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GUIDELINES ON DEVELOPMENT AND MANAGEMENT OF AQUACULTURE SYSTEMS AND NEW CULTURE FISH SPECIES BULKING TECHNIQUES

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Abbreviations and glossary

Abbreviation/specialist term	Explanation
ARDC	Aquaculture Research and Development Centre
BMP	Best aquaculture Management Practices
BW	Body Weight
CP	Crude Protein
CPM	CowPeas Meal
CRD	Completely Randomized Design
DAH	Days After Hatching
DALF	Department of Agriculture, Livestock and Fisheries
DGPA	Direction Générale de la Pêche et de l'Aquaculture de Tunisie
DO	Dissolved Oxygen
FCR	Feed Conversion Rate
FM	FishMeal
IAA	Integrated Aqua-Agriculture
INAT	Institut National Agronomique de Tunisie
KPI	Key Performance Indicators
MBR	Membrane BioReactor
MD	tilapia MicroDiet
MLM	Moringa Leaf Meal
MMD	unenriched *Moina* with the MicroDiet
NARO	National Agricultural Research Organisation
NPK	Nitrogen Phosphorus Potassium
NPO	Nile Perch Oil
RAS	Recirculating Aquaculture System
SBO	SoyBean Oil
SGR	Specific Growth Rate
SUA	Sokoine University of Agriculture
SSC	Sunflower Seed Cake
UNR	Unenriched *Moina microrura*

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FOODLAND

Task 4.2: Technological research for integrated aquaculture systems

Subtask 4.2.1: Experiments to improve green-water RAS technology for peri-urban and urban areas

Leader: ABT
Participants: DALF (KE), SUA (TZ)
Start-End: M10-M40
Status: *Late*

Subtask 4.2.2: Development of intensive-extensive aquaculture integration technology for rural and peri-urban areas

Leader: NARO
Participants: ABT, INAT, SUA (MT)
Start-End: M10-M40
Status: *Late*

Subtask 4.2.3: Research for integrated aquaculture systems: using aquaculture effluents for irrigation and fertilisation in agriculture

Leader: ABT
Participants: DALF (KE), NARO (UG),
Start-End: M10-M40
Status: *Late*

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1. Introduction

1.1 Historical data

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), and 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).

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 (*Clarias gariepinus*). 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 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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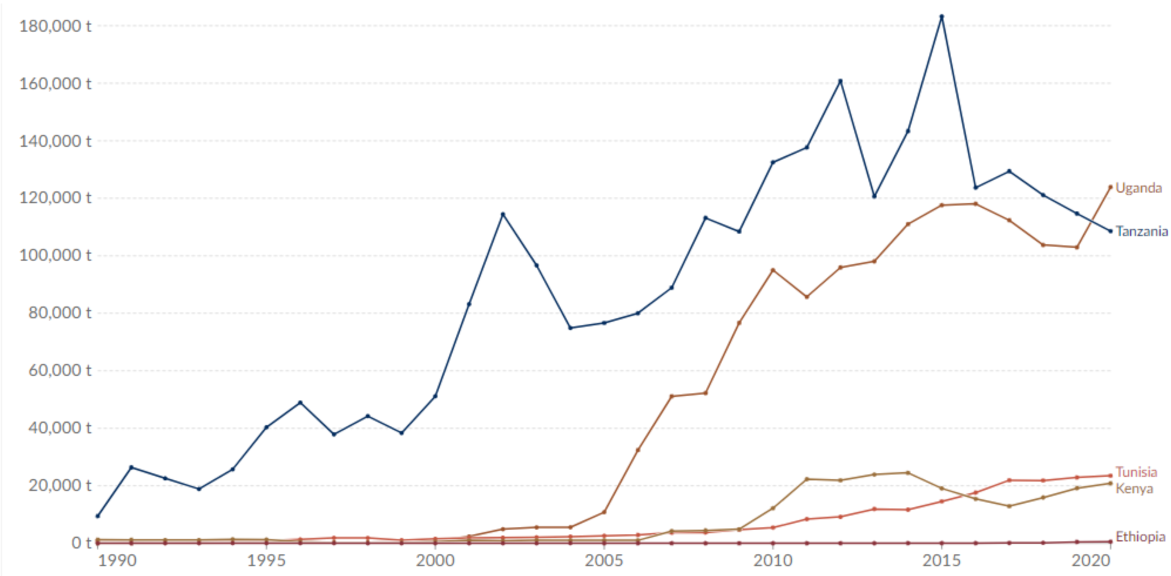

Figure 1. Aquaculture production in Ethiopia, Kenya, Uganda, Tanzania and Tunisia (Ritchie & Roser, 2021)

1.2 Aquaculture production by country

Kenya

Pond culture was introduced in the early 1920s starting with different species of tilapia followed by common carp (*Cyprinus carpio*) 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 (Figure 2). It is estimated that Nyanza and Western provinces alone had over 30,000 fishponds by the early 1970s. However, the big amount of fishponds 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 practiced 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 2 . Ponds in Bukani, Kenya (Odenke et al. 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 1,000t in the 1990s and until the middle 2000s (FAO, 2022). As the total national fish production reached around 160,000t 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 3. 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.

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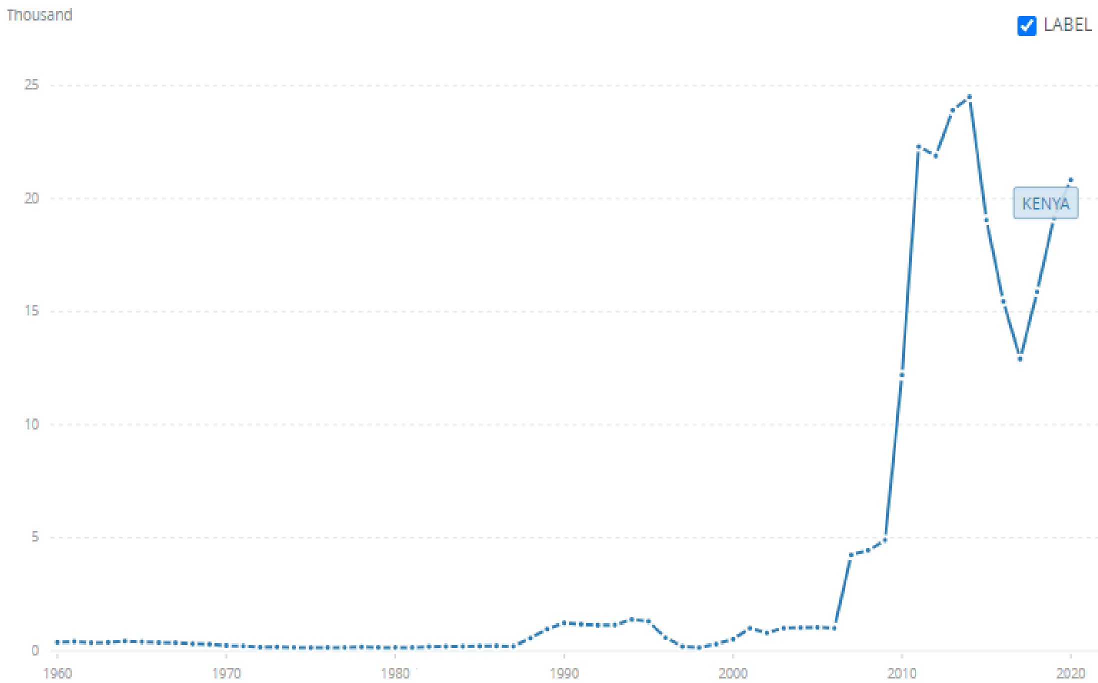

Figure 3. The aquaculture production (in thousands of tonnes) in Kenya since 1960 (FAO 2022)

The most farmed fish species in Kenya are: the Nile tilapia (*Oreochromis niloticus*), representing about 70% of farmed fish, followed by the African catfish, with about 21% of aquaculture production. 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%) (*Oncorhynchus mykiss*) 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, production reached 20,831t (FAO, 2022). Freshwater production is by far larger than marine production. Kenya has 1.4 million hectares of land suitable for

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aquaculture, with the capacity to produce 14 million tonnes (Odenke *et al*. 2022). Despite the massive potential for aquaculture production, the contribution of the 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 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 Zambia. The number of such farms is also growing very rapidly, except in Kenya (Odenke *et al*. 2022).

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. 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 300g from the ponds. If the temperature is lower than 25 °C in a system when harvesting at the end of the 6th month the fish will be smaller.

Raceway tanks are mainly used in rainbow trout production, being practiced in the Mount Kenya region (Figure 4) (Opiyo *et al*. 2018). According to Kenya's State Department of Fisheries, the amount of trout produced from raceways in 2014 was 241t 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 5). 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 at a considerably high density of 5-20 fish/m3 under controlled conditions. The expected production reaches 200 t/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).

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Figure 4. Raceways in Mombasa, Kenya (FAO 1982).

Figure 5 A RAS in Machakos, Kenya (hollandaqua.nl).

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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 (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 (Figure 6).

Figure 6. A cage farm in Mulukoba beach, Kenya (Odenke et al. 2022).

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

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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.

Several challenges are being encountered: high mortalities during larvae phase, inadequate supply of hatchery inputs and equipment, inadequate rearing facilities, high 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 to reduce cost with the use of monosex populations (male tilapia) and finally, more geneticists must be trained 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 practiced 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 (CP) for tilapia and catfish respectively (Opiyo *et al*. 2018). These feeds are too expensive for some farmers, so most of them use locally formulated mixed feeds. The feeds are made

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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); 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 7, aquaculture production can be seen with an increase in the late 80s, without any increase afterwards 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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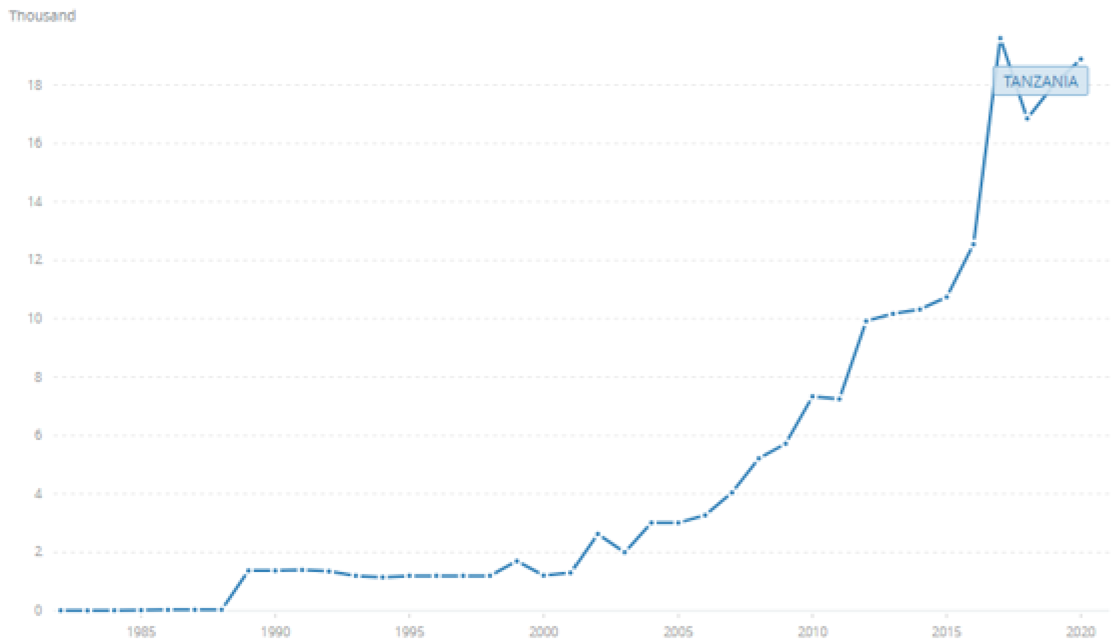

Figure 7. Aquaculture production (in thousands of tonnes) in Tanzania the last 40 years (FAO 2022).

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 t/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 10,000t in 2017. The first cage culture experiments in the lakes started in Lake Victoria and Lake Kumba with research carried out 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. 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, production reached 18,885t (FAO, 2022), with 90% of it coming from freshwater: 27,979 earthen ponds, 431 cages and one RAS farm (Peart *et al*. 2022).

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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:

- 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 8).

Figure 8. A semi-intensive system with ponds in Miswe, Tanzania

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- 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 (Figure 9).

Figure 9. Small-scale farming in ponds in Tanzania (https://www.permaculturenews.org)

45% of the farmers harvest over 2t/farm during the year, 13% of farmers harvested 1-2 t/farm and the rest (24%) harvest less than 1 ton/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.

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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 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 most 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.
- 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 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

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diseases and parasites spreading 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 seed production and grow-out facilities (Figure 10). The climatic conditions (especially temperature) favour an all-year production of fingerlings. Hatcheries produce both monosex and mixed-sex Tilapia fingerlings.

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.

Figure 10. The private hatchery in Miswe, Tanzania.

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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, 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

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several employment opportunities in addition to international exchange earnings. Indeed, this sector provides an average annual production of 125,000t 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.

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 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 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 practiced 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.

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Floating and submersible cage farming of sea bass and sea bream has been increased remarkably during the last few years (Figure 11). Fry and feed are mainly supplied through imports from France and Italy.

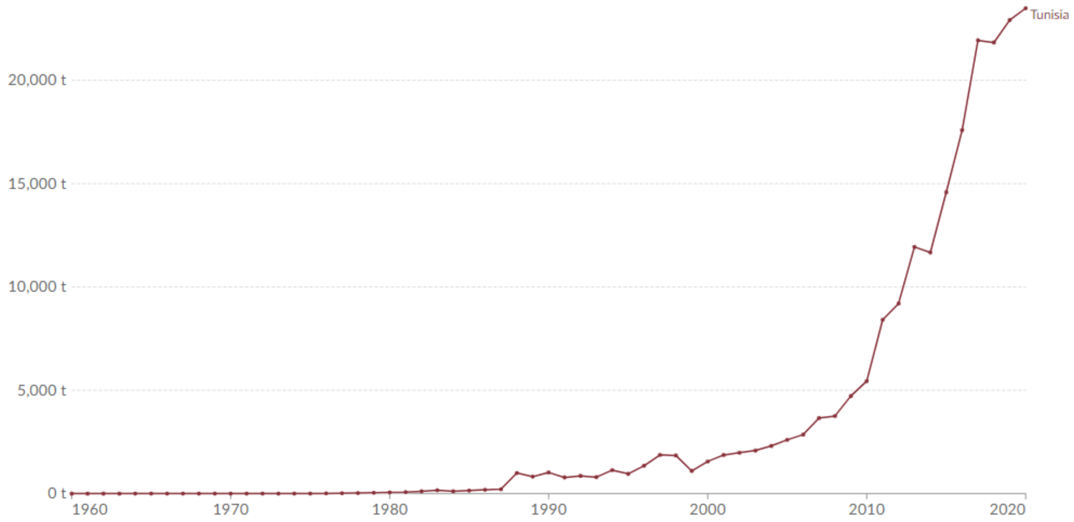

Figure 11. Aquaculture production (in thousands of tonnes) in Tunisia since 1960 (FAO 2022).

