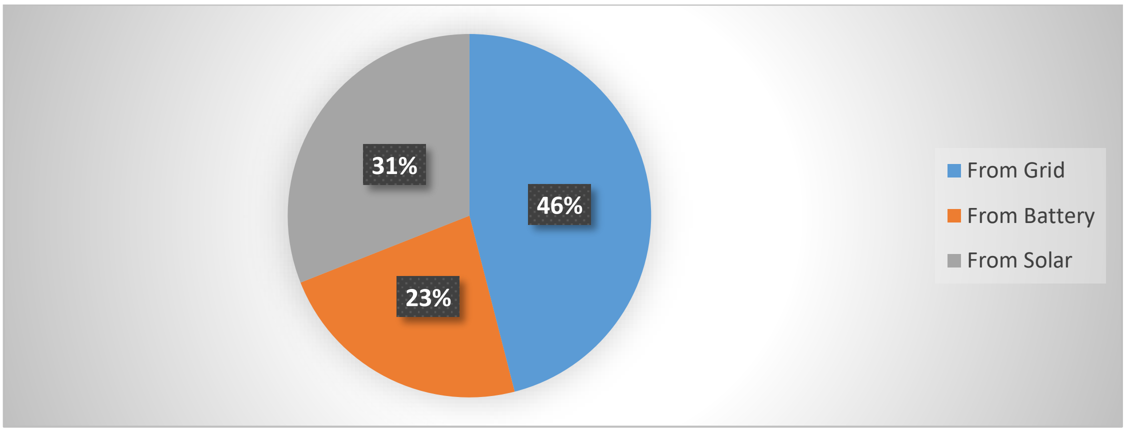

Figure 31. Power consumption from facility in last year (2022).

Water quality in RAS**:** Key water quality parameters being monitored within the recirculating aquaculture system are included in Table 5.

Table 5. Recorded records of water quality in RAS.

Water quality parameter	Range of Levels Recorded
Temperature	23-32^{0}c
Dissolved Oxygen	3.5-8.5mg/l

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pH	6 - 8
Ammonia	0-1.7mg/l

Fingerling production**:** Tilapia broodfish are normally selected and crossed for breeding for 10 days after which eggs are collected from female brood stock. Eggs are transferred to the egg incubation jars for hatching per batch while hatchlings are taken to the larvae tanks. Once eggs hatched, the swim-up fry swim out in the flow to the small trays where they will stay 24 - 48 hours. The free-swimming fry (swim-up fry) are then moved to the larvae system. The fry is fed with feed mixed with Methyl-Testosterone hormone (MT) powder to produce all-male fry. After 30 days, the fry is transferred to the nursery tanks where it is grown to 1 - 2gr and then dispatched to various farmers with the current production capacity at 30,000 monosex tilapia fingerlings.

Discharge of waste: the wastewater from and sludge from the RAS is used in the small garden we have at the plant system to grow some kales and traditional vegetables in order to reduce environmental impact from the RAS effluent.

Plans for the pilot site plant:

Increase production to more than 100,000 fingerlings per month.

Building of more aquaculture technologies like the raised ponds to support the production.

Modifying the RAS drum filter as the current filter membranes are not locally available.

Risks and Mitigation Measures

Risk	Mitigation Measures
Increased wastewater and solid waste	All the wastewater/effluent discharged from the RAS, will be reused in the agriculture except effluent from the larvae tanks where hormones is administered.
Fish brooders and fingerlings	Following strictly the Standards of Operation (SOPs) within the facility. All the dead fish will be carefully examined before disposal. Water quality will be constantly monitored. All the infected and dead fish will incinerated.
Accident and injury of workers	Provision of appropriate personal protective equipment to all workers
Strong wind	Planting of more trees to act as wind breakers

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Pond Polyculture

Labeo (Ningu) and *Barbus* (Kisinja) with the traditional African catfish and Nile tilapia

Literature review on production methods and potential markets of the species

Polyculture is the culturing of more than one aquatic species/organism in the same culture unit (e.g., pond, pen) through utilization of all ecological niches for increased productivity (Singh *et al.,* 2022). It combines species with different but complementary feeding habits (with non/limited competitiveness) to intensify fish-culture without the input of expensive artificial feeds (FAO, 2022b), or through limited feed supplementation. Today the cultured fish types in a unit range between two (most common in Africa) and five (most common in Asia). The major feed source is natural fish food organisms (plants and animals) living at different depths and locations in the water column usually enhanced through fertilization (chemical/manure). In commercial aquaculture however, fast-growing species are used, and the most economically viable fish species (Nile Tilapia in this case) are fed with an assumption that other species will feed on the natural pond food. However, feeds intended for fed species also directly benefit filter-feeders, especially if in powder form or non-water-stable pellet feeds (FAO, 2022b).

The feeding habits include bottom-feeders eating at the bottom like detritivores and

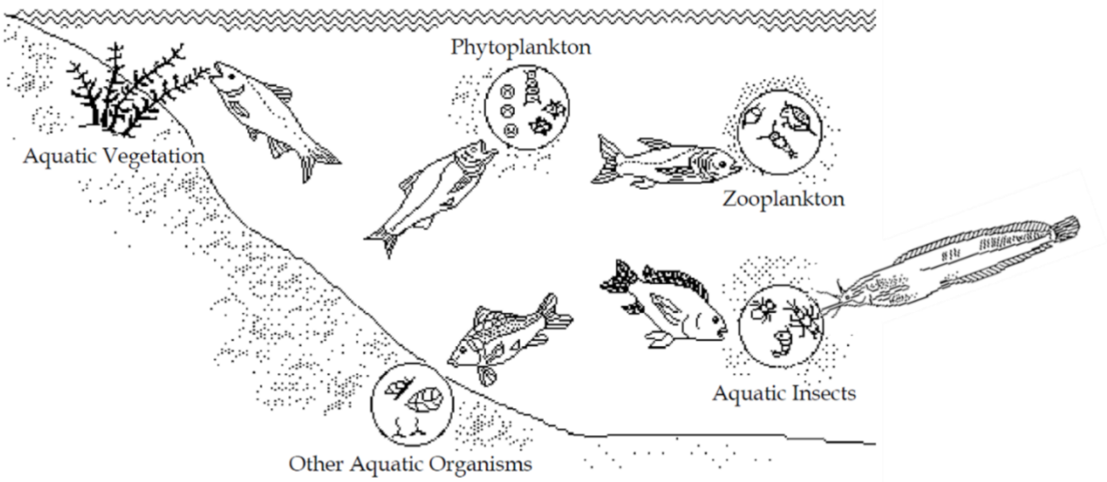

Figure 32. Polyculture utilizes natural foods efficiently (Modified from Auburn University, 2019).

column-feeders eating in the water column like planktivores eating microscopic organisms, herbivores eating aquatic plants, and piscivores/predators eating fish and other aquatic organisms (Figure 32).

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Through efficient tropical polyculture systems, fish productivity can be raised by 5-6 times more than usual (Trivedi, 2022) accounting for up to 8,000 kg of fish per hectare per year (Auburn University, 2019).

