Chapter

Promoting Domestic Production of Fish Using Recirculating Aquaculture System (RAS)

Shadrack Kwadwo Amponsah and Luiz Guilherme

Abstract

With the increasing global population and its associated high demand for fish protein, engineers are under pressure to develop systems that can maximise and intensify production of fish in an environmentally friendly and sustainable manner. This demand is escalated in the face of pandemics like the novel Covid-19, which have had serious toll on global food production and availability. The increasing fish demand over the years has caused the emergence of new aquaculture technologies such as the recirculating aquaculture systems (RAS). These fishponds are constructed in a way to ensure the efficient use of water. A technology extensively researched and developed by Brazilian researchers; the RAS technology has now been widely adapted to some developing countries in the sub-Saharan African sub region. Learning from the Brazilian and Ghanaian experiences, this chapter provides valuable information on these aquaculture production technologies and offers useful guidelines on their operation and management. The chapter also gives some highlight on available opportunities to better harness the RAS technology to promote sustainable food and nutritional security whiles improving on the general livelihood of adopters.

Keywords: aquaculture, recirculating, fish production, technology, Ghana, sustainable

1. Introduction

While the world's population and its appetite for fish is growing, wild fish stocks are shrinking. Over the last four decades, global consumption of fish has doubled, and the developing world has been responsible for 90% of this growth [1]. Globally, fish has maintained a prime position as the favourite source of animal protein for most people. Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans, and aquatic plants. Aquaculture can be freshwater or marine and it ranges from simple ponds using naturally occurring food sources to highly intensive systems with water control, aeration, and supplemental feeding. It is practiced inland, along the coast in brackish water systems, and in marine cages and net pens. Out of an estimated 179 million tonnes global fish production in 2018, aquaculture accounted for 46% of the total production and 52% of fish for human consumption equivalent to an estimated annual supply of 20.5 kg per capita [2].

Harvesting of aquatic resources and production is done either in the wild (capture fisheries) or in controlled environments (aquaculture). Unlike freshwater aquaculture, only a handful of the world population practice capture fisheries probably due to the high resource requirement in terms of skill and equipment. Aquaculture presents huge economic and environmental importance to the world economy. Fisheries and aquaculture are a vital source of jobs, nutritious food, and economic opportunities, especially for small-scale fishing communities. Aquaculture is also important for food security through the significant production of some low-value freshwater species (also through integrated farming) destined mainly for domestic consumption. Some economic importance of aquaculture includes alternative food and fuel source, increased jobs in the market, reduction in seafood trade deficit, increased production of food for human consumption, opening of commercially viable business opportunities, increased national exports and the substitution of imports by local production [3].

Recently, there is heightened interest by most people in developing countries to grow their own food to improve food and nutrition security whilst generating extra income. This move has led to the development of integrated food production systems which incorporates crop/animal production with aquaculture. In parts of Africa and South America, these integrated aquaculture systems consist of fish tanks or ponds that are used to culture Tilapia (*Oreochromis niloticus*), African Catfish (*Clarias gariepinus*) or *Heterobranchus* species whiles the pond effluent is utilised as manure to grow commonly consumed vegetables [4]. Pond aquaculture clearly has a huge potential for growth through sustainable intensification [5]. Similarly, Amponsah et al. [6] assessed the effect of rectangular, ellipsoid and circular tanks on production of Catfish using a recirculating aquaculture setup in an effort to promote the technology.

The increasing fish demand over the years has caused the emergence of new aquaculture technologies. An example of such systems is the water re-circulating pond. This type of fish tank is constructed in a way to ensure the efficient use of water. The effluent is not thrown away but simply emptied out into a reservoir where it undergoes treatment and is then pumped back into the pond [4]. In the phase of pandemics like the novel Covid-19, extra awareness is being created on the need for people in especially the developing countries to grow their own food in the comfort of their homes or communities. This practice, extensively adopted, is expected to create a sense of security, and improve the general livelihoods of the populace. Promoting home production of fish will greatly enhance the contribution of the aquaculture sector to sustainable economic growth. This chapter presents types, operation principles and management guidelines of tank aquaculture systems, focusing on experiences from some developing countries.