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 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. 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.

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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, 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).

Production numbers

The aquaculture production in Tunisia has increased from 4,000t in 2009 to 26,000t in 2021, 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 (Direction Générale de la Pêche et de l'Aquaculture de Tunisie (DGPA), 2021) (Figure 12).

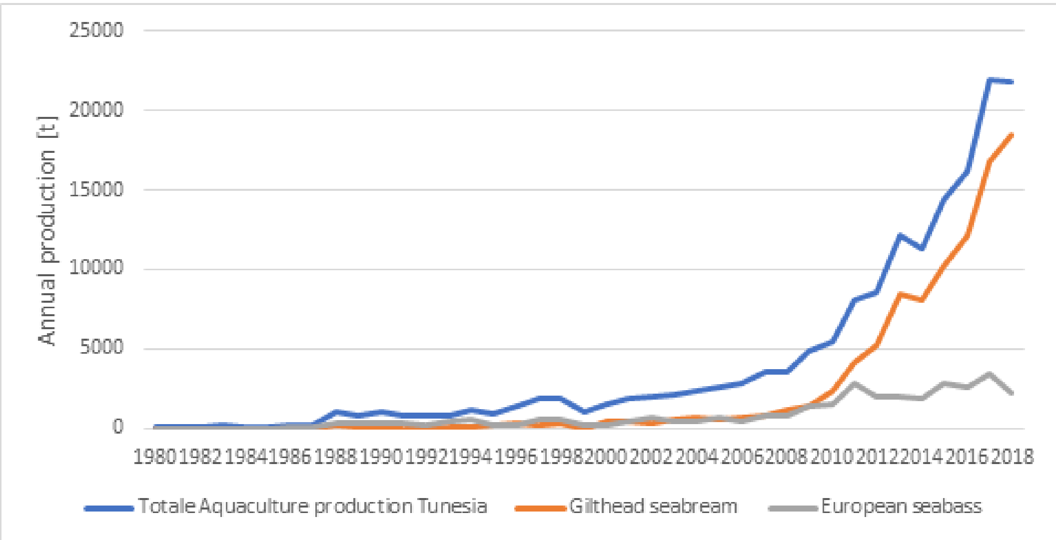

Figure 12. Aquaculture production in Tunisia per species (data from INAT).

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Marine fish farming represents the most productive sector with 90% of the production (23,000t 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 13A). The largest farm production is noted in eastern Tunisia (Monastir governorate) with 66% of total aquaculture production (Figure 13B).

Aquaculture productive projects are distributed mainly on marine fish farming with 23 projects and a total production of 23,000t during the year 2021 (

Table 1). Shellfish farming with a production of 169t was provided by 5 farms (1% of national aquaculture production) while algae-culture provided 12t: 7 farms of spirulina culture with a production of about 9t of dry spirulina and 1 farm of *Ulva* and *Gracilaria* culture with a production of 3t (DGPA, 2021). As for inland aquaculture, it has recorded an average production over the ten years of about 1000t, with approximatively 1.3 billion US$ of the total value of aquaculture.

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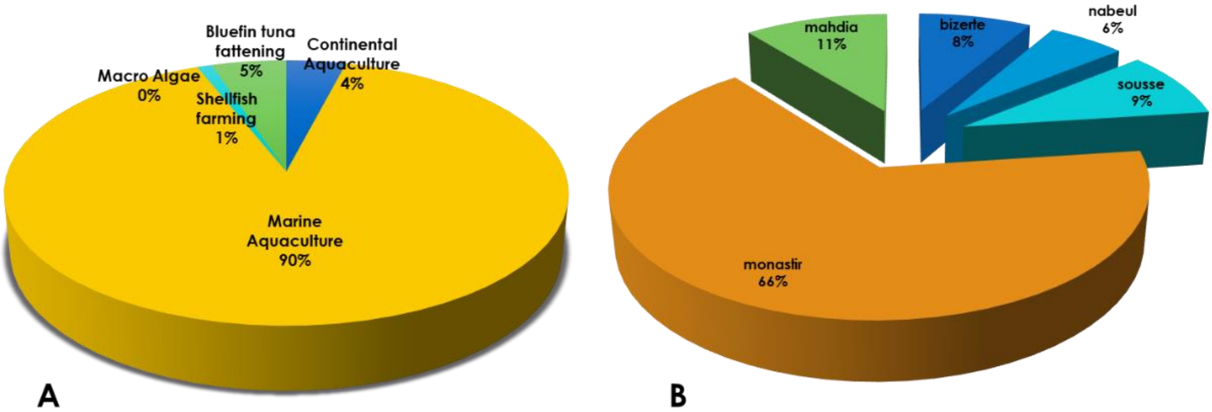

Figure 13. Distribution of production: A) by type of farming and B) by governate

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

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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*	*Mytilus galloprovincialis*		5	169
SHRIMP FARMING	RACEWAY POND	*Penaeus vannamei*			1	1
MACROALGAE	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. This fish is then transported to the retail markets in towns and villages under statutory health and hygiene conditions.

Culture systems

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

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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 14). 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 14. Intensive fish farming in raceways in Tunisia (photo from INAT).

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 2007, offshore cage culture has experienced significant growth with 25 active companies in 2015 (Figure 15).

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Figure 15. Fish farming in cages near Monastir (photos from INAT)

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. 33 dams were in operation in 2014 in the North and Centre of the country, to produce 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. 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)(

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Figure 16).

Figure 16. Fishing in dams (photo from INAT)

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.

Shellfish culture

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 17). These two culture techniques are practiced in the Bizerte Lagoon in the north of the country.

Figure 17. Shellfish farming in the Bizerte lagoon.

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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 20.000t in 2018, and considering this fingerling production sufficient for the future local producers, this capacity would enable extension of the Tunisian production to approximately 160,000t based on these two targeted species (Azaza, 2021).

Fish feeding

Feed production in Tunisia currently comprises 3 companies, with a total production capacity of about 90,000t/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 to provide the required additional feed in the case of increasing finfish mariculture activities in future (Azaza, 2021).

Conclusion

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

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strategy for 2030 a target production of 56,000t/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.

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 practiced 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 and Nile tilapia, resulting in the endorsement of carp. According to the Department of Fisheries Resources, 11,000 ponds were constructed by 1968, all focusing 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 285t (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 efforts, instead of carp (Bolman *et al.* 2018). As carp tolerate lower temperatures, they 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

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commercial fish farms to emerge. The first private hatchery was established in 1999, making an alternative source of fingerlings and fry.

The turning point, however, occurred in 2006 with the introduction of cage culture in Lake Victoria (Bolman *et al*. 2018) (Figure 18). 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 from several countries outside East Africa including Mauritius, Israel, Brazil, Vietnam and others (Bolman *et al*. 2018).

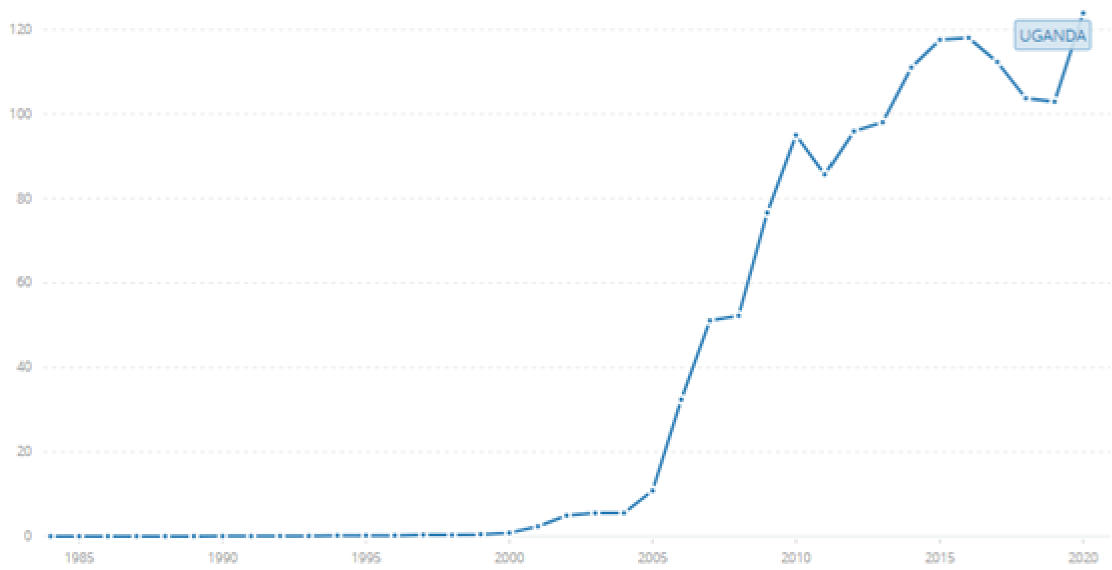

Figure 18. Aquaculture production in thousands of tonnes in Uganda since 1985 (FAO 2022)

Production numbers

By 2005, between 20,000 and 30,000 ponds were operated by approximately 7,000 farmers with an estimated total production of 1,500–5,500t. The average surface

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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 1,800 kg/ha/year in the period 2003-2005. By 2010, 25,000 ponds were recorded with a production of 95,000t. 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 1,349t 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 14,000t, 34,000t in 2020 and by the year 2025, it is expected to reach 98,000t. 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 123,897t. (FAO, 2022).

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

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 19). Previously subsistence farmers, that represented 99% of fish farmers, had ponds ranging anywhere from 50m^2 - 200m^2 (FAO, 2013), however with the commercialization of farming, pond surface increased to a current average of 500m^2 per fishpond (Rutaisire *et al*. 2017; Adeleke *et al*. 2021). 20-30% of smallholder subsistence ponds have been successfully transformed into

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profitable small-scale producers through developments in management and scale of production. 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).

Figure 19. A medium-scale pond farm in Uganda (Dutch Ministry of Foreign Affairs 2021)

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 20). Tank systems are also used in tilapia and catfish on-growing production with the use of bore water.

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Figure 20. A farm in Uganda using tanks (Dutch Ministry of Foreign Affairs 2021).

Cage culture systems in Uganda started in 2006 in Lake Victoria and Kyoga to boost aquaculture production (Adeleke *et al*. 2021)(Figure 21). 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).

Figure 21. Cages in Lake Victoria, Uganda (Dutch Ministry of Foreign Affairs, 2022)

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

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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 30,000t 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 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.

1.3 Objectives of the task

The current conditions in East Africa limit aquaculture development and consequently local efficiency and nutrient pluralism and food system transition in the region. Although aquaculture production in the examined countries is improving and the income of the people who practice fish-farming is increasing, the following issues still stand in the way of a greater advancement:

- Inadequate hatchery production due to deficient equipment and facilities, quality of water supplies, lack of genetic programs and restricted availability of specialized hatchery feeds.
- Many farmers still consider aquaculture a risky business where small amounts of fish can be produced extensively with poor economic return.

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- Lack of knowledge and training in fish husbandry that is needed for production.
- Unprofitable aquaculture systems due to low productivity. The low productivity is mainly due to poor quality feeds which are used to feed the cultured fish. Fish reared on these feeds are unable to meet their rearing requirements, especially for protein. This prolongs the harvest time or leads to production of small-sized fish, without profit.
- Fishmeal and soybean meal are expensive due to high demand for many uses and their inclusion in fish feeds increases their cost.

The aim of the Aquaculture Working Group of FoodLAND in Task 4.2 is to address these hurdles and bottlenecks, and design research trials for solutions for these issues. These solutions must be simple and cheap to facilitate their implementation, replicability and upgrade. Nevertheless, all the solutions suggested need to be tested to receive scientific validation.

The solutions tested within the FoodLAND project focused on integrated aquaculture systems where fish culture is integrated with other agriculture activities. These systems have the potential to increase the variability of protein and lipids sources and can contribute to tackling malnutrition in areas with limited land or water resources. Identification of alternative cheap and locally available feed ingredients were also investigated.

Integrated aquaculture systems were developed in three East African countries: Kenya, Tanzania and Uganda.

The experimental solutions tested in Uganda was led by NARO (National Agricultural Research Organisation) and in Kenya by DALF (Department of Agriculture, Livestock and Fisheries) and the objective of the studies was to identify integrated fish-vegetable models, for smallholder farmers, with high potential, value and affordability. The final goal was to improve food security and farmers' income while ensuring environmental sustainability.

Based on the same principles described above, SUA (Sokoine University of Agriculture) in Tanzania focused on improving existing RAS, which are efficient systems of farming fish using limited space and water. Efficient, cost-effective and solar-powered

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RAS that can be adopted by smallholder farmers were developed. The cost-effective RAS can be used by small-scale fish farmers in rural areas as well as peri-urban areas.

INAT (Institut National Agronomique de Tunisie: National Agronomic Institute of Tunisia) focused on seeding Mullet (*Mugil cephalus*) in dams, to diversify the diet of the local population (diet essentially based on vegetal proteins), as well as to provide suitable nutritional inputs to compensate the nutritional deficiencies of the people. The seed for farming were obtained from the wild environment. As biodiversity and sustainability are becoming more and more important all over the world, farming of indigenous and endangered species can be useful not only for preservation purposes, but for financial support to the farmer as well. The initiative of NARO, of not only developing mass-production protocols for two indigenous carps (*Barbus altianalis* and *Labeo victorianus*), but also their integration into the low-cost inland polyculture, represents a milestone for the sector to improve the livelihoods of the sector-majority.

1.4 Objectives and description of the innovations

The summary of the objectives, innovations and activities carried out by each partner at laboratory-scale in the field of Task 4.2 are reported in Table 2.

Table 2. Task objectives and contributions of each partner.

Expected Result	Specific Result	Country	Partner	Short description	Target food products
Methodological and technological innovations enhancing aquaculture production	Prototypes of integrated aquaculture systems	KE	DALF	RAS and new feeds	Fish
		KE	DALF	Irrigation from RAS effluents	Indigenous vegetables

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TZ	SUA	RAS	A cost-effective solar powered RAS unit using locally available materials (coconut shells) as biomedia for removing ammonia
TZ	SUA	Feed formulation from local ingredients	A cost-effective diet using mixture of sunflower seed cake and Moringa leaf meal as protein sources and maize bran and rice polishing as energy sources
TZ	SUA	Improved fish production	Pelleted diet made using locally available feed materials that can be used by small-scale farmers
TZ	SUA	Chicken-fish-vegetables	An integrated system based on cowpea, chicken and Nile tilapia integration.
UG	NARO	Polyculture of local fish species	Fish for consumption (Nile tilapia, African catfish, Ningu and Kisinjja

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		UG	NARO	Fish-vegetables	Fish for consumption (Nile tilapia and African catfish), assorted vegetables
	New culture fish species techniques	UG	NARO	Improved protocols for mass seed production of Ningu and Kisinjja	Fish seed for grow-out by farmers
	Increase in fish productivity in the Tunisian dams	TN	INAT	Dam seeding	Commercially interesting fish from the Tunisian dams

2. Description of small-scale tests and results

2.1 Experiments to improve green-water RAS technology for peri-urban and urban areas (DALF, SUA)

2.1.1 RAS and new feeds (DALF)

DALF farmed fish using wastewater filtrated with a Membrane Biological Reactor (MBR), in their RAS. Formulated fish feeds from locally available materials (Rice bran, maize bran, cotton seed meal, soya bean, lake shrimp, *Lemna* and *Azolla*) were used to identify the best diet as well as to assess the effects of flakes and pellets on fish growth, the water quality of the system and plankton abundance. At the same time, the green-water of the system was examined to show any effect it may have on the feeding rate of the fingerlings (used in the trials), on their Reed Conversion Rate (FCR) and on the behavioural response and egg quality of the broodstock.