Labeo is listed as critically endangered due its population severely declining (less than 80% in 10 years) due to being a delicacy among the local communities, destruction of its spawning grounds and its predictable migratory habits (anadromous) making its capture easy (Fish Base team RMCA & Geelhand, D., 2016). It is an omnivore predominantly feeding on detritus material (bottom feeder) consisting mainly of plant material (Owori-Wadunde, 2004).

Barbus on the other hand, is an omnivore, eating gastropod molluscs, insects, water plants, fishes and crustacea (Fish Base team RMCA & Geelhand, 2018). Like *Labeo*, it is heavily fished by the locals because of its aroma and taste when smoked. (Aruho *et al.,* 2020).

According to FAO's (2022) 'State of world fisheries report', globally, fisheries and aquaculture production (over 60% higher than the average in the 1990s) and consumption (over 20.2kg per capita in 2020) have continued to grow providing food (over 50% of animal protein in several countries in Asia and Africa) and employment (about 58.5 million people in primary production alone – approximately 21% women). Despite this growth, Africa's aquaculture production declined between 2019 and 2020. African non-fed-species aquaculture is not developed despite the introduction of filter-feeding carps in the 1950s and 1960s. Due to this, SOFIA 2022 considers it almost impossible, to identify and develop native finfish species to play the role of filter-feeding carps in developing low-cost inland polyculture with improved efficiency in harnessing natural productivity of the rearing water (FAO, 2022b). It should be noted, however, that East African aquaculture is greatly low-cost inland polyculture dominated by the culture of tilapia species (especially Nile tilapia), African catfish and mirror carp (*Carpio specularis*) in earthen ponds (Nakyewa *et al.,* 2019). Today, aquaculture sector in Uganda is dominated by smallholder fish farmers (nearly 95%), accounting for less than 10% of the sector's production annually.

The initiative of FoodLAND to not only develop mass-production protocols for the two indigenous carps (*Barbus* and *Labeo*) but also their integration into the low-cost inland polyculture is a great milestone for the sector as it will improve the livelihoods of the sector-majority.

Factors affecting species selection and stocking rates

1. **Water temperature:** Fish with similar temperature-tolerance ranges should be used. For example, systems using cold-tolerant fish like common carp and Chinese carp must be used if their temperatures drop below 18°C for best returns.

   Avoid species that will be temperature-stressed by your ambient culture temperatures.

2. **Tolerance to pond condition:** Polyculture ponds are usually heavily fertilized or manured. This practice may cause low oxygen levels and other conditions in the water that are stressful to fish**.**

   Hardy species with a wide and overlapping range of water parameters (temperature, dissolved oxygen - DO, pH, salinity, etc.) are best.

   Though fertilization is key for the success of the polyculture system, care must be taken for the transparency, turbidity, pH and DO ranges to remain in the safe/optimal ranges of the cultured species.

3. **Species selection:** The species mix aims at maximum utilization of food in the pond (artificial/supplemental and naturally occurring) with-out/minimal overlapping in ecological niches.

   Supplemental/commercial feeds should target the fish species with highest economic value leaving other fish to eat the wastes of the lead fish and natural food.

   A good mix of the species complementing each other's feeding habits helps in cleaning the pond (like Labeo) hence improving water quality and ecological footprint.

   Predator fish/piscivores (like catfish and Barbus) should be stocked in small ratios and body sizes than the species they prey on (like tilapia).

4. **Market value of fish:** The market price and demand should be considered before a fish species is chosen for culture.

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Given two or more fish species that fill the same feeding niche in a pond, the choice should be based on which will maximize economic returns to the farmer.

Advantages of polyculture

- More fish (types and yield) is cultured in the same space/pond/culture unit hence more economic returns.
- Promotes an appropriate ecological balance by maintaining water quality as one fish eats the would be wastes of the other fish.
- Requires less feed input in relation to output/fish yield as only 1-2 fish types of most economic value are fed supplemental feeds.
- There is limited or no feed and space competition among cultured fishes in the same pond.
- Through complete utilization of feed resources, the combined species contribute to improved pond health.

Disadvantages of polyculture

- It requires a supply of fry of different fish species some of which may be scarce.
- If poorly managed, may lead to big losses from stuntedness, predation, etc., hence the need for proper skill and tested and approved polyculture techniques.

Methodology

All actions in the study will be done in accordance with the national and European guidelines for protection of animal welfare (Directive 2010/63/EU), respecting the physiological and behavioural requirements of the fish.

Simulating smallholder farmer conditions who are the majority, the study will be done in earthen ponds of 100 – 300m^3 for a period of 10 months. The first phase will be done at NARO-KARDC in Kajansi for 6 months to determine the best management practices and polyculture mix giving the best economic returns. This will then be upscaled to other willing farmers (approximately 60-100 from each of the 6 regions/agro-ecologies) across the country for validation and future adoption. This will not only check for the ecological effect on the technology, but also accelerate its dissemination/adoption country wide. The farmers will be selected on basis of pond site quality, commitment of the farmer to feeding, record keeping and general farm management, and ability to prevent predators from eating the fish (properly fenced ponds).

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For the experimental design, a completely randomized design with three treatments and three replications. The traditional 2-species-polyculture (2SP) stocking of 8 mono-sex tilapia and 2 catfish per cubic metre will be used as the control. The three treatments will be: two 3-species-polyculture (3SP) of TCL = tilapia (T), catfish (C), *Labeo* (L), and TCB = tilapia (T), catfish (C), *Barbus* (B); and one 4-species-polyculture (4SP) of TCLB = tilapia (T), catfish (C), *Labeo* (L), *Barbus* (B). Fish will be stocked at a uniform size per species (between 5g and 10g) but with the predator species (catfish and *Barbus*) smaller than others (tilapia and *Labeo*) per pond.

Temperature, DO, pH and water transparency (Secchi disc depth), plus mortality and feed intake will be recorded daily while other physicochemical parameters (total alkalinity, total ammonia, nitrate, phosphate and chlorophyll-*a*) will be measured weekly per pond. Collecting the water parameters will be done at three pond positions and three water-depths per position. Fertilization will be done as required to maintain an average Secchi (algae bloom/ green water transparency) reading of above 24 inches (61cm) but less than 15 inches (38cm).

The growth parameters (Survival Rate, SR (%), Mean Initial Weight, Wi (g), Mean Final Weight, Wf (g), Specific Growth Rate, SGR (% Day-1), Weight Heterogeneity, CV, and Fulton condition index, FCF) per pond will be recorded fortnightly (every 14 days). FCF is also called the BMI (Body Mass Index) or health index of the fish to measure robustness or well-being of experimented fish (Joergensen, 2022).

The daily feed will be calculated at 3% of the body weight (3% BW) of only tilapia per pond with the fish fed twice a day for the first three months then once for the rest of the rearing period. After every fish growth sampling, the feed quantity will be adjusted as per estimated total tilapia biomass per pond each month. The cost of all inputs (labour, fish, pond-preparation costs, feed, fertilizer, etc.) will be captured as per receipt at the farm. At the end of the rearing period (10 months), the economic viability (high enough profit to justify the investment) per treatment and per farmer will be calculated.

Technology and production key performance indicators to be gathered

1. Growth performance per species and overall growth per pond determined fortnightly.
2. Number of farmers adopting the recommended technology.
3. Number of farmers trained in BMPs for the developed technology.