2. History of aquaculture

The term aquaculture is not new as it has been around for thousands of years [2]. Ancient Chinese manuscripts from the 5th century B.C. indicate that the Chinese practiced the fish culture of Carp in rice patties. The ancient Hawaiians furthered these methods by building pens to breed and raise Carp and Tilapia. According to Ling [7], the practice of aquaculture started in Asia (around 5000 BC), ancient Egypt (around 2500 BC) and in Central Europe. The earliest species of fish cultured was the common carp (*Cyprinus carpio*), by a native of China. In addition, Indian carp culture existed in the 11th Century AD [8]. Similarly, aquaculture started in Europe with the introduction of common carp culture in monastic ponds. During the 14th century, the propagation of trout was introduced in France as well as the method of artificial impregnation of trout eggs [9]. Subsequently, commercial trout culture in freshwater was developed in France, Denmark, Japan, Italy and Norway [8]. Specifically, the British introduced trout as sport fisheries in their Asian and African Colonies. Moreover, the development of fish culture in North

America became possible through the propagation of trout Salmon and Black bass. In the Czech Republic, these fishes were cultured in large ponds, which were built from around 1650, some of which are still in use [10]. Aquaculture in Brazil probably started in the 17th century, during the Dutch occupation of the north eastern region [11]. Originally, other culture facilities such as pens, and cages were used to grow Catfish in Cambodia. While the earliest brackish-water farming originated in Indonesia during the 15th Century AD. Atlantic Salmon also were cultured in cages in Norwegian fjords [8]. In West Africa, The Gambia started aquaculture in the 1970s in the form of trials using Tilapia culture in rice fields [12, 13]. Later on, in 1982, a company known as West African Aquaculture limited started the culture of Peneaus monodon in the coastal region [12]. This company became well established in The Gambia in 2000. Similarly, in 1988, two fish farms were operated in Western Region by Scan Gambia limited. Fish farming started in Ghana in 1953 by the former Department of Fisheries. Thus, it served as hatcheries to support the then culture-based reservoir fishery development programme of the colonial administration. In 1957, the government of Ghana adopted a policy to develop fishponds for farming within all irrigation schemes in the country [14, 15]. The modern form of aquaculture was started with pond culture, and this type of aquaculture is still prevalent in Ghana presently [16]. Production or holding systems used in Ghana are floating cages, earthen ponds, and concrete tanks. Majority of farmed Tilapia (approx. 90%) are from cage culture system with the remaining percentage from ponds and tanks [17]. Tank culture systems, though in the minority, offer great prospects to change the narrative in Ghana's fish sector if properly harnessed.

3. Overview of production systems

There are a wide range of aquaculture production systems used in the rearing of aquatic species. Production systems are diverse in terms of culture methods, practices, facilities and integration with other agricultural activities [2]. Few among them are cage and pen culture systems, earthen (dug out) ponds and tank culture systems. Earthen ponds remain the most commonly used type of facility for inland

Figure 1.
Earthen ponds or dug out systems.

Figure 2.
Cage/pen aquaculture systems.

Figure 3.
Tank culture systems.

aquaculture production, although raceway tanks, aboveground tanks, pens and cages are also widely used where local conditions allow [2]. Each of these aquaculture production systems/units are unique in its construction (**Figures 1–3**) and presents some pros and cons for consideration by potential adopters (**Table 1**).

4. Recirculating aquaculture system

Technological advances in tank culture systems led to the development of continuous recirculating aquaculture systems (RAS). This type of production system or holding facility is constructed in a way to ensure the efficient use of

Production system	Pros	Cons
Earthen pond/dug out	• Relatively cheaper to construct	• Requires physical security against theft
	• Large stocking capacity	• Fish could escape during flooding
	• Fish live in their natural environment	• Sorting may be difficult in earthen
	• Fish growth is rapid	• Pond water pollution and total pond collapse are common
	• High profit margin may be envisaged	• Expensive to manage and maintain over time
Cage/pen	• Fishes live in their natural habitat	• The construction process is cumbersome
	• Fish growth is rapid	• Risk of total fish kill during water pollution
	• Large stocking capacity	• High skilled labour requirement
	• Oxygen is always available	
Tank	• Lower risk of losing investment	• Higher initial investment
	• Lower skilled-labour requirement	• High dependency on reliable electricity and water
	• Smaller space requirement	• Overcrowding of fishes
	• Ease of construction	• Low stocking capacity
	• Ease of adoption and management at home	

Table 1
Pros and cons of aquaculture production systems.

water. The used water is not thrown away but simply emptied out into a reservoir where it undergoes treatment and is then re-used. A major advantage of the water re-circulating fishpond is that it offers the most efficient water usage, a higher dissolved oxygen percentage as well as a balanced pH level. The main challenge is the fact that electricity is required to power the system to be able to manage the waste effectively and efficiently in the pond. A typical recirculating aquaculture system essentially consists of a tank (pond water holding facility) and a filtration unit (pond waste management). **Figure 4** illustrates a well-labelled recirculatory tank culture system.