From the experiment carried out in their RAS, the growth performance of tilapia, reared using the locally made feed with the macrophytes (*Lemna*), showed a relatively higher growth rate than the treatment with *Azolla* ingredient, while the control treatment almost shows a similar result as that of *Lemna*. During the rearing period (7 months), several water parameters (Temperature, Oxygen, P and phosphate levels) were

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recorded, and all the levels were within the recommended range for tilapia culture except for the phosphates levels which were higher (1.72). This resulted in the colouration of water to green water, which finally led to the experiment i.e. utilization of the green water for the planting of the indigenous vegetables.

Some of the fish farmers were trained on fish feed formulation using locally available raw materials like *Lemna* plants. They can culture them in small areas next to ponds, harvest them and use them together with other feed ingredients and formulate feeds. This has really assisted them in cutting production costs with a higher return profit.

One of the observations made during the experiment in the RAS is that the FCR was low as compared to when the water was very clear (high FCR).

Another observation made on egg quality and number was that breeding in green water produces a lot of eggs with the majority fertilized than in clear water, while sometimes when the water is too green fecundity is reduced and the less hatching rate from the collected eggs.

Description of the system

The system has three sections namely: i) the Breeding section integrated with incubating jars i.e. used for tilapia breeding and egg incubation; ii) the Larvae/Fry section i.e. is used for rearing/nursing of larvae/fries for a period of one month; iii) Fingerlings section i.e. is used as a hardening area for the sex reversed fries until they attain an average weight of 1g-2g before they are sold to farmers.

Components of the system

-The main source of water is an MBR that treats wastewater. Treated water is first analyzed at Water Resource Authority Laboratory. After treatment, the clean water is pumped into the RAS through UV light system to the biofilter/sump as the first entry point.

-At the biofilter/sump, the bacteria attached to plastic media in a Moving Bed Biofilm Reactor (MBBR) is used to remove dissolved waste from the RAS fish tank water. This includes both the nitrification process, where the toxic nitrogen gas from ammonia is converted into the less toxic nitrogen form nitrate, as well as controlling dissolved organic materials.

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-The Protein Skimmer (i.e. Foam fractionation) is used to remove any settleable solids at the bottom of the header tank, fine solids and a degree or dissolved organic matter in the RAS water. This process also helps to degas carbon dioxide (CO2) preventing build up in the system.

-A pump (usually a centrifugal pump) is used to lift RAS water into the header tank.

-In the header tank (usually installed before the water returns to the fish tanks by gravity) oxygen is introduced into the water by aeration, using diffuser stones.

-A second UV lights unit is used to control the microbial population on the return RAS water to the tanks and to the egg incubator.

-The fish tanks, which are used as the main holding/farming/breeding water collections of tilapia fish.

-The drum filter, which is a rotating screen having a mesh size of 60 µm used to remove large, suspended solids. Alternatively, a sand/glass filter can be used to remove these large, suspended solids. The filter is periodically cleaned through the back wash using a high-pressure pump and flushed out of the filtration unit.

Cleaning and maintenance of the system

Key areas that need to be checked daily include:

- Water quality measurements (Ammonia, Dissolved Oxygen (DO), Temperature, PH and Turbidity)
- Check drum filter-nozzles in case of any blockage.
- Check heater (if applicable)
- Tank, sump and levels i.e. check water levels
- Check for leaks
- Check flow meters

Cleaning and sanitation procedures include:

- Purge and syphon
- Add buffer for pH if necessary
- Bleach and empty sludge tank

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- Clean buckets and probes
- Change rubbish, alcohol bottles

All personnel should follow the Personal hygiene rules:

- Wear clean work clothing such as overall, gumboots, apron and gloves, without watches and jewelry.
- Use footbath to disinfect boots
- Wash work-tools when they are dirty
- No eating in the work area
- Wash their hands properly
- Control the pests

Water quality management include:

- Monitor some important parameters (T, DO, pH) daily and continuously
- Purge and syphon
- Add buffer for pH if necessary
- Oxygenate tanks with air pumps or oxygen cylinders
- Introduce fresh water often
- Observe the water colour
- Use water quality kits often to monitor other parameters (Ammonia, conductivity, Nitrogen, etc.)

A good farm should always keep good records of:

- General hygiene practices (e.g. cleaning and sanitation, staff health, pest control)
- Water quality parameters (DO, Temperature and Ammonia)
- Feed management
- Fish health records (mortalities, diseases outbreaks, medication used)
- Post harvest management
- Traceability of the fish to farmers
- Staff training
- Maintenance of the system

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Of course, staff should get continuous training not only in fish farming techniques but also in supplementary fields, like biotechnology, water chemistry, and engineering to improve their efficiency and capabilities.

2.1.2 New cost-effective RAS system (SUA)

A cost-effective solar powered RAS unit, ideal for small-scale fish farmers in Tanzania, and other developing countries was developed. The RAS unit (Figure 22) comprised of two fish rearing tanks (each with a size of 1000L), one tank for mechanical filtration (1000 L), two biofilter tanks (each 200L), and water solar pump. The mechanical filtration tank contains gravels, while the biofilter tanks contain coconut shells of standard size for removing ammonia. The RAS unit is operated by solar power throughout, which is readily available and friendly to the environment.

Figure 22: A cost-effective RAS unit that uses locally available biomedia and is solar powered

2.2 Development of intensive-extensive aquaculture integration technology for rural and peri-urban areas (INAT, NARO, SUA)

2.2.1 Dam seeding (INAT)

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

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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).

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 or the transfer of broodstock of certain species such as zander (*Sander lucioperca*) and black bass (*Micropterus salmoides*) as well as forage fish (e.g. roach- *Rutilus rutilus* and the common rudd- *Scardinius erythrophthalmus*) (DGPA, 2019).

Seeding a dam with fry fish involves careful planning and execution to ensure the success of the stocking effort. There are many points that should be considered:

-Choose a suitable dam: Select a dam with appropriate water quality, temperature, and habitat for fish fry and ensure that the dam has sufficient food sources, such as plankton and small invertebrates, to support the fry. The number of fry depends essentially on the surface area of the dam.

-Obtain Necessary Permits: Check with local fisheries authorities to obtain the necessary permits for stocking fry fish and comply with any regulations regarding the species, quantity, and timing of stocking.

-Source Healthy Fry: Obtain fry fish from a reputable hatchery (for mullets ensure to obtain fry from Technical Center of Aquaculture) to ensure the health and genetic diversity of the stock and transport the fry in suitable containers with aeration to minimize stress during transportation (Figure 23).

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Figure 23 Transport of fry mullets in aired containers

-Transportation and Handling: Minimize transportation time to reduce stress on the fry and handle it gently and avoid overcrowding during transport to prevent injuries.

-Acclimatization involves carefully adjusting the fry to the water temperature of the dam by progressively blending the transport water with the dam's water over a specific duration. This gradual process aims to minimize shock upon release into the dam.

When fry originates from freshwater sources like wadis or lakes, temperature acclimatization is a gradual process, whereas acclimatization to salinity isn't required. Conversely, if fry is coming from the sea, acclimatization to salinity becomes crucial. This adaptation is conducted in ponds over a period of 10 days (

Figure 24), involving several steps:

- On the first day, the water salinity is reduced by 1 to 2 g/l.
- Over the subsequent 4 days, treatment with NaCl is initiated.
- During this acclimatization period, the fry are fed 5-6 times per day with a feed containing 40% protein.

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Figure 24 The process of salinity acclimatisation of mullet fry

-Water Quality Management: Maintain good water quality by monitoring parameters such as DO (use a DO meter), pH (use a pH meter), and temperature (use a thermometer) and address any issues promptly to ensure the well-being of the fry.

- Record Keeping: Keep detailed records of the stocking process, including the number of fry stocked, date of stocking, and any observations on their behavior and condition.

2.2.2 Polyculture (NARO)

The polyculture is one of the farming innovations that the smallholder farmers could easily adopt because of its ease in management, and the fact that the fish maximizes feeding at different trophic levels in the pond environment. The polyculture system was first conducted for six months in ponds at Aquaculture Research and Development Center (ARDC) between February 2023 to September 2023. However, the experiment was repeated because there was a consistent loss of stocked fish due to the heavy runoffs with poor water quality. In the subsequent arrangement for the same study, four species, 800 Nile tilapia (5±05g), 200 *Barbus altianalis* (3±0.09g), 200 *Labeo victorianus* (3±0.6g), and 400 *Clarius gariepinus* (10±0.7g) were randomly stoked in three well fertilized ponds of 500m^2 each at ARDC (on station). *Clarias gariepinus* were stocked 60 days after the other species had been stocked. The fish were fed twice a day at a body mass of 5% as juveniles and then 3% for the grow table size. Water exchange was done once every 4 days to ensure good water quality maintained below 0.5ppm of ammonia and >4 mg/lt of DO. The experiment ran from January to May 2023 (repeat and running for 4 months). 30 fish were sampled monthly for growth parameters.

Results indicated that the Specific Growth Rate (SGR) for Tilapia, catfish, Labeo, and Barbus was 2.1, 2.8, 1.9 and 0.5 respectively. These significantly deferred from each other (p<0.5). A good SGR per day for tilapia and African catfish ranges from 2-2.5 and from 3-4 respectively. The obtained values are within this range and the variation may arise from the feeds with varying nutrient composition offered to the fish. However, the average growth attained at 37±7.5g (M+SD) after 150 days for Ningu was

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comparatively much better than that of *Barbus altianalis* at 39.5±7.8g in the same period. *Labeo victorianus*'s maximum weight is about 250How g, while that of *Barbus* is about 1200g. This implies that *Labeo*'s performance is quite promising in polyculture systems.

Guidelines for the Preparation and stocking of polyculture farmed species -Tilapia, Catfish, Barbus and Labeo

Below are the guidelines for culturing the species:

- Conduct a good site selection; a gentle sloping place, with water holding clayish soils and having a running stream.
- Seek approval if the site is in restricted areas such as a swamp.
- Prepare the fishpond before stocking; one should follow the available Best aquaculture Management Practices (BMPs) that include establishing a good site selection; seek the expertise of aquaculture specialists at the districts.
- Ensure that the pond dykes are made firm and then apply lime to kill all unnecessary wild fish or as a disinfectant.
- Fill the pond with water and apply manure inside the pond until the pond turns green (This may take 1-2 weeks).
- Purchase mixed sex Nile Tilapia fingerlings of 5g and stock them first into the pond you have prepared. The other species, Kisinjja and *Labeo* are stocked at the same time and at a size range of 3-5g.
- The fish are fed on processed powder feed (>40% CP) three times a day until after 40 days and are then weaned to crumbles.
- The African catfish are stocked 60 days after other species have been stocked at 10g size
- The stocking density is 3.2kg/m^2 and the ration of stocking should be maintained at 4:1:1:2 for Tilapia, *Barbus*, *Labeo*, and African catfish respectively.
- The fish are fed twice a day at a body mass of 5% for juveniles and then 3% for the grow table size. Regular grading is done to remove especially the catfish shooters; this should be done at least once in a month.
- Water quality management should be done regularly by exchange water at least twice a week.
- This is done until 5 months, when the farmer starts harvesting the fish.

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- African catfish tend to have shooters whish should be removed through regular sampling, otherwise is not removed the shooters will eat other fish in the polyculture pond

2.2.3 Integrated aqua-agriculture (SUA) – Feed formulation from local ingredients

A survey was conducted in April–June 2022 in 21 villages of the Kilombero district to identify the feed materials used for fish feeding. The following feed-ingredients were identified: fishmeal, Sunflower Seed Cake (SSC), moringa leaves, maize bran and rice polishing. Then, feed samples were collected and analysed for chemical composition. Based on the chemical composition of the locally available feed materials, six well-balanced diets (D1, D2, D3, D4, D5 & C1) were formulated to contain 30% crude protein (Table 3). In D1 and D2, FishMeal (FM) was replaced by a mixture of SSC and Moringa Leaf Meal (MLM) at 75%, while in D3 and D4 was replaced at 87.5%. For D5, it was replaced at 75% with SSC alone and C1 was used as a control diet in which fishmeal was the only source of protein. Thereafter, an on-station experiment was carried out in indoor plastic tanks using RAS for 90 days to determine the best diet. Fish body weights were measured biweekly and growth parameters and FCR were calculated at the end of the experiment. Among the six diets formulated, D2 was found to be the best diet that supported higher growth rate (Figure 25)

Table 3: Proportions of feed ingredients in the on-station Nile tilapia experimental diets

Ingredients	**Diets**					
	D1	**D2**	**D3**	**D4**	**D5**	**C1**
FM (%)	10	10	5	5	10	40
MB (%)	38	38	38	38	38	38
RP (%)	21	21	21	21	21	21
SSC (%)	15	7.5	17.5	8.75	30	0
MLM (%)	15	22.5	17.5	26.25	0	0
Mineral (%)	1	1	1	1	1	1
Total	**100**	**100**	**100**	**100**	**100**	**100**

Note: D1: (Fish meal replaced with 37.5% Sunflower + 37.5% Moringa); D2: (18.75% Sunflower + 56.25% Moringa); D3: (43.75% Sunflower + 43.75% Moringa); D4: (21.87% Sunflower + 55.63% Moringa); D5: (75% Sunflower + 0% Moringa); C1: (not replaced).

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2.2.3.1 Results and achievements

Effects of substituting fishmeal with mixture of sunflower seed cake and moringa leaf meal on growth performance of Nile tilapia to determine the best diet

Figure 25 shows the growth performance of fingerings fed different diets in which fishmeal was substituted with the mixture of SSC and moringa leaf meal at different levels. The results in Figure 25 show that the Nile tilapia fingerlings fed the commercial diet (diet C2) had the highest growth performance, followed by those fed formulated diet D2 while those fed diet D1 had the lowest growth performance. The mean final body weight (12.54 ± 1.79 g) and weight gain (11.54 ± 1.77 g) of the fingerings fed the diet C2 did not differ ($P > 0.05$) from that of the fingerlings fed diet D2 (final weight = 11.98 ± 1.21 g and weight gain = 10.19 ± 1.09 g) in which fishmeal was substituted with the mixture of SSC (18.75%) and moringa leaf meal (56.25%) by 75%. But the fingerlings fed diet D1 in which fishmeal was replaced with the mixture of SSC (37.5%) and moringa leaf meal (37.5%) showed the lowest growth performance (weight gain = 8.76 ± 1.00 g). The fingerlings fed the diet containing fishmeal as the only protein source (diet C1) had lower growth performance (weight gain = 9.60 ± 1.14 g) compared to those fed diets C2 and D2, but slightly higher than of those fed diets D3 (weight gain = 9.23 ± 1.02 g) in which fishmeal was replaced with the combination of SSC and moringa leaf meal by 87.5%. On the other hand, the fish which were fed diet D5 in which fishmeal was replaced with only SSC by 75% showed lower growth performance than those fed diets D3 and D4. Therefore, the preliminary results clearly demonstrated that the combination of SSC (7.5%) and moringa leaf meal (22.5%) can substitute fishmeal in Nile tilapia diets up to 75% without compromising the growth performance.