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4. Yield per farmer after 10 months rearing period.
5. Economic value per species at harvest and overall harvest profitability.

Risks and Mitigation Measures

Risks	**Mitigation**
Limited availability of *Labeo* and *Barbus* fingerlings for grow out.	Ensure sufficient production by KARDC hatchery. Teach other hatchery operators the skills of mass seed production of the two species.
Poor management by farmers.	Regular monitoring and sampling to ensure effective feeding and fish handling.
Some of the farmers likely not to feed due to financial issues.	Train farmers about on-farm made feeds Prior assessment before a farmer is qualified as a validation participant.
Climate change effects - dry spells and heavy rains.	- Select farmers with well-constructed and designed pond sites (having a water reservoir too). - Recommend stocking at the start of 1st rains for drought related locations.
Low adoption rate.	Train farmers on the benefits of this technology over the already practiced one.

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Rearing Technologies of Potential New Species

Barbus altianalis

Literature review on production methods and potential markets of the species

Barbus altianalis (also called *Labeo barbus altianalis*), locally known as Kisinja, is a native cyprinid (carp) in rivers and lake systems in Uganda, Rwanda, Kenya and Eastern DRC (Greenwood, 1966; Snoeks *et al.,* 2012). The species is heavily fished for the cultural and aesthetic value attached to it by many communities in Uganda, but also largely cherished by many consumers because of its aroma and taste when smoked. Due to this over-fishing, the species has now largely been confined to tributaries and rivers connected to Lake Victoria and Edward, particularly in the upper Victoria Nile and in the rivers and streams close to Lake Edward (Aruho *et al.,* 2018). Although there is paucity of information about catch statistics, current annual production is estimated to be 3,000 tones, amounting close to $1.5 (USD) million in value (Nakiyende *et al.,* 2020). Approximately less than 50% is consumed by communities in the western part of the country while more than 50% is sold across the border in the DRC, where there is a huge market of fish products largely from Uganda. About 1,500 tonnes ($0.75 USD million) are estimated to be caught from the upper Nile River, with most of this quantity being consumed in the central region of Uganda. There has been an effort towards its domestication in order to increase its production; cover the high demand and make it available for many consumers; as well as to conserve it by reducing fishing pressure (Rutaisire *et al.,* 2015; Aruho *et al.,* 2020).

The species was successfully induced to breed with the synthetic hormone Dagin in running water in 2013 (Rutaisire *et al.,* 2015). However, due to high larvae mortalities (> 60%) there were still insufficient fingerlings for use by farmers and consequently the protocols were again improved by Aruho *et al*. (2017). A much cheaper process then included the use of catfish pituitary extracts which induced the successful spawning of the fish. This was important because despite being effective in inducing *Barbus* to spawn, Dagin is an expensive synthetic hormone, not affordable by most hatcheries in Uganda unlike the African catfish pituitaries. For the first time also, the spawning process used the F1 generation broodstock raised in captivity. There are still more challenges regarding spawning protocols and there is a need to continuously optimize the protocols so that mortalities can be significantly reduced, and more seed is available to multipliers and eventually to the smallholder fish farmers in the country for mass production.

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Optimize survival of species from hatchery/nursing ponds

As earlier stated, the low survival reported during initial stages of domesticating the fish

Figure 33. Ripe B. altianalis are stripped at the landing site at Forest landing site, at Kira Dam.

(Rutaisire *et al.,* 2015), led to the improvement of the hatching and weaning protocols in the subsequent phases (Aruho *et al.,* 2017). Ideally what affects the quality and survival of the eggs will consequently affect the hatchability and survival of the seed during larvae/fingerling nursing (Aruho 2018). Previous studies on weaning, indicated that the fish begin feeding at the age of 7 days post hatch (Aruho *et al.,* 2019), a time when the yolk sac is significantly reduced. Performance was good with decapsulated *Artemia* and the combination of diets (dry microdiets with live feed *Moina*). The nursing was first done indoors with glass tanks and three weeks later, they were transferred to outdoor nursing tanks. The process of weaning improved the *Barbus* survival by 20% (unprocessed ARDC Data, 2021). This indicated that still more experiments need to be done to optimized protocols for weaning.

Figure 34. Collecting mature wild broodstocks at Forest landing site. Kira Dam.

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Optimizing spawning protocols using the riverine circular tanks system at ARDC

Circular tanks were constructed to induce breeding of Chinese carp but had not been used before to breed the local/native carp. In the current study to optimize the seed production protocol, 16 broodfish (10 females and 6 males) were collected from the wild at the upper River Nile (Forest landing site, Kira Dam) and transported to ARDC Kajjansi in a broodstock transportation vehicle (Figure 33). They were left to rest for one day before they were hormonally induced. However, those found to ovulate were immediately stripped and fertilised at the landing site before being transferred to the station for induced spawning (Figure 34). The ripe fish were not induced as they may quickly overripen and degrade and will not hatch even when they are fertilized (Aruho *et al.,* 2017).

Figure 35. The riverine circular tank hatching system at ARDC Kajjansi used to hatch the carp.

After being acclimatized for one day, 3 females were injected with African catfish pituitary extract (for the ration of 1kg to 1kg) and were placed in one of the circular tanks with 2 males, which were not induced with any hormone as they had running milt (Figure 35). 3 different females were treated with Ovatide (0.4ml/kg) and placed in a second circular tank system together with 2 males with running milt. Water was then allowed to run through the inducing tanks, circulating and overflowing through the central pipe placed in the middle of the tanks. After 12 hours some eggs started appearing in the tanks and were collected by the net placed at the outlet of the circular tanks for each treatment (Figure 36).

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More eggs were collected from the circular tank with fish that were treated with Ovatide synthetic hormone, when compared with those injected with the African catfish pituitary. However, the eggs produced from these tanks were fewer compared to the 2 fish that were directly stripped at the landing site and fertilized before being transported to ARDC Kajjansi. The total number of eggs estimated from individuals treated with African catfish pituitary were 20,000 (measured by extrapolating the number of eggs in 5g out of the total number of eggs), while the total number of collected eggs from the fish in tank treated with ovatide was 25,000. The eggs were then transferred to the hatching frames (Figure 37). The fertilized eggs from the wild, were incubated in glass tanks and an estimation of 5,000 eggs hatching successfully. About 1,000 eggs from the females treated with Ovatide, hatched. At the same time 600 eggs from fish treated with African catfish pituitary extracts hatched. This implied a high mortality rate in the hatching frames. Fertilization rate was 50% with African catfish pituitary compared to 70% fertilization rate from females treated with Ovatide. The riverine circular hatching system for the carp is a good system that has been successful in hatching exotic cyprinids (Unprocessed data from ARDC, 2020) but does not seem to be successful with Kisinjja.

Figure 36. Hatching tanks.