These production systems are suitable for both home and commercial culture of fish and comes in different sizes and shapes. Standard size for the circular geometry tanks is 4.2 m diameter at 0.9 m height, whereas the rectangular geometry is 4 m length by 3 m width at a height of 0.9 m. The advent of these production systems has restored hope for aquaculture enthusiasts, making it possible to grow fish in an environmentally friendly manner in the comfort of your home [4]. The tank frames can be constructed with locally available materials such as bamboo, tree branches, stones, clay (earth), empty paper cartons and cement blocks. These tank frames are usually lined with UV-resistant polyethene sheets or high-grade canvas material to make them water-resistant. Waste is managed using biological or mechanical filtration units installed on the tanks.

The innovation is an aquaculture system composed of a raised tank structure (rectangular, circular, or ellipsoid) made of either a cement block or wooden frame and lined with a canvas material to make it watertight. Water in the tank is set

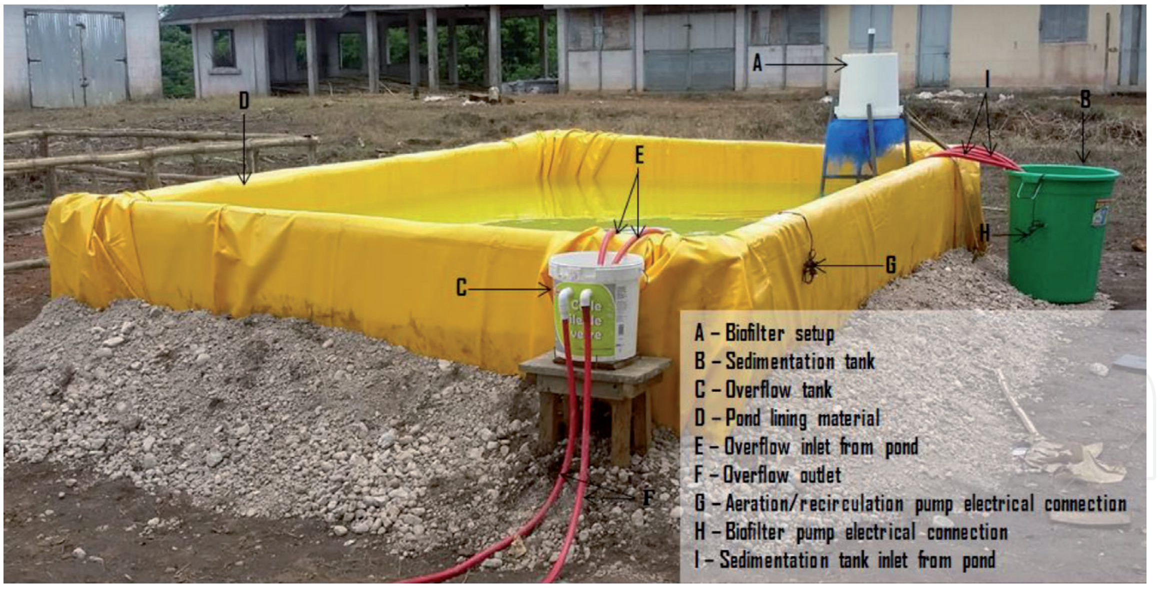

Figure 4.
Parts of a typical recirculating aquaculture setup.

in motion using a submersible water pump, placed at one point along the inner periphery of the tank. The pump also helps with aeration by constantly pumping atmospheric air through the water. The pump inlet is fixed on a perforated PVC pipe and placed on a concrete stand underneath the water. Once the pump is turned on, water is drawn through the perforations and by the centrifugal force generated, suspended solids are pushed along the inner periphery of the tank to the central area of the pond. Water hose is placed at the central bottom area to draw suspended solids by capillary action into a sedimentation tank placed outside the pond. The tank has at its bottom, a nylon thread mesh which filters solid waste from the incoming water for safe disposal through a valve opening at the lower side of tank. Filtered water from the sedimentation tank is brought back into the pond using a second submersible pump (i.e., to achieve water recirculation) through a bucket (stuffed with nylon thread mesh) placed at a height above the pond. Potential energy generated by the falling water produces bubbles aimed at providing extra oxygen for the fishes. The activity bacteria, pumps and mesh together help to remove ammonia from pond through the process of nitrification, making the water safe for fishes. This process is the referred to as biological filtration (biofiltration) which employs sets of biofilters to perform its function.