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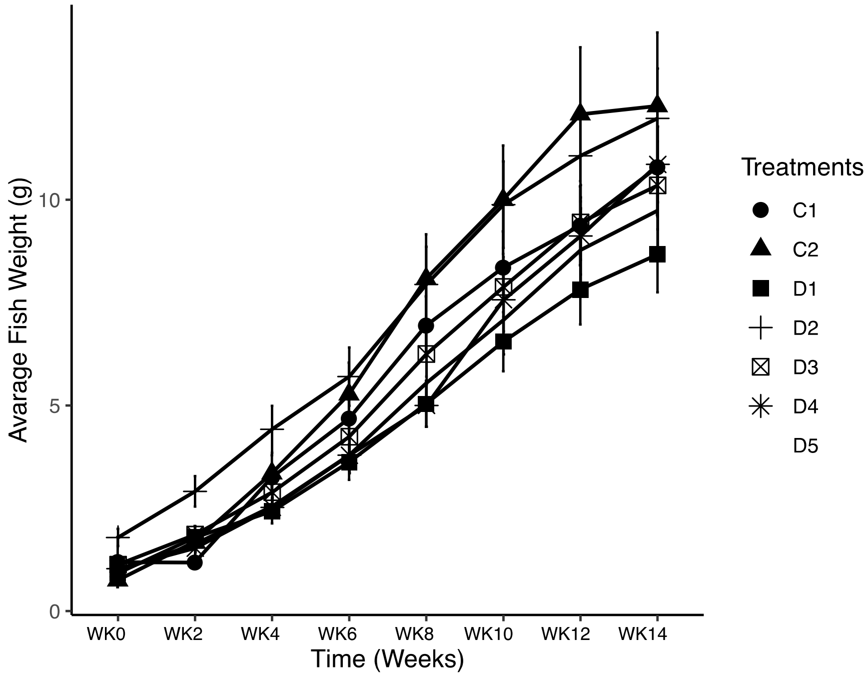

Figure 25. Effects of replacing fishmeal with different levels of the mixture of sunflower seed cake and moringa leaf meal on growth performance of Nile tilapia

2.2.4 Improved fish production (SUA)

Following the identification of the best diet, on-farm and a second on-station experiments were conducted to validate the findings of the first on-station feeding experiment that identified D2 as a cost-effective tilapia diet. The diet comprised of fishmeal (10%), maize bran (38%), rice polishing (21%), SSC (7.5%), *Moringa oleifera* leaf meal (22.5%) and mineral premix (1%) and contained approximately 30% crude protein. Fishmeal, SSC and *Moringa oleifera* leaf meal were used as the main sources of protein while maize bran and rice polishing served as the main energy sources.

Most fish farmers in Kilombero use mash feeds, which are not stable and segregate in water most of the time. In this study, two forms (mash and pellet, Figure 26) of the best diet (D2) were made and used in on-station and on-farm feeding experiments to determine which form supports higher growth performance.

In the on-farm experiment, a total of five farmers from three villages (Kiberege, Mang'ula B and Mkamba) in Kilombero district were involved and each farmer constructed two ponds, whereby in one pond the fish were fed mash feed and in the other one,

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fish were fed with pelleted feed. The two treatments were assigned randomly. Concurrently, the on-station experiment was conducted in 10 concrete tanks (each 2.4m^2). Five tanks were randomly allocated to pelleted feed and the remaining five tanks received mash feed. Before the start of the experiments, all ponds and tanks were filled with water and fertilized with 50g/m^2 of chicken manure. One week following fertilization, the ponds/tanks were stocked with Nile tilapia fingerlings (*Oreochromis niloticus*) averaging 2g with a density of 5 fish/m^2. The fish were fed the respective diets (mash/ pellet) twice per day, at 5% of body weight and reared for eight months. The fish body weight was measured before the start of the experiment to get the initial weight and then fortnightly during the experimental period. In addition, water quality parameters (pH, temperature, DO, conductivity, alkalinity and total Total Dissolved Solids) were measured every two weeks. At the end of the experiments, the fish were harvested (Figure 27), measured to determine fish yield and then sold to determine the revenue. Body weight at harvest and fish yield were compared between the fish fed mash and those fed pelleted feed.

Pellets Mash

Figure 26. Types of feed used in the on-farm and on-station experiments

Figure 27: Fish harvesting in farmers pond in Kilombero district after 8 months

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2.2.4.1 Results and achievement

Effects of form of diet made from locally available feed ingredients on growth performance, feed utilization, survival and profitability of Nile tilapia

-On-station experiment to identify the best form of the diet

The growth performance of Nile tilapia fed with pelleted and mash diets is shown in Figure 28. The results show that the fish fed with the pelleted diet showed significantly higher growth performance than those fed with the mash diet. The average final weight, weight gain, daily weight gain and specific growth rate for the Nile tilapia fed with the pelleted diet were higher ($P \leq 0.0001$) than those fed with the mash diet (Table 4). The final weight of fish fed pelleted diet ranged from 213.7 to 376.6g and was significantly higher compared to that of those fed with the mash diet which ranged from 158.3 to 325.1g. The fish fed with the pelleted diet grew faster and their mean weight gain exceeded the mean weight gain of those fed with the mash diet by 53.0g. Similarly, the FCR and the condition factor (K) for the fish fed with the pelleted diet differed ($P > 0.05$) from that of those fed with the mash diet (Table 4). The FCR for the fish fed with the pelleted diet was lower (1.99 ± 0.03) than the mash diet (2.32 ± 0.05) while K was higher (1.88 ± 0.03) for the fish with the pelleted diet than for those with the mash diet (1.81± 0.02). Survival of the fish was very high and did not differ ($P > 0.05$) between the fish fed with pelleted feed and those fed with mash feed.

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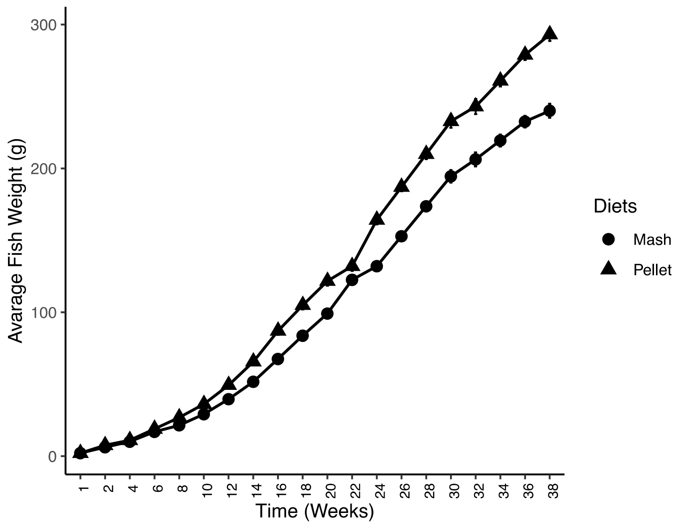

Figure 28. Comparison of growth performance of Nile tilapia fed pelleted and mash diets during an on-station experiment

Table 4. Comparison of growth performance, feed utilization, condition factor and survival rate of Nile tilapia fed pelleted and mash feeds during an on-station experiment

Variable	**Treatment**		**P value**
	Mash (mean ± se)	**Pellet (mean± se)**	
Initial body weight (g)	2.12 ± 0.05	2.14 ± 0.05	0.8029
Final body weight (g)	240.04 ± 4.90	293.06 ± 4.51	0.0001
Weight gain (g)	237.92 ± 4.91	290.92 ± 4.52	0.0001
Daily weight gain (g/d)	0.89 ± 0.02	1.09 ± 0.02	0.0001
Specific growth rate (%/d)	1.78 ± 0.01	1.85 ± 0.01	0.0001
Condition factor (K)	1.81 ± 0.02	1.88 ± 0.03	0.042
FCR	2.32 ± 0.05	1.99 ± 0.03	0.0001
Feed intake (g/d)	2.03 ± 0.02	2.15 ± 0.01	0.0001
Survival rate (%)	96.67 ± 2.04	93.33 ± 4.08	0.4022

The results in Table 5 show that the estimated annual yield of Nile tilapia fed with pelleted feed was significantly higher by 678.62kg compared to those fed with mash feed. The results in Table 5 further show that among the variable costs (fingerling, transport, feed and labour costs), only feed cost differed significantly between the fish fed with mash and pelleted diets. The estimated average annual total variable costs per ha per year for the fish fed mash feed was lower by TZS 5,093,027.39 compared to those fed pelleted feed. As a result, the total revenue and gross margin for the fish fed with the

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pelleted diet exceeded those, that were fed with mash feed by TZS 8,143,356.65 and 3,050,329.25, respectively.

Table 5: Estimated annual fish yield, variable costs, revenue and gross margin of Nile tilapia fed pelleted and mash feeds in an on-station experiment

Variable	Treatment	
	Mash (mean ± se)	**Pellet (mean ± se)**
Estimated annual yield (kg/ha/year)	4,048.57 ± 137.96	4,727.19 ± 220.45
Revenue per ha per year (TZS)	48,582,867.13 ± 1,655,514.34	56,726,223.78 ± 2,645,382.17
Variable costs		
Fingerling cost per ha per year (TZS)	2,622,377.62	2,622,377.62
Feed cost per ha per year (TZS)	18,210,396.27 ± 585,865.79	23,303,423.66 ± 1,255,044.97
Transport cost per ha per year (TZS)	7,284,382.28	7,284,382.28
Labour cost per ha per year (TZS)	5,400,000.00	5,400,000.00
Total variable costs (TZS)	33,517,156.18 ± 585,865.79	38,610,183.57 ± 1,255,044.97
Gross margin (TZS)	15,065,710.96 ± 1,103,630.44	18,116,040.21 ± 1,411,079.31

-On-farm experiment to identify the best diet form under farming conditions

The results for on-farm experiment corroborate with the results of the on-station experiment that the fish fed with the pelleted diet had slightly higher growth performance compared to those fed with the mash diet (Figure 29). The results in (Table 6) show that the mean final body weight, weight gain, daily weight gain and SGR of the fish fed with the pelleted diet were higher ($P \le 0.05$) than of those fed with the mash diet. The final body weight at harvest and the weight gain for the fish feed pelleted diet exceeded that of those fed with the mash diet by 21.86 and 26.96g, respectively. Similarly, the daily weight gain for the fish fed with the pelleted diet was higher (1.76 ± 0.06 g/day) compared to that of those fed the mash diet (1.61 ± 0.01 g/day). On the other hand, the feed intake and FCR for the fish fed with the pelleted diet were lower ($P \le 0.0001$) than of those fed with the mash diet (Table 6).

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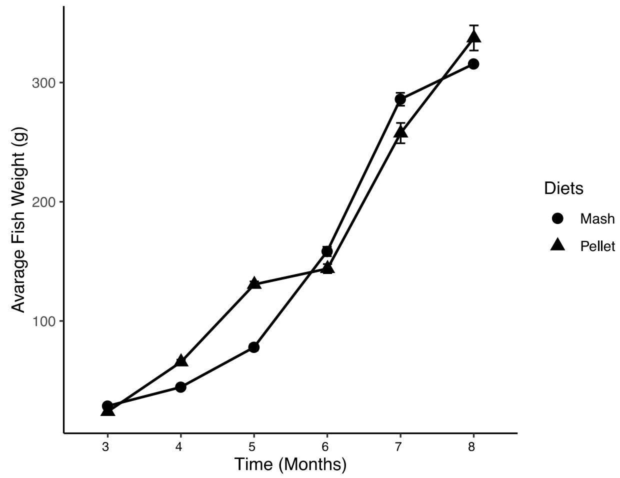

Figure 29. Comparison of growth performance of Nile tilapia fed with pelleted and mash diets during an on-farm experiment

Table 6 Comparison of growth performance and feed utilization of Nile tilapia fed pelleted and mash feeds during an on-farm experiment

Variable	Treatment		P value
	Mash (mean ± se)	Pellet (mean ± se)	
Initial body weight (g)	28.62 ± 1.12	24.04 ± 0.94	0.0027
Final body weight (g)	315.58 ± 1.81	337.44 ± 10.50	0.0447
Weight gain (g)	286.96 ± 1.95	313.40 ± 10.52	0.0167
Daily weight gain (g/d)	1.61 ± 0.01	1.76 ± 0.06	0.0167
Specific growth rate (%/d)	1.36 ± 0.02	1.49 ± 0.02	0.0002
Feed intake (g)	732.22	690.45	0.0001
FCR	2.56 ± 0.02	2.25 ± 0.05	0.0001

The analysis of profitability for the on-farm experiment indicated that the variable costs were the same for the fish fed mash and pelleted feeds, with exception of the feed cost (Table 7). The feed cost for the pelleted diet was higher by TZS 27,108,433.73 compared to that of the mash diet. Consequently, the total variable cost for the fish fed with pelleted diet exceeded that of the fish fed mash diet by the same amount as all other costs were the same for the two groups. As it was observed for the on-station experiment, the estimated fish yield per ha per year and the resulting revenue and gross margin for the fish fed pelleted diet were significantly higher compared to that of the fish fed mash diet (Table 7).

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Table 7: Estimated fish yield, variable costs, revenue and gross margin of Nile tilapia fed pelleted and mash feeds in an on-farm experiment

Variable	**Treatment**	
	Mash (mean ± se)	**Pelleted (mean ± se)**
Estimated annual yield (kg/ha/year)	22,548.31	27,190.83
Revenue per ha per year (TZS)	157,838,150.60	190,335,777.10
Variable costs		
Fingerling cost per ha per year (TZS)	13,994,728.92	13,994,728.92
Feed cost per ha per year (TZS)	108,433,734.94	135,542,168.70
Transport cost per ha per year (TZS)	948,795.18	948,795.18
Water cost per ha per year (TZS)	3,162,650.60	3,162,650.60
Labour cost per ha per year (TZS)	10,843,373.49	10,843,373.49
Total variable costs (TZS)	**137,383,283.10**	**164,491,716.90**
Gross margin (TZS)	**20,454,867.47**	**25,844,060.24**

2.2.4.2 Conclusions

The results of the first experiment revealed that fishmeal can be replaced up to 75% by the mixture of SSG (7.5%) and Moringa leaf meal (22.5%) in Nile tilapia diets without compromising the growth performance and this can reduce significantly the cost of feeds. The second experiment demonstrated that the use of pelleted diet significantly improves growth performance and feed utilizations efficiency compared to mash diet. Though mash diet is cheaper than pelleted diet, the use of pelleted diet results in higher profit because of improved growth performance and better feed utilization efficiency. We recommend farmers to use the mixture of SSC and moringa leaf meal as protein sources in place of fishmeal and should adopt the use of pelleted feed to take advantage of better utilization of the pellet form of feed.