A number of challenges were noted during the hatching process. Most of the fish had eggs that were not clearly mature and could not ripen with the treatment of the hormones and this was evidently poor with females treated with African catfish pituitary compared

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to those induced with ovatide. Ovatide is a well processed hormone and because of its purity, it looks more effective than the African catfish pituitary. The other problem was that most of the eggs died during the incubation process in the hatching basins, where

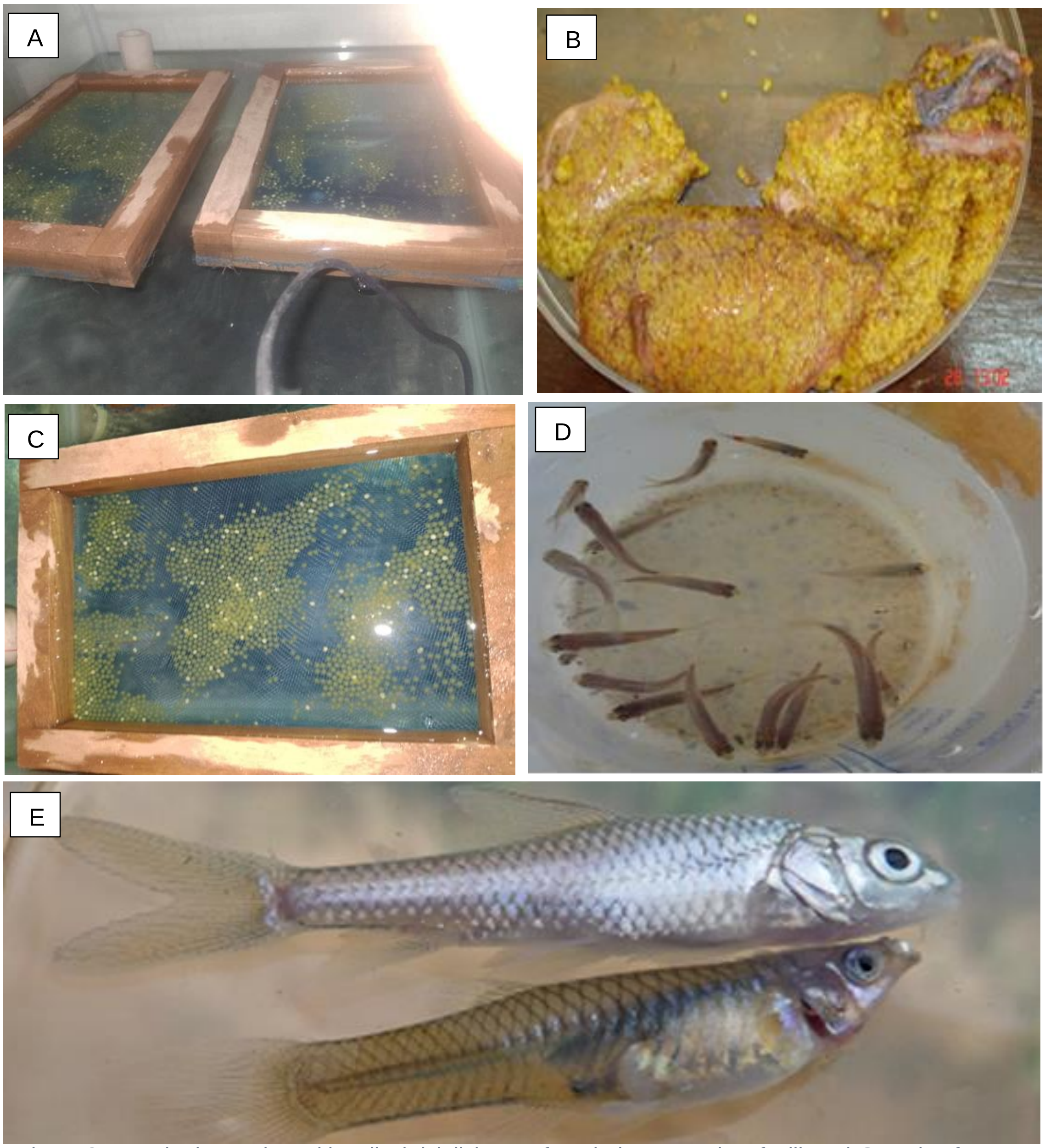

Figure 37. Incubating Barbus altianalis *(Kisinjja) eggs from indoor aquarium facility. A) Sample of mature eggs. B) Fertilized eggs place on the hatching trays C) developing embryos D) one months old Larvae. E) Three months fingerlings*

most of the time eggs were drifting as the water circulated around the system. Moreover, the newly hatched larvae had quite a lot of infections and most of them died. Generally, the results from this unit were not very successful.

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On one hand, the hatching rate of the eggs fertilized immediately in the field and incubated in the laboratory glass tanks (based on the incubation process by Aruho *et al.,* 2020) was 90% higher than the previously recorded hatching rate from the same species by Aruho *et al.* (2017). The only difference in the new technique is not to induce the already ripe individuals that were collected from the river. It is possible that well fed and conditioned broodstock can be stripped without being induced with hormones. In the development of the spawning protocols, this will be included. Fish with running eggs upon pressing must not be injected but should be stripped directly and fertilized with milt from the males.

The experiments will continue to establish and refine the system designed for carp to ensure massive production of carp seed that the farmers could use for stocking their ponds. Although large scale mortalities were experienced in the hatching frames, there were many eggs produced in the circular tanks and therefore it is recommended that, the protocol should include the use of circular tanks for induced spawning and then eggs should be collected and transferred to aquaria hatching systems.

Optimizing feeding /nursing protocols

Feeding larvae on the decapsulated artemia, Moina with microdiets

The effect of feeding using two locally available dry larval diets, i.e., K1 and M2, was evaluated (on survival rate, feed conversion ratio-FCR, growth rate). Every treatment was conducted in 3 replicates in 40lt aquaria water tanks, each stocked with 300 larvae. Initially, from day 6 post hatch, the fry was fed on *Moina* alone for seven days (13 Days After Hatch DAH). After that, all larvae were weaned off, but were introduced to another feed using a co-feeding strategy up to 28DAH, they were fed on 50% microdiets (56% CP) and 50% *Moina* in respective treatments. Sampling was done every 7, 13 and 28 DAH to record the fish weights using an analytical scale. Specific growth rate $= \frac{InL\ (final\ weight)-(inLintial\ weight)}{Number\ of\ culture\ days} * 100$ The fish survival = $\frac{number\ of\ surviving fish}{theintial\ number\ of\ stocked} * 100.$

With the exception of survival, there were significant differences in average weight gain (p ≤0.5) and specific growth rates (p ≤0.5) between K1 and M2 (Table 6). Despite the same percentage of crude protein, K1 (with *Moina*) performed better than M1 (with *Moina*). This implies that there is an advantage in K2 formulation over that in M2. These are local feeds that should father be improved for larval nursing given the fact that most of the larvae feeds are imported and are three times higher in cost than those made by

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farmers within the country. However, this experiment is still ongoing and will provide more information when completed including the proximate analysis levels of the used feeds.

Table 6. Mean growth-related parameters and survival (± standard Deviation) recorded for larval feeding experiment for Barbus altinalis; means with different letter subscripts indicate a significant difference between treatments.