4.1 Biofilters

Biological filter (biofilter) setup is the single most important component of the pond system as far as waste management is concerned. Biofilters use natural processes and organisms (bacteria) through the Nitrogen cycle to break down Ammonia into less harmful components. It also helps to remove faecal waste and leftover feed from the pond water to ensure that the water is conducive for fish culture.

A standard biofilter setup is composed of submersible pumps (a and f), water hoses (e), nylon mesh-stuffed bucket on a stand (d), nylon mesh-stuffed basket inside the waste tank (b), sedimentation/waste tank with its accompanied plumbing components (c) as shown in **Figure 5**. In each biofiltration setup, there are two submersible pumps, recirculating/aeration (a) and return (f).

Figure 5.
The components of the biofiltration setup.

4.1.1 Biofilter installation procedure

The step-by-step installation procedure for the biofiltration setup is described as follows:

1. Fill your pond with potable water. Note that for chlorinated water, it is important to allow 3–5 days prior to stocking to allow the chemical to breakdown to tolerable levels for the fingerlings.

2. Gradually lower or place your biofilter unit (labelled *d* in **Figure 5**) into the pond – **Figure 6**.

3. Position your waste tank unit (labelled *c* in **Figure 5**) a little below the pond height, making sure it is well levelled and the outlet does not impede movement around the pond – **Figure 6**.

4. Gently fix the nylon mesh-stuffed basket (labelled *b* in **Figure 5**) inside the waste tank – **Figure 6**.

5. Cut the water hoses for the different connections on the biofilter, ensuring that they are well straightened before use – **Figure 7**. Cut at least four sets of 3-meter length and one piece of 1-meter length.

6. Fix the shorter hose inside the component labelled d and secure it with an end cap – **Figure 7**.

7. Place the return pump (labelled *f* in **Figure 5**) inside the waste tank and on top of the nylon mesh-stuffed bucket on a stand (labelled *d* in **Figure 5**) – **Figure 7** (insert).

8. Carefully place the longer hoses in the central area of the pond and gently siphon pond water into the waste tank – **Figure 8**.

9. Position the recirculating/aeration pump (labelled *a* in **Figure 5**) inside the pond on a firmly grounded stand, ensuring that it is fully submerged in water – **Figure 8**.

4.2 Pond management

After the pond has been constructed and biofilter installation is completed, all other production activities from pond stocking to harvesting of matured fish fall under pond management. It is important to note that within the production cycle, management of the pond is critical to ensuring good yield at harvest and nothing should therefore be taken for granted.

Figure 6.
Illustration for steps 2, 3 and 4 of the biofilter installation process.

Figure 7.
Illustration for steps 5, 6 (insert) and 7 of the biofilter installation process.

Figure 8.
Illustration for steps 8 and 9 of the biofilter installation process.

4.3 Pond stocking

The process of putting fish into the pond is termed stocking. This marks the beginning of a production cycle and is among the most stressful processes the fish go through during production. The process of stocking starts with the collection of fingerlings from the hatchery, transporting them to the pond location and finally putting them into the pond.

Poor stocking procedures are among the major causes of low survival in grow-out ponds and usually result in disease outbreaks, reduced growth and mortality. Successful stocking depends on the quality of fingerling, how they are stocked and when they are stocked. Stocking should be done in a manner that minimises stress on the fish. It is therefore advisable to get fingerlings from an approved source or outlet. Apart from the various hatcheries under the Ministry of Fisheries and Aquaculture Development, several private hatcheries are available across the country where quality stock can be procured. It is advisable to stock a pond before sunrise or at sunset to avoid heat stress on the fingerlings. As a precautionary measure to arrest any bacterial/fungal infection, salt treatment (using plain rock salt) of pond water is required prior to stocking. Salt treatment may be repeated from time to time, especially when fungal or bacterial infection is suspected. **Figure 9** illustrates the salt treatment process of pond.

As a caution, fish should not be poured straight into the ponds. Always allow fish to be acclimatised to the new environment for the first 15 to 30 minutes before gradually releasing them into the pond (**Figure 10**). This helps them adapt to the differences in water quality between the transport container and the pond without shocking the fish. When fish are shocked by the sudden changes in water quality, they become stressed or may die. It is important to stock fish of uniform size; otherwise, the larger fish (especially for catfish) will cannibalise the smaller ones. They will also dominate the feeding area which will result in them growing bigger and the smaller fish remaining small. Such a situation can negatively affect fish survival rate and total yield at harvest.