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2.3 Research for integrated aquaculture systems: using aquaculture effluents for irrigation and fertilisation in agriculture (DALF, NARO, SUA)

2.3.1 Integrated aqua-agriculture (DALF)

The wastewater from the RAS was used to grow vegetables using drip irrigation system i.e Spider plants, black nightshade, and kale planted in a small garden (1m x 8m) as shown below in Figure 30 to reduce the environmental impact of the RAS effluent. The vegetable yield and value were determined from the harvest collected.

Figure 30. The vegetables' area with the irrigation system at the beginning and at the end of the trial in DALF.

The utilization of the pond water to plant some vegetables around the fishponds has been successfully implemented in most of the fishponds. This has really boosted the farmers' income through the sales of vegetables.

Components of the system

The system was constructed using the following materials:

For the Drip irrigation system:

- The source of water of water, which in this case is the RAS tanks.
- The drip tank, where the water from the fish tanks is concentrated
- The main pipe
- Drip line
- Connectors
- Sieve/mesh that will not allow the system to clot

The following seeds were used:

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- Tomato
- Spider flower
- Spinach,
- Collards (Sukuma wiki)
- Black nightshade

Green water contained all the organic fertilisers needed for a faster growth.

Description of the procedure

Before any construction begins, land needs to be prepared by:

- Clearing of any vegetation around the pegged area.
- Ploughing of the land.
- Levelling of the ploughed land.
- Making of the raised seedbed.

Afterwards, the drip irrigation system along the raised seedbed can be installed. As soon as the irrigation system is installed, planting of the raised seedlings from the nursery to the raised seedbed can commence. Spacing of the seedlings can be done as following:

- Tomato: 60cm by 60cm
- Spider plant:45cm by drill
- Spinach: 60cm by 30cm
- Collards: 60cm by 60cm
- Black nightshade: 45cm by drill

Management of the vegetables and irrigation system

An efficient method to manage your vegetables should involve:

- Watering in the morning and evening through the drip irrigation system.
- Weeding.
- Pruning/Thinning and
- Disease control

On the other hand, the irrigation system needs:

- Continuous monitoring and repairs on the drip line, in case of holes.

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- Land preparation for the installation of the drip system line.
- Frequent checks for any clotting on the drip line nozzles.
- Straitening of the drip lines for a more efficient flow of water.

2.3.2 Integrated aqua-agriculture (NARO)

Wastewater from fish tanks was used to irrigate and supply nutrients to selected vegetables cultured in vegetable gardens for 14 weeks (4 weeks of nursery bed and 10 weeks after transplanting) however, spinach and kales continued to yield more leaves until their life span (10 more weeks). In this experiment, fibre tanks were used to simulate fish production facilities with vegetables grown in earthen gardens adjacent to these tanks. Each of these fibreglass tanks was stocked with African catfish (*Clarias gariepinus*). As a control, an earthen plot was prepared and planted with the same vegetables and irrigated using underground water. Irrigation with aquaculture wastewater was done as illustrated in the schematic flow diagram (Figure 31).

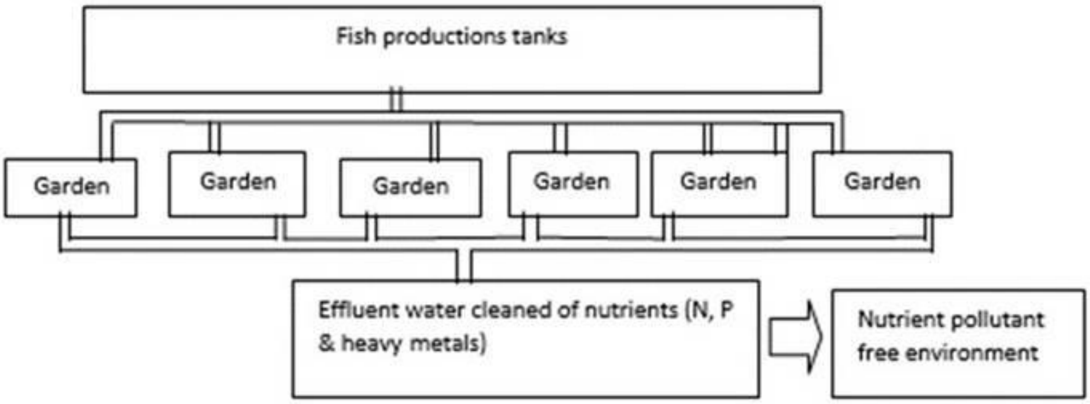

Figure 31. A layout of a mini-irrigation system with wastewater from the fish production tanks used to grow vegetables.

The vegetables extract nutrients from the wastewater, contributing to the circularity of the system. After pre-trials, an experiment was carried out at the ARDC, Kajjansi, between February and June 2023. The experiment was arranged in a completely randomized design with two irrigation treatments and three replicates. The treatment included systems irrigated with fish effluent water, whereas the control consisted of systems supplied with irrigated groundwater. Wastewater from six fish production tanks was used to irrigate the vegetables using pipes (Figure 32). Vegetable plots

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consisted of Sukuma wiki (kales), spinach, Red amaranthus (Buga) and Chinese cabbage (*Brassica rapa chinensis*), which were selected based on demand in the hub. One month old vegetable seedlings were transplanted at a spacing of 30cm by 15cm inter and intra row spacing. Water quality parameters (DO, temperature, pH) that might cause acute stress to the fish were monitored daily in each of the fish production tanks.

Figure 32. Experimental vegetable growing in the garden planted in pipes (A), and African catfish in the fibreglass tank (b) providing the waste for vegetable farming.

The average lengths and number of leaves of vegetables were recorded during the planting cycle. During the growth cycle, the nutrients (ammonia, nitrite and nitrate) were discharged from the fish effluent and were taken up by the vegetables through the pipes filled with soil (Figure 32). Each tank was stocked with 20 African catfish pieces of average weight of 10±1 g. Their growth was monitored for a period of the crop cycle (16 weeks). The fish were fed twice a day with feed pellets of sizes ranging from 1-3 mm depending on the fish weight (based on the feeding chart developed at ARDC-Kajjansi). The water quality parameters including temperature, pH, Total Dissolved Solids, DO and electrical conductivity were monitored twice a week using a multiprobe meter and were kept within the required range for optimal growth performance during the growth cycle. Additionally, the Nitrite (NO_2-), nitrate (NO_3-) and ammonium nitrogen were recorded once a week using a nutrient comparative test kit (Palintest). Plant growth was recorded

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using a tape measure and the weight of the leaves were measured using a weighing scale. Data was analysed using Microsoft Excel.

Total fish and crop harvest as well as nutrients extracted were estimated at the end of the culture period. The number of vegetable cycles produced per fish cycle (varies per vegetable type) was also determined.

Results

Experimental results showed that kales had a higher plant height and leaf length than other plants when irrigated with fish effluents compared to the control (Figure 33). The total number of leaves of Kale, spinach, Buga and Chinese cabbage at harvest per the cycle was 3041, 2097, 11766 and 2185 for the effluent fed respectively. This translated into 100kg and 34kg for kale and spinach respectively. The observed plant length for Kales was significantly higher for those treated with fish effluent than those in the control ($p \leq 0.5$). However, the leaf length for spinach, Buga and Chinese cabbage did not show significant differences between those treated with fish effluent and those in the control ($p \geq 0.5$). It was observed that all the plants maximized the use of the effluent containing ammonia, nitrite and nitrate. In the two cycles (6 months in total), Kale was found to utilize fish effluent more efficiently than the other plants. Previous studies have shown that the utilization of fish effluent in farming allows for efficient usage of limited water, reduces fertilizer costs and increases crop yields. The study by Limbu *et al* (2017) reported a significant yield in Chinese cabbage which yielded 80% more under fish effluent irrigation than the conventional production.

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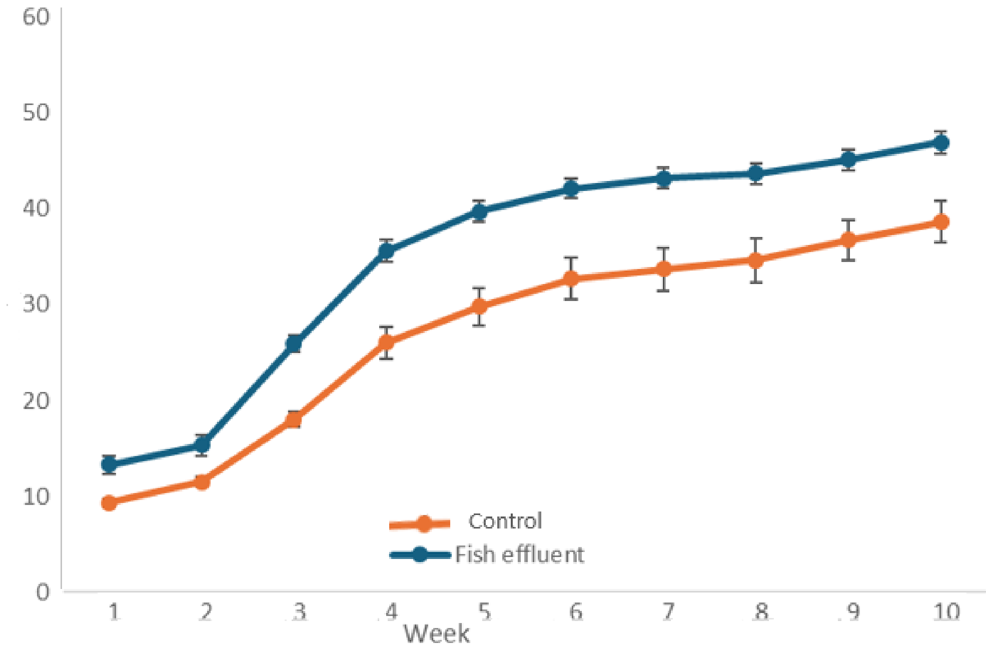

Figure 33. Kales plant height increased over 10 weeks, fed on effluent before and after absorption compared to the control.

The results also indicated that in sixteen weeks fish grew to an average of 4 kg/tank of 1m^3, making a total of 24kg for six tanks. There was only one cycle of crop production for every one cycle of fish growth, although kale and spinach continued producing more for eight more weeks before being exhausted. However, once the harvesting had commenced, the leaves were continuously harvested until total harvesting together with the end of the fish cycle. The assumption extrapolated for Kale suggests that an area of 0.1 acres produced 1000kg (100kg*10 harvests) of Kale total yield per cycle. This translates into an estimated UGX 1,700,000 (€425) as gross earnings (each is estimated at UGX 1,000 (€0.25) per kilo). The production cost was estimated at UGX 500,000 (€125) and therefore a net profit of UGX1,200,000 (€ 300) can be achieved from 0.1 acres. Estimates for other vegetables are indicated in (Table 8).

The effluents from the fish tanks had components of suspended particles, nitrates, nitrites, nitrogen, ammonia and total phosphorus. These components are considered fish aquaculture pollutants resulting in major environmental challenges such as eutrophication and oxygen depletion. Research has shown that the production of 1t of channel catfish releases an average of 9.2kg of nitrogen, 0.57kg of phosphorus,

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22.5kg of Biochemical Oxygen Demand (BOD) and 530kg of settleable solids into the environment (Oladoja *et al*., 2015). Such statistic values suggest that the use of fish effluents is therefore an environmentally friendly approach to reducing pollution and utilization of minerals in crop production.

Table 8. The estimated production of different vegetables and net profit from 1 acre of farming.

Plant	Yield in kg	Unit Cost for each kg in €	Total sales in (€)	Estimated production Cost (€)	Estimated Net Profit (€)
Kales	17,000	0.25	4,250	1,250	3,000
Spinach	12,000	0.25	3,000	1,000	2,000
Chinese Cabbage	12,000	0.25	3,000	953	2,048
Buga	10,000	0.125	1,250	375	875

It is observed that the use of fish effluent as a water source for irrigation proved to be beneficial since it improved plant yields and is an environmentally friendly way of reducing pollutants from the discharge from fish tanks or fishponds. Utilizing fish effluent saves the cost of fertilizer and water. This model, if rolled out to farmers, will increase their yields in both fish and vegetable farming, enabling them to utilize resources efficiently and earn more income from this farming approach.

Guidelines for adoption of the integrated crop fish culture technology

- A production system (500m^3) with 2000 Nile tilapia/ African catfish can irrigate 2000 to 4000 m^2 garden area of vegetables
- Carry site capability and suitability studies and analysis to aid fish and vegetable species/strain selection. Selected site should allow for water flow and movement by gravity as a means of minimizing pumping costs.
- Site selection may include carrying out appropriate soil tests to ensure the selection of the best site for the fish and vegetable species/strains to be cultured. However, a farmer must seek guidance from the district aquaculture specialist/ extension officer.
- Design the system based on the nature of bio-physico-chemical characterization of the site.

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- Setup as depicted in Figure 31.
- However, farmers may have slight variations in the designs, e.g. i) making the channels running from the pond outlet to the gardens if the water moves by gravity; ii) having a pumping system that sucks water from the pond and then through a mini spray system deliver it in the garden. Some farmers may not use tanks as they could be expensive for some smallholder farmers.
- Key requirements needed by established farmers include a water pump, pipes for plumbing works and sprinklers. Some farmers whose ponds are close to the gardens could use the watering cans or Manual pedal pumps.
- Select for active, disease and deformity free fish seed and vegetable seedlings from known (or certified) sources.
- Ensure that vegetables are planted as per recommended spacing for the vegetable under consideration by the aquaculture expert at the district (spacing of 30cm by 15cm is recommended for most vegetables).
- Routine water quality monitoring should be done to ensure the bio-physico-chemical parameters are maintained within acceptable ranges for the cultured fish species (recommended charts are provided by aquaculture experts at the districts -also provided in D5.8).
- Ensure frequent control of weeds in the gardens.
- Fish in the production unit should be fed with at least 30 CP formulated diets.
- Fish and vegetables should be regularly screened for disease and any abnormalities during selection, planting, and grow-out.
- More procedures and guidelines have been included in the training guide.