Feeding strategy	Average weight gain (mg)	Specific growth rate (%)	Survival (%)
K1	19.3 ± 0.6^{b}	20.1 ± 0.3^{b}	99.2 ± 0.2^{a}
M1	24.7 ± 0.6^{a}	21.5 ± 0.1^{a}	99.0 ± 0.6^{a}

Larval nursing with enriched Moina experiment

To improve the survival, quality and growth of the fry/larvae, hatched fry was fed with a mixed diet of *Moina* and dry microdiets; i) enriched *Moina* (with Nile perch oil) fed together with micro diet (50% crude protein), ii) un-enriched *Moina* with the same micro diet. The two treatments were conducted in triplicates. Weight data was recorded continuously for two weeks. In previous work, the larvae fed with the mixed microdiet of *Moina* (not enhanced), significantly performed better than other diets i.e the microdiets alone, hatched *Artemia* and *Moina* alone (Aruho *et al.,* 2020). This study sought to improve the feeding protocol with enhanced *Moina* and microdiet given to the young fry 10 days after hatch (DAH). Decapsulated *Artemia* was used between 6DAH and 9DAH before the *Moina* experiments. The preliminary result indicated, no significant difference ($p>0.5$) between the two diets (treatments). Survival was not significant but was slightly better with the enriched diet at 93% and 89% with unenriched diet. It is possible that the effect of *Artemia* had conferred a better advantage to the growth of the larvae and was able to maximize the nutrients from diets irrespective of the treatments. These results are not conclusive, and more data and other experiments are still ongoing and will probably provide more information about these protocols.

Use of live feed (Moina) to support mass production

There is undoubtedly understanding among the fish seed multipliers on how important *Moina* is in feeding the larvae of many fish species in hatcheries during nursing. The biggest challenge is maintaining the *Moina* for long periods to enable regular feeding of the larvae in the hatcheries. The studies being conducted are aimed at defining a good protocol for maintaining the *Moina* cultures. Previous studies on *Barbus altianalis* have shown that diets dominated by *Moina* improved the growth and survival of *B. altianalis*. Three weeks after hatch, was the period found to be suitable for nursing the *B. altianalis*

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larvae in the outdoor tanks and the larvae were fed with microdiet in tanks until they were fingerling size and distributed to the farmers. The gap here was to continuously maintain the *Moina* to feed the larvae in the out-door tanks. Better survival and growth are necessary to facilitate fast growth to attain the fingerling size suitable for distribution.

In the study to maintain the *Moina* culture, four fiberglass tanks of 1,000L to be inoculated with green water were filled with water; and 200g/m^3 of chicken manure and 200g/m^3 sunflower cake were added to each of the tanks (previous work used 0.08gL^{-1} of NPK fertilizer). The substrate or mixture was rested for four days. During the four days a stick was used to stir the mixture every morning and every evening to facilitate the nutrients dissolving and mixing well with the water. Green water cultures (mixed microalgae-dominated by *chlorella spp*) were concentrated from the ponds to make approximately 9x10^6 cells per litre using 50µm planktonic net that prevented unwanted zooplanktonnes to pass through. About 10L were used to inoculate each of the tanks and they became green within 4-6 days. These tanks were the sources of green water used to feed the *Moina.*

Six large fiberglass tanks of 1,000L were filled with water and inoculated with green water until they became green. When they were green, they were inoculated with *Moina micrura* concentrated from the lagoons from Entebbe with 150µm net. Little aeration was provided to maintain good oxygen circulation, while approximately 20% of the water was replaced daily through the bottom of the tanks. The six tanks were fed daily with about 10L of green algae each, to continuously feed the *Moina*. The density of the *Moina* increased from the 5th day until the 15th day when they reached their peak and when their density was 100 - 120 *Moina* per ml, they were harvested to feed the *Barbus* larvae in aquarium tanks. Regular harvest of *Moina* was done to avoid over population in the tanks. The culture was maintained by addition of green water daily until the larvae were mature enough to be transferred to the outdoor tanks. The first 4 green water tanks were replenished with manure and sunflower cakes every 5 days. Despite the availability of this protocol now, experiment to obtain more results are still ongoing and the result will be used to update this protocol.

Suggestions for upscaled production technologies

There are still challenges in optimizing seed production in order to have mass production of fingerlings for the smallholder farmers in the country. One of the key drawbacks is lack of broodstock for breeding. No hatchery is known to have this species and the few

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farmers that farm *Barbus* sell it to consumers at premium prices. This specie does not naturally spawn in ponds and farmers are reporting relatively slow growth compared to other exotic species of carp. There is generally an understanding among the farming communities and researchers that more work needs to be done to mass produce more seed, distribute it to many farmers in different regions and determine growth performance using various methods. And then from these distributions more broodfish will be collected and used as broodstock for producing more seed for distribution. Mass production is necessary to enable distribution of broodfish to hatcheries and then farmers. Under the FoodLAND project, some hatchery technicians will be trained on how to produce Kisinjja and then apply the technologies to boost seed production for distribution to farmers. The hatchery farmers will be provided with training on the process of producing the live feed and feeding the young fish in hatcheries.

Protocol/guidelines for breeding *Barbus altianalis*

1. Prepare a checklist of materials and requirements that you will need during spawning.
2. Check the worthiness of the hatching, nursery, and holding tanks aeration system, heating system, or power sources.
3. Clean and disinfect all contact points, including worktops, containers, hatching, and broodstock holding tanks.
4. Test the system at least a day before the beginning of the spawning.
5. Organize enough workforce depending on the scale of operation.
6. Use natural (catfish pituitary) or artificial hormones to induce the females.
7. Inject the fish with the hormone (African catfish pituitary 1:1 female; 10 μg kg^{-1} + 20 mg kg^{-1} s GnRHa OR Ovatide).
8. Place the injected fish into the circular tank system for breeding carps.
9. The males are placed in the same system the ratio is 1:1 or 2:1 (female to male).
10. Allow the water to circulate in the tanks constantly.
11. Depending on the temperature, the fish will be ready to spawn between 8 to 12 hours.
12. When ready, the eggs will be collected in the net as the water flows out of the circular tank system.

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13. After fertilization of the eggs, immediately transfer the eggs to the incubation unit (in this case we still encourage the hatchery operators to use largely the indoor system e.g., that of the African catfish).
14. Incubate for at least 40hrs then the fry will begin to emerge.
15. Feed after six days with both live feed (*Moina* raised from ponds or tanks) with micro diets (45%-55% crude protein).
16. Ensure good water quality for the larvae; clean and maintain a steady water flow system.

Technology and production key performance indicators to be gathered

- *B. altianalis*, growth performance of the fish in the production systems (the specific growth rates; lengths and weight) will be measured.
- Number of farmers/hatchery operators adopting the technology
- Number of farmers/hatchery operators trained in BMPs for the developed technology
- Number of fingerlings produced by the hatchery operators

Risks and Mitigation Measures

Risks	Mitigation
Climate change effects (dry spells and heavy rains)	Resistant structures
Fewer broodstock for spawning	Get more from the wild for breeding
Poor management by farmers	Regular monitoring to ensure feeding
Some of the farmers likely not feeding due to financial issues	-Train on farm-made feeds -Prior assessment before farmer is given the feed

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Labeo victorianus

Literature review on production methods and potential markets of the species

Labeo victorianus (Ningu), is a potamodromous endemic cyprinid of the Lake Victoria basin; it's described to have a wide extent of occurrence in Burundi, Kenya, Tanzania, and Uganda. Their natural habitats are shallow areas of lakes, rivers, and swamps (Fish Base team RMCA & Geelhand, 2016). According to Cadwalladr (1965), during the early 1940s and 50s, *L. victorianus* was a commercially important fishery. The catches of *L. Victorianus* were reported to be reducing in the 1950s in Lake Victoria and the mouth of rivers as a result of unregulated gill netting of gravid mature fish during their upward migration and the use of scoop traps to harvest the fry during their downward migration (Ogutu-Ohwayo, 1990). Only two populations exist in the rivers Kagera and Sio around Lake Victoria in Uganda, although at a decreasing trend; hence the species is listed as critically endangered (Rutaisire, 2003, Fish Base team RMCA & Geelhand, 2016).