2.3.3 Integrated aqua-agriculture (SUA) – Chicken-Fish-Vegetables

Cowpeas Integration with Chicken and Fish for income generation for small-scale farming systems

In Tanzania, the human population is expected to increase from the current size of 61.7 mil to 135.2 mil in 2050. Therefore, there is a need to increase agricultural production to provide enough and quality food to the people and increase income for improving their livelihoods. Despite the population increase, the amount of land available for agriculture is limited. This limits the efforts to increase agricultural productivity. Integrated

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Aqua-Agriculture (IAA) appears to be a solution for challenges of ongoing food insecurity, nutritional insecurity, unemployment, and poverty among smallholder farmers. Poultry and aquaculture production have a potential for improving income and alleviating protein malnutrition, especially in rural areas. However, both rely heavily on fishmeal and soybean meal as the major protein sources in feed formulation which are expensive and not readily available. Cowpeas (*Vigna unguiculata*) has high protein content, is drought tolerant and can grow well in many places of Tanzania. Thus, it has the potential to replace soybean as a protein source in poultry and fish diets. The study evaluated the advantages of cowpea, chicken and Nile tilapia integration, whereby chickens provided manure to fertilize both cowpea plots and fishponds, while cowpea grains served as protein source to both chickens and fish and the fish pond water was used to irrigate the cowpea plots (Figure 34). Also, the study evaluated the effects of cowpea protein concentrate as a replacement for soybean meal in the diets for Nile tilapia and Sasso chickens.

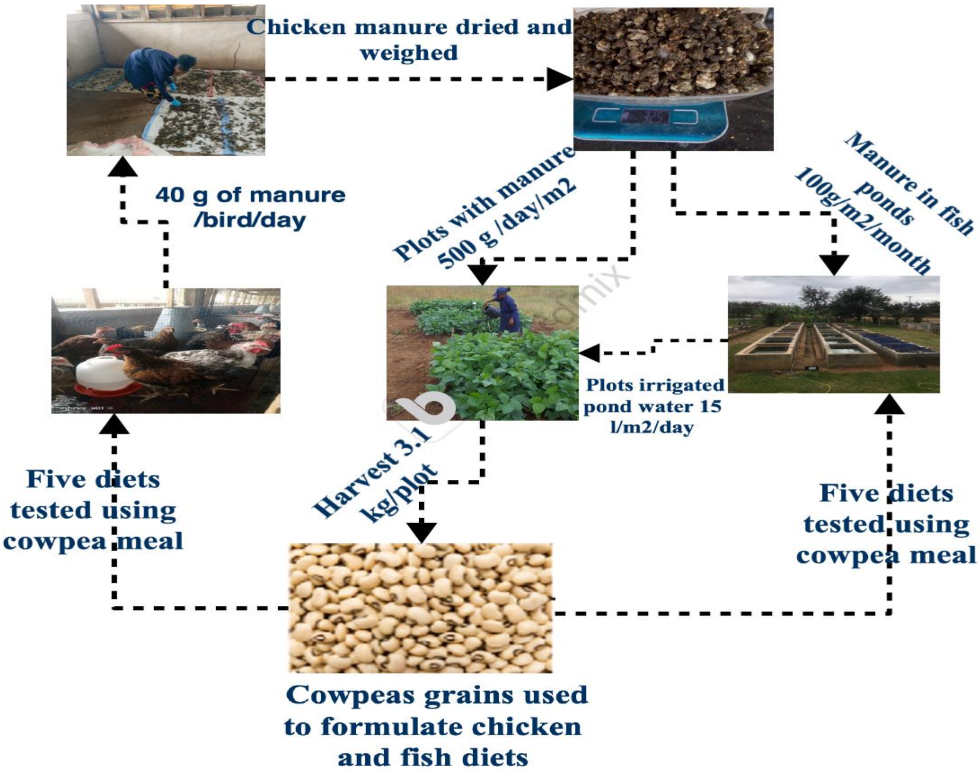

Figure 34. Integration of Chicken- fish - vegetable (cowpeas) for small-scale farming systems

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Chicken sub-system

One hundred Sasso chickens were fed a commercial starter diet during the brooding period from 1 day old to 30 days old. After brooding, the chickens were randomly allocated to five dietary treatments, with 20 chickens each. Each treatment was replicated four times with five chickens per replication. The treatments were diets formulated such that CowPeas Meal (CPM) replaced soybean meal by 0% (T1) (Control diet), 25% (T2), 50% (T3), 75% (T4) and 100% (T5) (Table 9).

The experiment lasted for 90 days. For each treatment, the amount of feed provided was measured and the refusal was determined daily before the next feeding. Feed intake was computed as the difference between the amount provided and the refusal. Body weight of each bird was measured before the start of the feeding experiment and then once per week during the experimental period. At the end of the experiment, growth rate and FCR were computed. After the experiment, eight chickens per treatment were randomly selected, weighed and then slaughtered to determine the carcass weight, dressing percentage and carcass composition.

Table 9. Diets formulated for the chicken experiment

Ingredients	**T1 (0% CPM)**	**T2 (25% CPM)**	**T3 (50% CPM)**	**T4 (75% CPM)**	**T5 (100%CPM)**
Maize meal	30	30	30	30	30
Hominy meal	28	28	28	28	28
Sunflower seed cake	5	5	5	5	5
Soybean meal	30	22.5	15	7.5	0
Cowpea meal	0	7.5	15	22.5	30
Fish meal	5	5	5	5	5
Mineral premix	2	2	2	2	2
Total	100	100	100	100	100
Estimated					
Crude protein	23.2	22.5	21.1	19.5	18.3
ME (MJ/kg)	13.3	13.5	13.5	13.5	13.5

Fish sub-system

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A total of 15 concrete tanks (Figure 35), each having a surface area of 3.75m^2 were used for the experiment. Prior to the start of the feeding experiment, all tanks were drained, cleaned, limed and then refilled with fresh water. Tanks were fertilized with chicken manure at 50g/m^2 two weeks prior to stocking and then at weekly intervals during the experimental period. Nile tilapia fingerlings were stocked in all concrete tanks at a density of 4 fish/m^2. The treatments were diets formulated using cowpea meal as a source of protein to replace soybean meal by 0% (D1), (control diet), 25% (D2), 50% (D3), 75% (D4) and 100% (D5) (Table 10). The concrete tanks were assigned randomly to five treatments. Fish were fed daily at 5% of Body Weight (BW) at 10:00h and 16:00h. Fish BW and water quality parameters were measured bi-weekly during the experimental period of 90 days. BW gain, daily BW gain and FCR were computed at the end of the experiment.

Figure 35. Chicken – fish – cowpeas integration

Table 10. Diet formulated for Nile Tilapia experiment

Ingredients (in %)	**Treatments**				
	D1	**D2**	**D3**	**D4**	**D5**
Maize meal	4	4	4	4	4
Hominy meal	33	33	33	33	33
Soybean meal	38	28.5	19	9.5	0
Cowpea meal	0	9.5	19	28.5	38
Fishmeal	23	23	23	23	23
wheat flour	1	1	1	1	1
Mineral	1	1	1	1	1
Total	100	100	100	100	100
Estimated crude protein (%)	31.3	30.9	30.1	29.2	28.2

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Vegetable sub-system

Nine vegetable plots, each with a size of $6m^2$ were prepared and planted with cowpea (*Vigna unguiculata*) at a spacing of 35cm within a row and 45cm between the rows. The plots were randomly allocated to three treatments under a completely randomized design (CRD) with three replications per treatment. The treatments were: plots irrigated with tap water (T1), plots irrigated with fishpond water (T2), and plots fertilized with chicken manure and irrigated with tap water (T3). Decomposed chicken manure was applied at the rate of $150g/m^2$ two weeks before planting. All vegetable plots were irrigated twice a day at 09:00h and 17:00h at a rate of $10L/m^2$ at once. The experiment lasted for three months.

2.3.3.1 Results and achievement

Growth performance and feed utilization of Sasso chickens fed cowpeas

Growth performance parameters of chickens fed diets containing different levels of soybean and cowpea meals are shown in Figure 36. The average final BW (2624.56 ± 62g), average total BW gain (ATWG) (1824.37 ± 42.43 g) and average daily gain (31.91 ± 0.90 g/day) were higher ($P \leq 0.001$) in T5 than in other treatments, indicating effectiveness of cowpeas in promoting growth performance. The highest value of average daily feed intake was shown in T5 and the lowest value was observed in T1 and T3 ($P \leq 0.001$). The chickens in T4 and T2 showed higher FCR while those in T1, T3 and T5 had lower values ($P \leq 0.001$), suggesting that the chickens in these treatments were more efficient in converting feed into weight gain. Generally, the chickens in T5 performed better in terms of BW gain, feed intake and FCR. This suggests that cowpea meal can completely replace soybean meal as a protein source in chicken diets.

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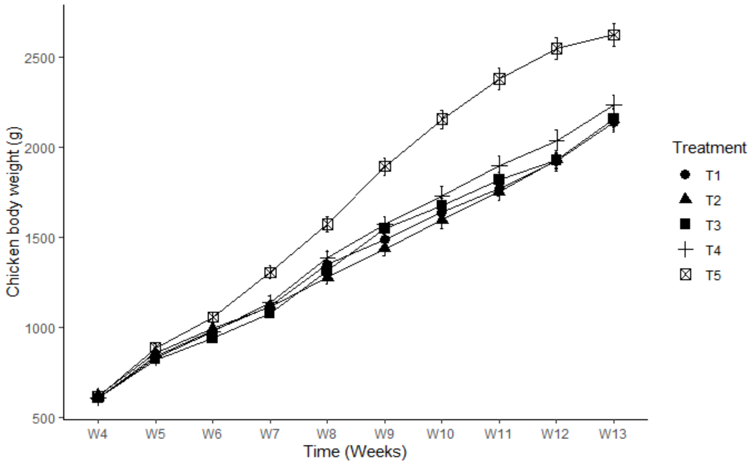

Figure 36. Comparison of growth performance of Sasso chickens fed diets containing different levels of soybean and cowpea meals (cowpea grains produced from the integration system)

Note: T1 = Diet with 100% soybean meal (SBM) and % cowpea meal (CPM), T2 = Diet with 75% SBM and 25% CPM, T3 = Diet with 50% SBM and 50% CPM), T4 = Diet with 25% SBM and 75% CPM, T5 = Diet with 0% SBM and 100% CPM.

Fish Growth performance

Results revealed that the mean fish weight increases with time in all treatments. The results showed further that fish fed diet D4, in which soybean meal was replaced with cowpea meal by 75%, showed the highest mean weight starting from week 8 to 14 (Figure 37). At the end of the experiment, it was found that the fish on D4 had higher weight gain (75.88 ± 2.10g) ($P \leq 0.001$) and growth rate (0.94 ± 0.02g/day) than those on other treatments.

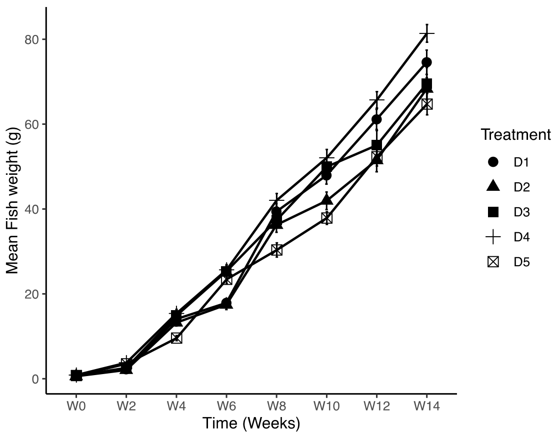

Figure 37. Comparison of growth performance of Nile tilapia (Oreochromis niloticus) fed diets containing different levels of soybean and cowpea meals (cowpea grains produced from the integration system)

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Plant growth performance

The growth performance of cowpeas plant is shown in terms of mean plant height (Figure 38) and number of leaves (Figure 39) over time. The results revealed that plants subjected to treatment T3 in which plant plots were fertilized with chicken manure had the highest growth performance followed by plants irrigated with fishpond water (T2).

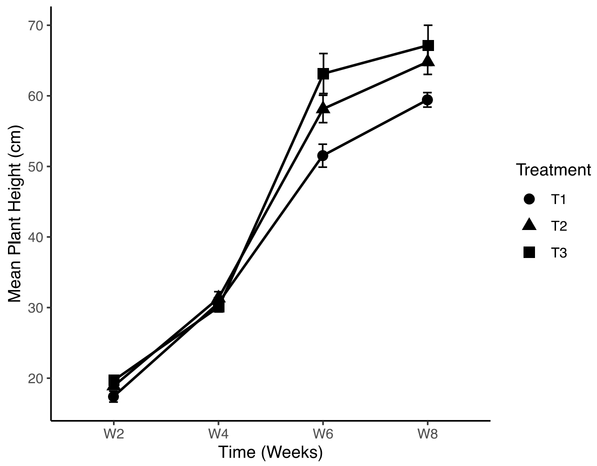

Figure 38. Mean height of cowpeas over time under different treatments: tap water (T1), pond water (T2) and chicken manure (T3).

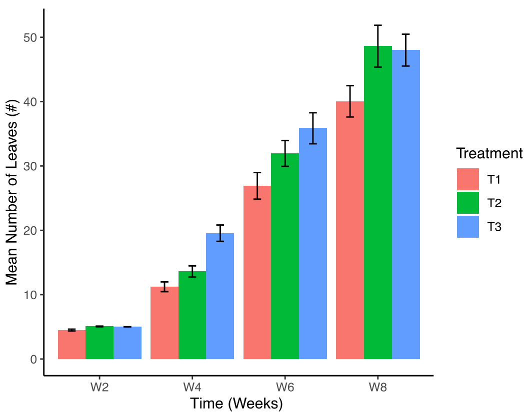

Figure 39. Mean number of cowpea leaves over time under different treatments: tap water (T1), pond water (T2) and chicken manure (T3).

Cowpea grain yield under different treatments

Figure 40 shows the grain yield obtained from the cowpeas grown in plots irrigated with tap water only, plots irrigated with pond water and plots fertilized with chicken manure and irrigated with tap water. The results indicated that the highest grain yield

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(8,398.5 ± 248.3 kg/ha) was obtained on plots fertilized with chicken manure, followed by the plots irrigated with fishpond water (7,705.5 ± 208.0 kg/ha) and those irrigated with only tap water (6,510.0 ± 179.3kg/ha). The yield of cowpea grains from plots irrigated with fishpond water (Figure 40) did not differ significantly from the yield of plots fertilized with chicken manure. Pond water contains organic matter, fish waste, and beneficial microorganisms, which provide essential nutrients like nitrogen, phosphorus, and potassium. Using fishpond water to irrigate the cowpeas plots was an effective way of providing nutrients to the plants while also recycling water.