Figure 38. A. holding facility for broodfish, B. inspection of reproduction circular tanks for eggs/embryos C. egg collection from a net connected at the outlet pipe D. Eggs/embryos collected from reproduction tanks.

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On the other hand, aquaculture in Uganda has grown from 15,000 tonnes in 2,000 to an estimated 120,000 tonnes in 2018 (FAO, 2020), contributing nearly 20% of the total fish production in the country (FIP report, 2020-2025). However, this is insignificant compared to the required target of 1,000,000 tonnes by 2030 to meet the increasing demand for a cheap source of protein and more for foreign exchange earnings for a population of over 40 million (Fisheries and Aquaculture policy, 2018).

Labeo victorianus is a food delicacy among many consumers, especially in central and eastern Uganda. The species is also favoured as a bait for Nile perch fishery due to its high survival as live and bait on hooks (personal communication with the fishermen). Given this apparent demand, *Labeo victorianus* fetches US$2-4 per kg. Rearing of this endangered fish species has the potential to alleviate fishing pressure and provide food fish and job opportunities to riparian communities. Furthermore, its culture can provide fingerlings that could be restocked in natural environments to rejuvenate the critical population of this fish species.

Successful induction trials of mature *L. victorianus* collected from the wild have been

Figure 39. The hatching system was designed for cyprinids, where eggs in this trial were inoculated for incubation and subsequent hatching.

conducted using a commercial hormone, "Dagin" in semi-artificial captive conditions in Uganda (Rutaisire & Booth, 2004). However, this was not seen as a successful artificial reproduction method as all eggs died after 24hrs. These observations show the need for

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more trials to optimize spawning procedures to produce high quality and quantity of *Labeo* seed, especially using artificial spawning methods. Artificial spawning methods have been proven more efficient than semi-artificial spawning procedures in many fish species (Marte, 1989; Harvey & Carolsfeld, 1993). Currently, the performance of an agents are not readily available and are costly. Therefore, the use of cheaper and readily available pituitary extracts from African catfish was investigated in the current study.

Studies on larval nursing have focused on feeding using undifferentiated phytoplankton and zooplankton in experimental glass aquaria. In this fish species, hatchlings start ingesting exogenous feeds in 5 to 6 days when the yolk sac is fully used, and a mixture

Figure 40. A Injecting of the broodfish in the dorsal ventral muscle with inducing hormones, B-Sampling of eggs to determine progress to ovulation C-Analysis of egg maturation stage using a microscope, D-Striping of female with ripe eggs, E-Stripping of milt from running male broodfish, F. Weight of stripped eggs, G. mixing the eggs with milt and then wáter to fertilize, H. Spreading of eggs in the concrete tanks.

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of unisolated zooplankton showed the best results (Owori-Wadunde, 2004 & 2009). However, low survival (35-60%) of *Labeo victorianus* during nursing and outgrow experiments have been recorded. The studies show the need for optimizing larval nursing procedures (feeding and nursing conditions) to improve the survival of Ningu in captivity.

Generally, all studies on *L. victorianus* are experimental and have not been taken up by producers. We could trace only three fish farmers rearing *L. victorianus in* Uganda. There is a need to continuously optimize the protocols of spawning and larval nursing so that mortalities are significantly reduced to produce adequate quality seed for hatchery operators and farmers.

General objective

The study's overall objective is to develop cost-effective mass seed production protocols to facilitate hatchery producers, including women and youth, to produce quality and sufficient *Labeo victorianus* (Ningu) seed for smallholder out-growers with a view of supporting their incomes and nutritional needs.

Objectives

- To evaluate the spawning performance of using different locally available inducing agents under artificial and semi-artificial methods
- To evaluate the performance of ningu fry/fingerlings on different live feed to identify the best diets that are suitable for mass fry/fingerling production
- To evaluate the costs associated with mass seed production using developed technologies.
- To demonstrate to farmers, including women and youth, and support training needs on the best management practices for ningu fry and fingerling production.

Experimental design

Complete artificial spawning process

The broodfish used in this experiment were collected from the wild at the river mouth of Sio (Maduwa landing site, Busia district) and transported to ARDC Kajjansi in an insulated tank on a broodstock carrying vehicle with constant aeration (Figure 38). They rested for one day before they were reproductively induced (Figure 38A). The ripe

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broodfish were grouped in 3 sets, each with 20 females and 20 males. One set of females was treated with African catfish pituitary (10.5mg/kg) and another set was treated with Ovatide (0.4ml/kg) while the third set was considered as control group which was treated with a blank physiological solution (0.4ml/kg). These were stocked in separate tanks of 18m^3 (Figure 38B). Females with mature eggs produced eggs on slight application of gentle pressure. Mature males had creamy milt on the application of gentle pressure on the belly (Figure 40E). The males were stocked in three tanks with females respectively. The water flow rate through the tanks was maintained at 20lt/min. The onset of spawning was monitored every two hours until 8 hours post-induction, following the method by Rutaisire and Booth (2004). The embryos/eggs were collected by the net placed at the outlet of the circular tanks. Egg/embryo collection was done 8 hours after onset of spawning for each treatment (Figure 38 C&D). The eggs were inoculated in a facility designed to hatch riverine species supplied with water by a flowing stream (Figure 39).

Semi-natural spawning process

In this trial, the broodstock were grouped in 3 sets, each with 10 females and 10 males. Each set of females was treated with African catfish pituitary (10mg/kg), another with Ovatide compromising of Gonadotropin-Releasing Hormone analogue 20mcg + domperidone 10mg at 0.4ml/kg according to the manufacturer's instruction for carp, and the third set with blank physiological solution (0.4ml/kg). They were transferred to rectangular concrete tanks of 24m^3 by volume that acted as post-induction facilities. The flow rate in the post-induction facilities was maintained at 20L/min. During the pre-stripping period, fish from each treatment were monitored for progress toward ovulation by randomly sampling eggs from three females for two hours after 8 hours post-induction using a gentle press (Rutaisire & Booth, 2004) (Figure 40 B&C). The treatment with fish having 80% of the oocytes transparent and were stripped into a clean, dry, and pre-weighed container; the weight of the eggs obtained was recorded, and to determine the number of spawned eggs, samples of known-weight eggs were counted (Figure 40F). The milt was also obtained by stripping the males into the mortar containing physiological saline solution (Figure 40E). The eggs were then fertilized by adding the milt solution into the bowl containing the eggs and mixing by swirling; shortly after, freshwater was added and mixed further by swirling for at least 1 minute (Figure 40G). The eggs were transferred in 10L buckets and allowed to absorb water for 15-30 minutes and later spread in tanks filled with stream water (Figure 40H). The flow-through stream was

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maintained at a rate of 20L/min during incubation. Some eggs/embryos obtained from both treatments were incubated over trays laid in 40L aquaria tanks (Figure 41A). Two-hours post-fertilization, the fertilization rate was determined by recording the number of eggs and embryos. The hatching rate was established by registering the number of hatchlings.

Larval feeding experiment

Larval feeds (treatments), including decapsulated *Artemia* cysts, *Artemia* nauplii, and *Moina* (Figure 42), were used to evaluate their effect on larval performance (survival rate, feed conversion ratio (FCR), growth rate). Every treatment was conducted in 3 replicates of 40L aquaria water tanks, each stocked with 400 larvae (Figure 41A). The treatments were administered for ten days. After that, all treatments were weaned using locally made artificial feeds of at least 40% crude protein using a co-feeding strategy of 5 days, where they were fed on 50% dry feed and 50% of their respective feed treatments.

Figure 41, A- 40-liter glass tanks stocked with 400 larvae each and B sampling of larvae using a sensitive (0.000 g) and ruler,

Sampling was done every five days to record the fish weights and lengths using an analytical scale and ruler, respectively (Figure 41B). The formula determined the specific

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growth rate $= \frac{InL\,(final\ weight)-(inLintial\ weight)}{Number\ of\ culture\ days} * 100$; the feed conversion ratio $= \frac{\text{Total weight of feed consumed}}{\text{Total weight of fish}}$; and the fish survival = $\frac{number\ of\ surviving fish}{theintial\ number\ of\ stocked} * 100$.

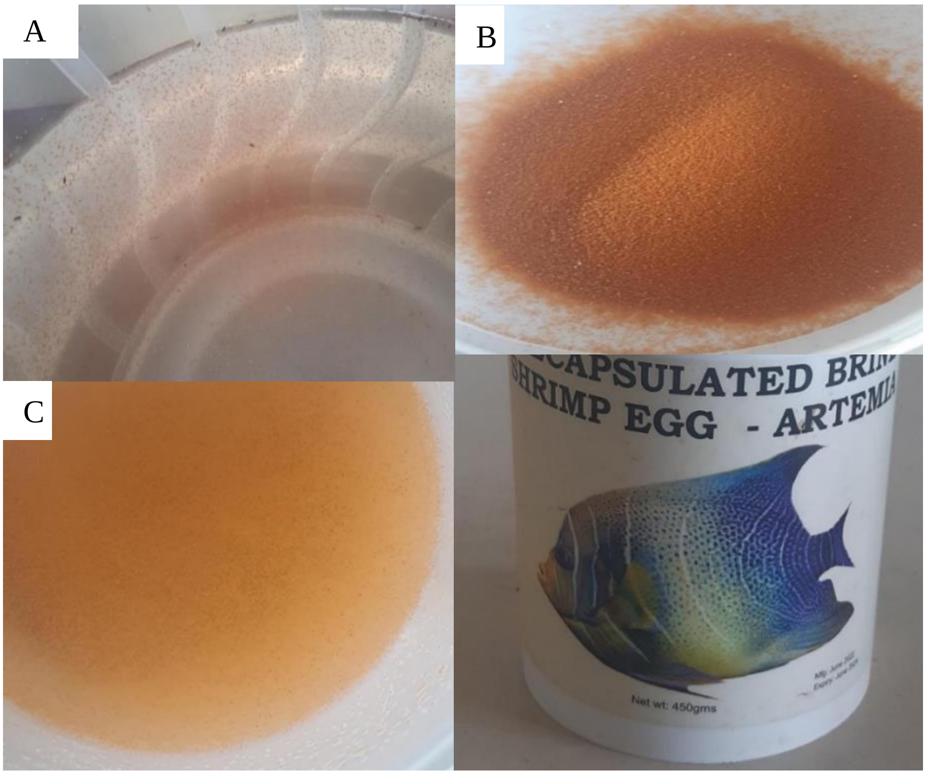

Figure 42. Larval feeds used in the experiment A- Moina, B-Decaspsulated Artemia, C-Artemia nauplii.

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Preliminary results and discussion

Complete Artificial spawning process

Broodfish induced using African catfish pituitary extracts took less time to ovulate. However, they produced fewer eggs and registered lower fertilization rates than those reproductively caused using Ovatide (Table 7). All embryos died after 6 to 10 hours post fertilization. The results indicate that the semi-artificial method can produce fertilized eggs using Ovatide and African catfish pituitary extracts. The challenge could have been the poor quality of water and the water force in the hatching unit where eggs were placed. This system used by the carps has not been used before, it allows stream water to be constantly circulated around the eggs in the hatching unit during the incubation. On one hand, the number produced was comparatively lower than those reported by other authors (Rutaisire & Booth, 2004, Orina *et al*., 2014) using circular system; hence more investigations (experiments) are being done to determine appropriate spawning techniques using the same system.

Table 7. Spawning parameters for the semi-artificial spawning method of Labeo victorianus.

Inducing agent	Time to ovulate (min)	Eggs produced (1,000/kg)	Fertilization rate (%)
Ovatide	850	8.397	98
African catfish pituitary extracts	688	6.650	76.5
Blank	-	-	-

Semi-natural spawning process

Broodfish induced using African catfish pituitary extracts took less time to ovulate and produced more eggs than those induced using Ovatide. The resultant eggs and embryos for Ovatide-induced broodfish registered high fertilization and hatchability compared to those induced using fresh African catfish pituitary extracts. However, there was no significant difference in fertilization and hatchability between commercially available inducing agent Ovatide and African catfish pituitary extracts at P>0.05 (Table 8).

Table 8. Spawning parameters for the artificial spawning method of Labeo victorianus

Inducing agent	Eggs produced (1,000/kg)	Time to ovulate (min)	Fertilization rate (%)	Hatchability (%)
Ovatide	224.8133	911	99.3±0.6a	95.1±1.7a
African catfish pituitary extracts	316.7716	782	91±2.1a	75.4±0.7a
Blank	-	-	-	-

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Preliminary results indicate the complete artificial method is more effective that the semi-natural process. There is close control of events and processes, and this forms part the protocol that should be adopted for breeding Ningu. It is observed that the African catfish pituitary was equally as effective as the Ovatide. This implies that hatchery operators can easily use the cheaper pituitary extracts instead of using Ovatide which is a bit expensive and inaccessible by many hatchery operators.

Larval feeding experiment

The specific growth rates, survival and weight gain of post larvae fed on *Artemia* cysts, artemia nauplii did not significantly defer from each other ($P \geq 0.05$) (Table 8). However, the growth parameters of larvae fed the decapsulated *Artemia* performed better than other diets (Table 9). These observations could be related to the particle size of the feed types used in the experiment. The decapsulated *Artemia* cysts are smaller than *Artemia* nauplii and *Moina*, respectively and *Artemia* nauplii are smaller than *Moina*; hence they can easily be ingested by the post larvae. The larger *Moina* may act as good larval feed for this species when administered at slightly bigger larva/fry.