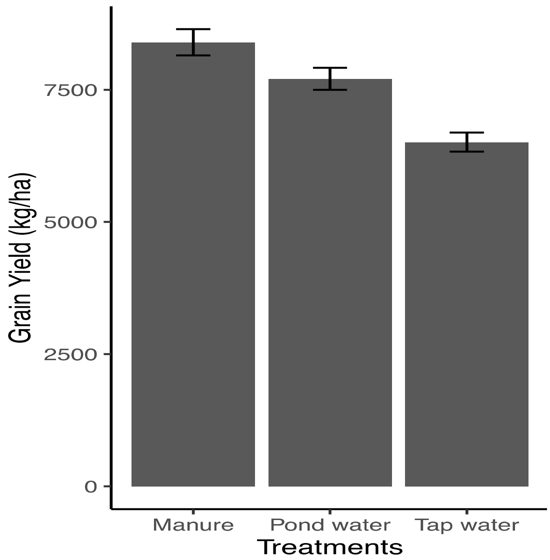

Figure 40. Cowpeas grain yield when manure, pond water, and tap water ware used as a source of nutrients

2.3.3.2 Conclusions

Cowpea meal can completely replace soybean meal as a protein source in chicken diets, while in Nile tilapia diets, soybean meal can be replaced with cowpea meal by 75%. Using fishpond water to irrigate vegetables can be an effective way to provide nutrients to the plants while also recycling nutrients and water. Hence, fishpond water can be used to fertilize crop fields.

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2.4 Research for new species husbandry (NARO)

2.4.1 Barbus altianalis

2.4.1.1 Literature review on production methods and potential markets of the species

Barbus altianalis (also called *Labeo barbus altianalis*), locally known as Kisinjja, is a native cyprinid (carp) in rivers and lake systems in Uganda, Rwanda, Kenya and Eastern DRC (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 million (USD) 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 1,500t ($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 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

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multipliers and eventually to the smallholder fish farmers in the country for mass production.

2.4.1.2.Optimize survival of species from hatchery/nursing ponds

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

2.4.1.3 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 41). 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 42**Errorea! Ez da erreferentzia-iturburua aurkitu.**). 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).

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Figure 41 Collecting mature wild broodstocks at Forest landing site. Kira Dam

Figure 42 Ripe B. altianalis are stripped at the landing site at Forest landing site, at Kira Dam.

After being acclimatized for one day, 3 females were injected with African catfish pituitary extract (for the ration of extract from 1kg of catfish per 1kg of female Barbus) and were placed in one of the circular tanks with 2 males (**Errorea! Ez da erreferentzia-iturburua aurkitu.**A), which were not induced with any hormone as they had running milt. 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

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were collected by the net placed at the outlet of the circular tanks for each treatment (**Errorea! Ez da erreferentzia-iturburua aurkitu.**B).

Figure 43. The riverine circular tank hatching system at ARDC Kajjansi used to hatch the carp.

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 44). The fertilized eggs from the wild were incubated in glass tanks and an estimated 5,000 eggs hatched 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.

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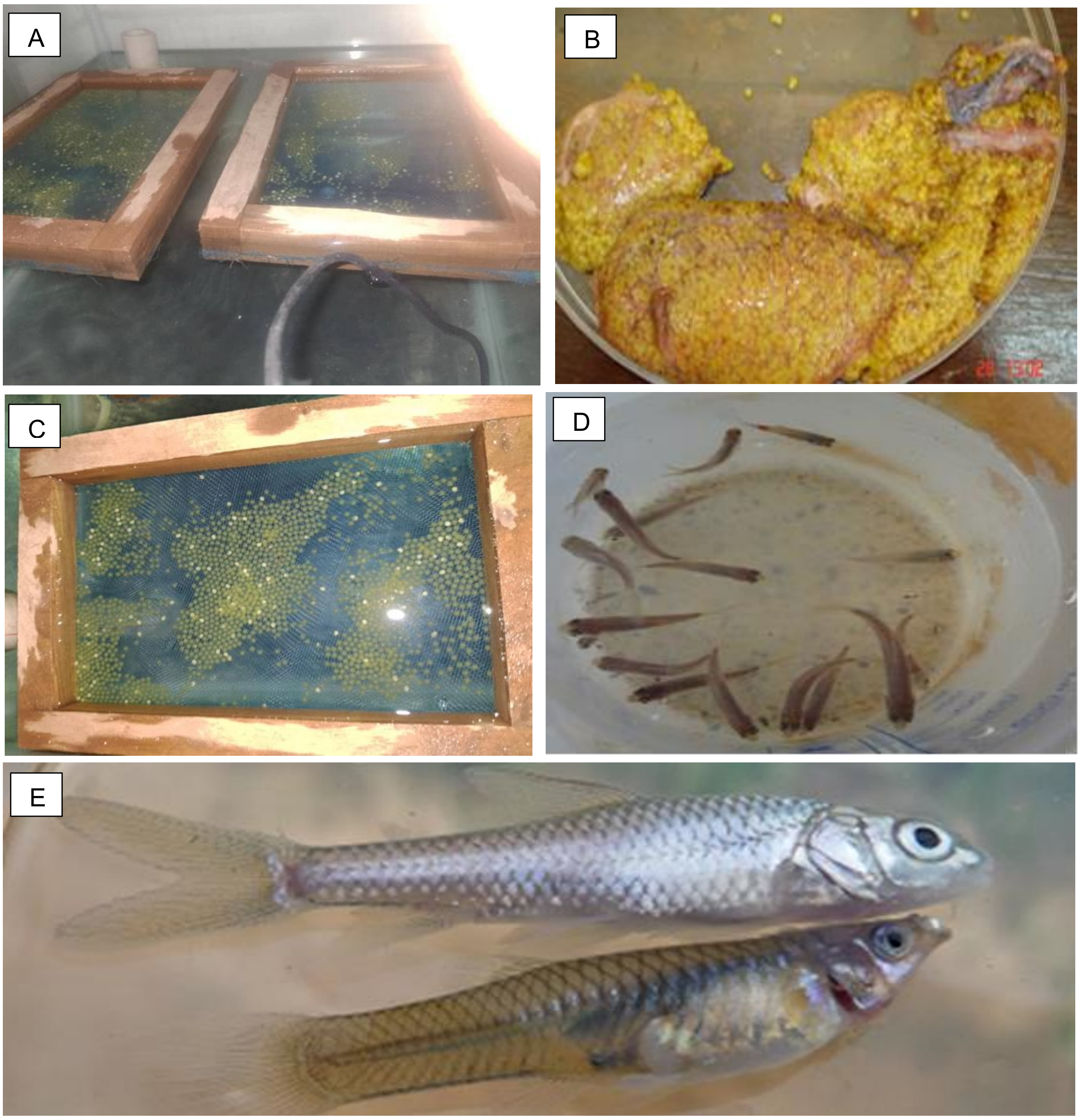

Figure 44. Incubating Barbus altianalis (Kisinjja) eggs from indoor aquarium facility. A) Sample of mature eggs. B) Fertilized eggs place on the hatching trays C) developing embryos D) one months old Larvae. E) Three months fingerlings

Several 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 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

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was that most of the eggs died during the incubation process in the hatching basins, where 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.

In 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. Upon pressing, fish with running eggs 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.

2.4.1.4 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, FCR, and growth rate). Every treatment was conducted in 3 replicates in 40lt aquaria water tanks, each stocked with 300 larvae. Initially, from Day 6 After Hatching (6 DAH), the fry was fed on *Moina* alone for seven days until 13 DAH. After that, all larvae were weaned off and introduced to another feed using a co-feeding strategy up to 28 DAH. They were fed on 50% microdiets (56% CP) and 50% *Moina* in respective treatments. Sampling was done at 7, 13 and 28 DAH to record the fish weights using an analytical scale and calculate the following:

-Specific growth rate $= \frac{(final\ weight)-(initial\ weight)}{Number\ of\ culture\ days} * 100$

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-The fish survival = $\frac{number\ of\ surviving\ fish}{the\ initial\ number\ of\ stocked} * 100.$

They were later stocked in concrete tanks at a stocking rate of 7.5g/m^3 for advanced nursing for 60 days and fed with the best performing larval feed used in the experiment of glass tanks.

Apart from survival, there were significant differences in average weight gain (P≤0.5) and specific growth rates (P≤0.5) between K1 and M2 (.

Table 11). 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 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 11. Mean growth-related parameters and survival (± standard Deviation) recorded for larval feeding experiment for Barbus altianalis; 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

During the advanced nursing stage, the growth rate was 3.18%, with a daily body weight increase of 0.02 g/day. The survival rate was 51%, and the FCR was 0.47kg.

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

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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 DAH. Decapsulated Artemia was used between 6 DAH and 9 DAH 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 Moina enriched with fish or vegetable oils and a commercial microdiet in nursing Labeo victorianus larvae

Five experimental diets were fed to 10-day old Ningu (*Labeo victorianus*) larvae of average 0.002±0.001g for 35 days to determine their effects on growth, survival and fish body composition. The diets were: i) Unenriched *Moina micrura*, the freshwater flea (UNR); ii) *Moina* enriched with SoyBean Oil (SBO); iii) *Moina* enriched with Nile Perch Oil (NPO); iv); a 50% 0.5mm CP tilapia MicroDiet (MD) and v) unenriched *Moina* with the microdiet (MMD). All diets were offered to satiation in triplicate to 1,500 larvae (100 per tank) in fifteen 60-litre glass tanks in a completely randomized design. Results depicted comparable weight gains among fish fed UNR, SBO, NPO and MMD (P>0.05). MD yielded a significantly lower mean weight gain than all the other treatments (P<0.05). SGR was highest on UNR (15.61% day-1). This result was comparable with SBO, NPO or MMD (P > 0.05) but significantly higher than MD (P<0.05). The CP composition of larvae fed MD was significantly lower (P<0.05) than the CP of other treatments. Crude fat (CF) composition of SBO larvae was significantly higher than the CF of all other treatments (P<0.05). Survival was highest for the SBO enriched diet at 88.67% and lowest in the MD at 47.67%. These results demonstrate that enrichment of *Moina* with fish or vegetable oils had insignificant effect on growth of Ningu larvae when compared with unenriched *Moina*. However, the formulated microdiet adversely affected Ningu growth, body composition and survival. Future studies should investigate the amino acid and fatty acid profiles of Ningu larvae fed enriched *Moina*. Future studies will also explore

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the use of green water (algae) in combination with *Moina* and other zooplankton, especially rotifers on growth performance and survival of *Labeo* larvae.

Use of live feed (Moina) to support mass Labeo and Barbus 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* larvae in the outdoor tanks and the larvae were fed with microdiet in tanks until reaching 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 0.08g/L of NPK fertilizer (Nitrogen, Phosphorus, Potassium). 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 9x106 cells per litre using 50µm planktonic net that prevented unwanted zooplankton 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

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Moina increased from the 5th day until the 15th day when they reached their peak and when their density was 100 - 120 *Moina*/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.

2.4.1.5. 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 farmers that farm *Barbus,* sell it to consumers at premium prices. This species 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.

2.4.1.6. Guidelines for seed production of 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 including harvesting nets.

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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 + 20 mg/kg GnRHa OR Ovatide).
8. Place the injected fish into the circular tank system for breeding carps (**Errorea! Ez da erreferentzia-iturburua aurkitu.**).
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 embryos will be collected in the net as the water flows out of the circular tank system.
13. 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 40h at 28^{o}C 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.

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Figure 45 Hatching Tanks in ARDC

2.4.1.7. Technology and production key performance indicators (KPIs) 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

2.4.2. Labeo victorianus

2.4.2.1 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, but 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, their populations started decreasing since the 1960s (Ogutu-Ohwayo, 1990). Only two populations

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exist in the rivers Kagera and Sio around Lake Victoria in Uganda, at a decreasing trend however, hence the species is listed as critically endangered (Fish Base team RMCA & Geelhand, 2016).

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, *L. victorianus* fetches US$2-4/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 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 24h. These observations show the need for 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. Currently, agents that induce reproduction in many species are very costly and moreover have not been tried on *Labeo*. Therefore, the use of cheaper and readily available pituitary extracts from African catfish was investigated in the current study.

Low survival (35-60%) of *Labeo victorianus* during nursing and outgrow experiments have been recorded (Owori-Wadunde 2009). 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. NARO 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

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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.

Other 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.

2.4.2.2. Experimental design

Semi-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 41). They rested for one day before they were reproductively induced (Figure 46A). The ripe 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 46B). 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. The males were stocked in three tanks with females respectively. The water flow rate through the tanks was maintained at 20L/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

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each treatment (Figure 46C&D). The eggs were inoculated in a facility designed to hatch riverine species supplied with water by a flowing stream (Figure 47).

Figure 46. 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.

Figure 45. The hatching system was designed for cyprinids, where eggs in this trial were inoculated for incubation and subsequent hatching.

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Completely artificial 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) (Figure 48A), 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 48B&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 48F). The milt was also obtained by stripping the males into the mortar containing physiological saline solution (Figure 48E). 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 48G). 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 48H). The flow-through stream was 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 49A). 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.

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Figure 48 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 water to fertilize, H. Spreading of eggs in the concrete tanks.

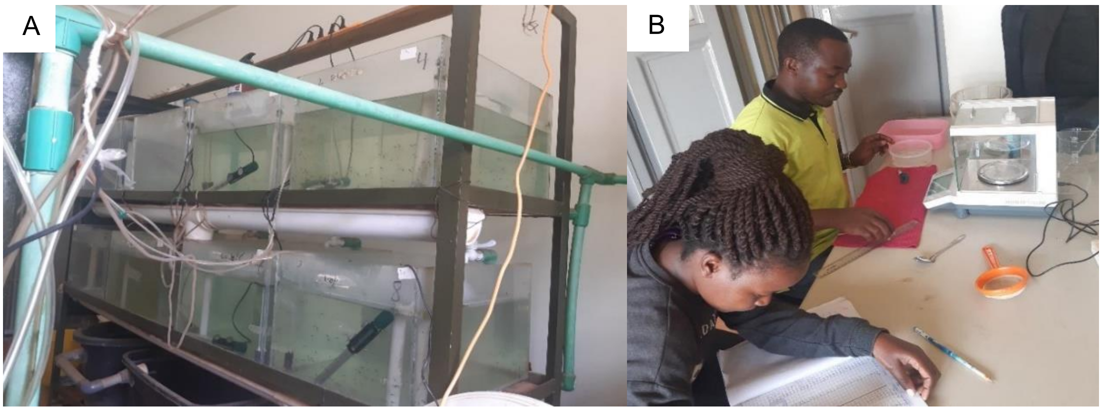

Figure 47. A) 40-liter glass tanks stocked with 400 larvae each and B) sampling of larvae using a sensitive (0.000 g) and ruler.

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Larval feeding experiment

Larval feeds (treatments), including decapsulated Artemia cysts, Artemia nauplii, and *Moina* (Figure 50), were used to evaluate their effect on larval performance (survival rate, FCR, growth rate). Every treatment was conducted in 3 replicates of 40L aquaria water tanks, each stocked with 400 larvae (Figure 49A). The treatments were administered for ten days. After that, all treatments were weaned using locally made artificial larval feeds of using a co-feeding strategy of 5 days, where they were fed on 50% dry feed and 50% of their respective feed treatments. Sampling was done every five days to record the fish weights and lengths using an analytical scale and ruler, respectively (Figure 49B). Once again SGR and fish survival were calculated along with FCR using the known formula= $\frac{\text{Total weight of feed consumed}}{\text{Total weight of fish gained}}$. They were later stocked in concrete tanks at a stocking rate of 27 pieces/m^3 for advanced nursing for 60 days and feed with best performing larval feed used in the experiment of glass tanks.

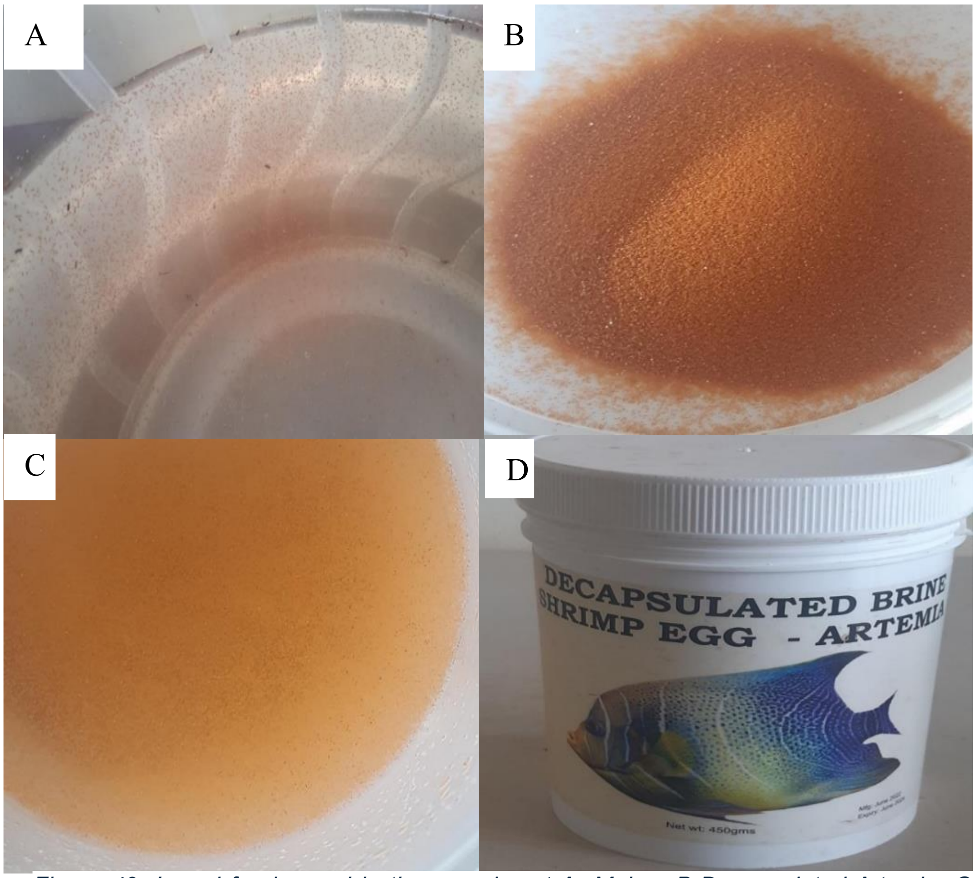

Figure 49. Larval feeds used in the experiment A- Moina, B-Decapsulated Artemia, C-Artemia nauplii.

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2.4.2.3. Results and discussion

Semi-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 12). 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 12. Spawning parameters for the semi-artificial spawning method of Labeo victorianus.

Inducing agent	**Eggs produced (1,000/kg)**	**Time to ovulate (min)**	**Fertilization rate (%)**
Ovatide	224.8133	911	98
African catfish pituitary extracts	316.7716	782	76
Blank	-	-	-

Completely artificial 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 *13*).

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Table 13. Spawning parameters for the artificial spawning method of Labeo victorianus

Inducing agent	Average body weight of females (g)	Time to ovulate (min)	Eggs produced (1,000/kg)	Fertilization rate (%)	Hatchability (%)
Ovatide	49.9±9.6	850	8.397	99.3±0.6a	95.1±1.7
African catfish pituitary extracts	42.9±6.8	688	6.650	91±2.1a	75.4±0.7
Blank	45.6±5.3	-	-	-	

Results indicated that the complete artificial method is more effective than the semi-natural process in the production of eggs; however, the eggs did not hatch. There is need to conduct more trials before this protocol can be adopted for seed production of the Ningu. It is observed that the African catfish pituitary was equally as effective as the Ovatide. This implies that hatchery operators can easily use cheaper pituitary extracts instead of Ovatide, which is a bit expensive and inaccessible to many hatchery operators.

Larval feeding experiment

The SGR, survival and weight gain of post larvae fed on *Artemia* cysts and nauplii did not significantly defer from each other (P≥0.05) (Table 14). However, the growth parameters of larvae fed the decapsulated *Artemia* performed better than other diets. 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 14. Mean growth-related parameters (standard deviation) recorded for larval feeding experiment for Labeo victorianus.

Larval feed types	Average weight gain (g)	SGR (%)	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

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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.

During the advanced nursing stage, the growth rate was 4.52%, with a daily body weight increase of 0.034 g/day. The survival rate was 83.6%, and the FCR was 0.493kg.

2.4.2.4. 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.

2.4.2.5. Protocol for spawning and larval nursing of Labeo victorianus

Broodstock selection

- Females with bulging stomachs should be selected.
- Ready females will produce eggs with the application of gentle pressure. The eggs should be of uniform size and colour (Figure 48).
- Select ready males to produce creamy milt with gentle pressure on the belly (Figure 48).
- Select healthy brooders without deformities and injury.

Pre-induction conditioning

- To limit stress among brooders, they should be rested for at least 6 hours before induction.
- Broodstock should be kept in tanks with clean water supply and a continuous flow-through system.

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- They should be stocked at 1kg/m^3.

Induction

- 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.
- In semi-artificial spawning, keep the fish of both sex in fishponds/tanks with a continuous flow-through system at a rate of 20-40L per minute for 8 to 10h.
- For artificial spawning, the males and females are kept in separate containers.

Egg collection

- 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 46).
- These can be collected using a scoop net of 0.5m mesh size; they can also be obtained by draining through harvest basins and nets.
- In artificial spawning, the females can be striped for eggs after 10 to 16 hours in a dry container (Figure 48).

Egg incubation and hatching

- 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.
- The water temperature is maintained at 26-28^{o}C.
- 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.
- The shell and dead eggs left behind on the tray should be removed immediately after most embryos have hatched to avoid bacterial build-up.

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- 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.
- At least 50% of water in the hatching facility should be replaced every day to maintain optimal water quality parameters.

Larval nursing

- 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.
- Stocking rates should be maintained between 10 to 20% by volume.
- Then, they can be weaned to dry feeds of at least 40%CP.
- At least 50% of water in the larval rearing facility should be replaced every day to maintain optimal water quality parameters.

2.4.2.6. Technology and production KPIs 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.

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3. Risks and mitigation measures

Partner	Description of risk	Level of likelihood: low/medium/high	Proposed risk-mitigation measures
INAT	Mortality of fry during transport and acclimatization due to stress or poor conditions	Low	- Use aerated transport tanks to ensure oxygen levels are maintained. - Gradually replace saline water with freshwater to reduce stress.
	Overcrowding in the dam leading to resource competition and reduced growth rates	Medium	- Optimize stocking density (500–1,000 fry/ha). - Monitor fish growth and survival to adjust future stocking rates.
	Potential water quality issues in the dam affecting fry survival and growth	Medium	- Regularly monitor water parameters (oxygen levels, pH, and temperature). - Implement corrective measures like aeration or water exchange if needed.
	Limited fisher training on sustainable harvesting and value-added product development	High	- Provide capacity-building workshops for fishers on sustainable practices and product diversification (e.g., producing dried fish and Bottarga).

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	Predation of fry by natural predators in the dam	Medium	- Assess predator presence before seeding and, if necessary, implement deterrents or controlled predator removal.
	Lack of proper collaboration between stakeholders (e.g., fishermen, researchers, managers)	Low	- Establish regular meetings and communication channels to coordinate efforts and resolve issues promptly.
DALF	Disease outbreak	Medium	-Strict following of biosecurity measures put in place. -Construction of quarantine facility for Isolation of any diseased fish.
	Water pollution	High	-Strict following of the biosecurity measures put in place. -Installation of wastewater treatment plant/Biofilter filtration unit to take care of the wastewater that might leads to water pollution.
NARO	Climate change effects (dry spells and heavy rains)	Medium	Climate smart structures
	Limited catches of broodstock from the wild	Low	Target collection of broodstock from at least two landing sites
	Poor management by farmers	Medium	Regular backstopping on good management practices of farmers through farmer visits

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	Fish mortalities due to poor water quality	Low	Regular water quality monitoring in the fish production units to ensure that water quality is maintained within acceptable ranges
	Crop pest and diseases	Low	Selection of pest and disease-free seedling; Screening and control of access to the vegetable production site
SUA	Farmers do not adopt the technologies developed cost-effective RAS unit, cost-effective diet made from locally available feed materials and integrated vegetable-fish-chicken farming) to rear fish	Medium	The technologies are based on the use of locally available materials that can be easily obtained by the farmers. The farmers will be sensitized to adopt the technologies through training workshops
All	Lack of proper collaboration between stakeholders (e.g., fish farmers, fishermen researchers, managers)	Low	Establish regular meetings and communication channels to coordinate efforts and resolve issues promptly.
All	Farmers do not adopt the technologies developed from the project	Medium	The farmers/fishermen will be sensitized to adopt the technologies through training workshops

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4. Work plan for the validation activities

4.1 New cost-effective RAS (SUA)

Activity	2025											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Designing and testing of simple solar RAS	X	X										
Conducting farmers sensitization workshop for adoption of simple solar RAS				X	X							
Training of fish farmers and construction simple solar RAS					X							
Rearing of fish in simple RAS by farmers					X	X	X	X	X			

4.2 Pond Polyculture (NARO)

Activity	2025											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Selection and training of fish farmers and data collection clerks.	X											
Pond preparation and pre-stocking data collection (inputs, challenges, etc.).		X	X									
Pond stocking and start of fish and environmental data collection (including inputs and challenges).				X	X	X	X	X		X	X	X
Data management and validation report/ improved guidelines development.				X	X	X	X	X		X	X	X

4.3 Integration of Aquaculture and Agriculture (NARO)

Activity	2025											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

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Fish and vegetable survival, growth performance assessment			X	X	X	X	X	X	X	X	X	X
Developing Guidelines & BMPs on integrated fish and vegetable production technology				X	X							
Training Farmers and prospective farmers on best practices for fish and vegetable production technology				X	X							
Validation activity (fish and vegetable) with the farmers				X	X	X	X	X	X	X		
Data collection and analysis				X	X	X	X	X	X	X		

4.4. New culture techniques for *Barbus altianalis* (NARO)

Activity	2025											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spawning *Barbus altianalis* on-station at ARDC	X	X										
Growth, maintenance & Distribution of *Barbus* fingerlings to some farmers in the food hub			X									
Training Farmers and hatchery operators on best practices for spawning technology			X									
Training of hatchery operator on production of *Moina*			X									
Validation activity (*B. altianalis* spawning & *Moina* production) with the hatchery operators			X	X								
Data collection and analysis					X							

4.5.New culture techniques for *Labeo victorianus* (NARO)

ACTIVITY	2025											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Spawning and larval nursing trials at ARDC	X	X										

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Training Farmers and hatchery operators on best practices for spawning and larval nursing of *Labeo victorianus*			X									
Validation of developed technologies on farms			X									

4.6 Dam seeding (INAT)

ACTIVITY	2025											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Conduct preliminary site assessments (Bouhertma Dam). Gather baseline environmental data and assess water quality. Start coordination with stakeholders (fishers, local authorities).	X	X										
Finalize logistic arrangements, secure equipment (nets, aerated transport tanks), and confirm fry availability with suppliers. Stakeholder training sessions begin.			X									
Adjust stocking density estimates based on current dam conditions.				X								
Begin collection of fry (*Chelon ramada*, *Mugil cephalus*) from saline water sites using Italian seine nets. Ensure minimal stress during capture.				X	X	X						
Transport fry to Bouhertma Dam in aerated tanks and Release fry at optimized densities (500–1,000 fry/ha). Acclimatize fry during transport by gradual substitution of saline water with freshwater. Ensure a 100% survival rate during the process.				X	X	X						
Begin monthly monitoring of growth rates, survival, and water quality parameters in the dam. Identify and address any emerging challenges.							X	X	X	X	X	X
Continue monitoring. Assess predator presence and implement mitigation measures if necessary.							X	X	X	X	X	X
Consolidate data on fry growth (length increase) and survival rates. Engage with fishers for observations and feedback on the seeding process.							X	X	X	X	X	X
Analyse data, prepare scientific publications, and develop outreach materials (guides, presentations) for local fishers. Hold workshops to disseminate results and lessons learned.										X	X	X

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5. Technology and production KPIs to be gathered

Food Hub	Technology	KPIs measuring the achievements
Kisumu, KE - DALF	Integration of Fish-Vegetable using the treated wastewater done under a small-scale system	At least 500 fish farmers to practise integrated aquaculture-agriculture technology by 2027
	Fish feed formulation using macrophytes (Lemna and Azolla) under small scale farming system	At least 500 fish farmers to practise own farm feed formulation by 2027
Jendouba, TN - INAT	Seeding dam with mullet fry	-100% survival of fry during transport from the collection site to the dam. -100% success rate during acclimatization of fry to fresh water. -Growth rate of seeded fry: average length increase: 10-20 mm per month for *Chelon ramada* and 15-30mm for *Mugil cephalus*. -Fish production in Bouhertma dam for 2023-24 was 3198t compared to 0t in 2021-22. -Increase in income: From 5-19 USD/kg for fishermen depending on the season and if the mullet is a mature female or not.
Masaka Kajjansi, UG - NARO	Integrated fish-vegetable farming	-Fish productivity/yield percentage ranged from 1.14-1.6kg/m^3 compared to what was suggested (1.5-2.0kg/m^3) -Calculated profit: 122.67€-188.64€ per month (based on data from two farms).
	Spawning/breeding technology of Kisinjja and Ningu	Fingerlings survival improved by 10%
	Polyculture of new species and traditional species	Achieved fish productivity: tilapia 2.01g/day; *Labeo* 1.67g/day; *Barbus* 1.74g/day; catfish 2.9g/day when the target was 2.3g/day, 2.1g/day, 2.5g/day and 3g/day respectively; representing 89.2%, 79.6%, 69.7% and 95.9% for tilapia, *Labeo*, *Barbus* and catfish respectively. This

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		represented a good performance, with room for research & implementation of the best management practices.
Kilombero, TZ - SUA	Integration of chicken-fish-vegetable (cowpeas) under small-scale farming systems	At least 100 farmers to be practising integration farming system by 2028
	Chicken and fish diets based on cowpea was a protein source	At least of 20% of fish-farmers to be using cowpeas as a protein source in fish and chicken diets in Kilombero district by 2028
	A cost-effective and good quality diet formulated from local feed ingredients	At least 30 farmers to be using the diet by 2028
	Improved fish production	30% increase in fish productivity in Kilombero district by 2028

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