Table 9. Mean growth-related parameters (standard deviation) recorded for larval feeding experiment for Labeo victorianus.

Larval feed types	Average weight gain (g)	Specific growth rate (%)	Survival (%)
Decapsulated *Artemia* cysts	13.9±11.2	23.1±6.6	99.3±0.5
Artemia nauplii	7.3±1.884	18.6±2.2	99.5±0.4
Moina	5.2±3.2	15.4±4.7	98.8±1

Considerable size variations were observed among larvae feeding on *Moina* and decapsulated *Artemia*, which may indicate the need for size grading during larval rearing while using these feeds. However, these feeding experiments are still ongoing.

Expected technologies for upscaling/adoption by farmers for spawning and larval nursing *Labeo victorianus*

- Spawning procedures using identified spawning and hatching facilities and inducing with locally available agents (African catfish pituitary extracts and Ovatide).
- Larval nursing using decapsulated *Artemia* cysts and *Artemia* nauplii.

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Protocol for spawning and larval nursing of *Labeo victorianus*

Broodstock selection

1. Females with bulging stomachs should be selected.
2. Ready females will produce eggs with the application of gentle pressure. The eggs should be of uniform size and colour (Figure 39).
3. Select ready males to produce creamy milt with gentle pressure on the belly (Figure 39).
4. Select healthy brooders without deformities and injury.

Pre-induction conditioning

1. To limit stress among brooders, they should be rested for at least 6 hours before induction.
2. Broodstock should be kept in tanks with clean water supply and a continuous flow-through system.
3. They should be stocked at 1 kg per m^3.

Induction

1. Induce to ovulate by injecting the fish dorsal ventrally at a rate of 0.4ml/kg for the females and 0.2ml/kg for the males using Ovatide or African catfish pituitary extracts at a rate of 1 pituitary extracted from 1kg fish to 1kg of female broodstock and half the dose for the male ones.
2. In semi-artificial spawning, keep the fish of both sex in fishponds/tanks with a continuous flow-through system at a rate of 20 to 40L per minute for 8 to 10 hrs.
3. For artificial spawning, the males and females are kept in separate containers.

Egg collection

1. In semi-artificial spawning, after 8 to 10 hours, the eggs will be produced, uptake water, and become semi-buoyant along the water column (Figure 33).
2. These can be collected using a scoop net of 0.5 m mesh size; they can also be obtained by draining through harvest basins and nets.
3. In artificial spawning, the females can be striped for eggs after 10 to 16 hours in a dry container (Figure 39).

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Milt collection

1. In artificial spawning, the males are stripped for milt into a bowl containing a physiological saline solution (Figure 39).

Egg fertilization

1. The eggs are fertilized by adding the milt solution into the bowl containing the eggs and mixing by swirling.
2. Shortly after, fresh water is added and mixed further by swirling for at least 1 minute.
3. The eggs are transferred in 10L buckets and allowed to absorb water for 15-30 minutes.

Egg incubation and hatching

1. The eggs are spread over trays made from 0.5mm net material and wood frames laid in tanks filled with clean water, preferably supplied by an underground well.
2. The water temperature is maintained at 26 to 28^{o}C.
3. After 24 to 36 hours, larvae start to emerge. They go through the perforations of the trays to the bottom of the hatching/incubation container.
4. The shell and dead eggs left behind on the tray should be removed immediately after most embryos have hatched to avoid bacterial build-up.
5. The eggshells and dead eggs that settle on the bottom of the hatching facility should be removed immediately by siphoning to avoid build of ammonia in the system.
6. At least 50% of water in the hatching facility should be replaced every day to maintain optimal water quality parameters.

Larval nursing

1. Three to five days after hatching, the larvae start feeding and can be provided with satiation using decapsulated/shell-free *Artemia* cysts for 5 to 10 days.
2. Stocking rates should be maintained between 10 to 20% by volume.
3. Then they can be weaned to dry feeds of at least 40CP.
4. At least 50% of water in the larval rearing facility should be replaced every day to maintain optimal water quality parameters.

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Technology and production key performance indicators to be gathered

- Number of hatchery operators trained on the spawning procedure and fingerling production of *Labeo victorianus.*
- Number of farmers/hatchery operators adopting the developed technology.
- Number of fingerlings produced by the hatchery operators using the technology.

Risks and Mitigation Measures

Risks	Mitigation
Fewer broodstock for spawning	Intensify mobilization of fishermen to catch more from the wild
The slow adoption rates of farmers in adopting the developed technologies	-Sensitization of farmers on the importance of spawning this fish species -Training the farmers on the utilization of the developed technologies

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Work plan for Validation Activities

Feed Formulation (SUA)

ACTIVITY	2023											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Formulate and conduct on-station feeding experiment and identify the best diet												
Conducting experiment to compare flakes and pellets to determine the best form of diet												
Conduct on-farm feeding experiment to verify the best diet												
Training of farmers to formulate fish diet												

Integration of Chicken-Fish-Vegetables (SUA)

ACTIVITY	2023											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Preparation of training materials												
Training of fish farmers on integrated aquaculture												
Construction of improved chicken house by farmers												
Stocking and management of fishponds												
Management of chickens	Continues until May 2024											
Establishment and management of vegetable plots												

Integration of Aquaculture and Agriculture (NARO)

Activity	2023											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Experimental set-up of integrated fish and vegetable production on-station at ARDC												
Fish and vegetable survival, growth performance assessment												
Developing Guidelines & BMPs on integrated fish and vegetable production technology												

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Activity	2023											
Training Farmers and prospective farmers on best practices for fish and vegetable production technology												
Validation activity (fish and vegetable) with the farmers												
Data collection and analysis												

Recirculating Aquaculture System Tanzania (SUA)

ACTIVITY	2023											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Designing and testing of simple solar RAS												
Conducting farmers sensitization workshop for adoption of simple solar RAS												
Training of fish farmers and construction simple solar RAS												
Rearing of fish in simple RAS by farmers	Continues until Dec 2024											

Pond Polyculture (NARO)

Activity	2023 (NARO-KARDC trials)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pond preparation and pre-stocking data collection (inputs, challenges, etc.).												
Pond stocking and start of fish and environmental data collection including inputs and challenges).												
Data management and study report/ guidelines development.												
Validation												
Selection and training the validation fish farmers and data collection clerks.												
Pond preparation and pre-stocking data collection (inputs, challenges, etc.).												
Pond stocking and start of fish and environmental data collection including inputs and challenges).	Continues into early 2024											
Data management and validation report/ improved guidelines development.	In early 2024											

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Barbus altianalis (NARO)

Activity	2023											
	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Spawning *Barbus altianalis* on-station at ARDC												
Growth, maintenance & Distribution of *Barbus* fingerlings to some farmers in the food hub												
Training Farmers and hatchery operators on best practices for spawning technology												
Training of hatchery operator on production of *Moina*												
Validation activity (*B. altianalis spawning & Moina production*) with the hatchery operators												
Data collection and analysis												

Labeo victorianus (NARO)

Activity	2023											
	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Spawning and larval nursing trials at ARDC												
Training Farmers and hatchery operators on best practices for spawning and larval nursing of *Labeo victorianus*												
Validation of developed technologies on farms												

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