Ensure to keep a record of all the stocking information including the source of the fingerlings, average size stocked, total number and kilogrammes stocked as well as any notable observations such as mortalities and disease outbreaks during the stocking process and all through the production cycle. The recirculating pond systems could take a maximum of 400 tilapia fingerlings or 1000 catfish fingerlings ($\geq$10 g) to be fattened to a size of at least 0.3 kg and 1.0 kg respectively within a period of 4–6 months.

Figure 9.
Salt treatment procedure.

Figure 10.
Pond stocking procedure.

4.4 Feeding and nutrition

After stocking, fish requires the right nutrition to grow and promote good yields at harvest. It is also important to feed your fish with the right quantity of feed at the right time and growth stage. It is advisable to buy commercial floating pelleted feed to minimise feed wastage. These commercial feeds come in various sizes and nutritional contents to meet the demand of the fish at the different stages of growth.

In administering the feed, it is required to use the response feeding method while ensuring that the fishes are fed to satiation (**Figure 11**). Response feeding is proven to be the best feeding method. Not only does it help minimise feed wastage, but it also ensures that the pond water quality is well maintained. The most important rule in fish nutrition is to avoid overfeeding. Overfeeding is a waste of expensive feed. It also results in water pollution, low dissolved oxygen levels, increased biological oxygen demand, and increased bacterial loads.

Figure 11.
Response feeding of fingerlings.

Figure 12.
Removal of waste from waste tank.

4.5 Water quality and maintenance

Water quality is the first most important limiting factor in pond fish production. It is also the most difficult production factor to understand, predict and manage. Water is not just where the fish live. Its quality directly affects feed efficiency, growth rates, the fish's health, and survival. Most fish mortalities, disease outbreaks, poor growth, poor feed conversion efficiency and similar management problems are related to poor water quality. Water quality refers to anything in the water (physical, chemical, or biological) that affects the production of fish. The objective of pond management is to manage the water quality, to provide a relatively stress-free environment that meets the physical, chemical, and biological standards for the fishes' normal health and production performance.

The following are some general pond managements and troubleshooting tips/practices for improved pond water quality and fish production:

- Ensure waste in sedimentation tank is safely removed daily by opening the outlet valve whilst stirring water in the bucket continuously to dislodge the waste and allow it to freely move out (**Figure 12**).

- Ensure to check and service the submersible water pumps at least once every week.

- Check and top up pond water to optimal level from time to time or where necessary, especially after every waste removal activity.

- In extreme cases, flush out the water from the pond entirely and replace with fresh one. This becomes necessary when there is more waste than the biofilter system can handle or when the biofilter pumps are not functioning due to power outage.

- Reduce the feeding frequency to about half in situations where the biofiltration system is not functioning for more than 3 days due to power outage. This is done to reduce the quantity of waste produced and maintain the water quality till the problem is addressed.

4.6 Diseases and management

Disease is a condition in living organisms in which normal physiological functions are being impaired due to alteration in the body systems and typically manifested by distinguishing signs and symptoms. Sustainable aquaculture production can only be feasible when fish are healthy and free from disease. Disease is a significant source of constraint to aquaculture development and sustainability from both social and economic viewpoints. Production costs are increased through investment lost in dead cultured fish, cost of treatment and decreased quality and quantity of yields. Again, livelihood and standard of living may be affected due to reduced products availability, loss of income and employments.

Fish diseases and infections in ponds may occur when pathogen load increases above what the natural resistance of the fish can cope due to external factors like poor water supply. Such external factors may cause drastic changes in water quality and lower fish resistance, making them susceptible to diseases and even the risks of 100% fish mortality. Fish disease management is a combination of both preventive and curative measures required to avoid and treat possible disease, respectively. Healthy fish can adapt to reasonable environmental changes and in turn resist diseases.

Generally, two forms of diseases affect fish: infectious and non-infectious. Infectious diseases are caused by living/pathogenic organisms (viruses, bacteria, fungi, or parasites) present in the aquatic environment or carried by other fish. Fish become vulnerable to pathogenic infections when there are stressors (environmental abnormalities, water quality deterioration, unbalanced nutrition, or bodily injuries) which weaken fish natural resistance (immune system). Infections can occur internally and externally affecting tissues, organs, and other fish body parts. They are mostly contagious diseases, and some types of treatments may be

Figure 13.
Tail rot bacterial infection on an African catfish juvenile.

necessary to control the disease outbreaks. Infectious diseases can be further grouped into parasitic, bacterial, fungal, and viral diseases based on the causative agent. Bacterial infections are considered the major cause of mortality in aquaculture. Antibiotics are commonly used in the treatment of bacterial infection of fish. In some cases, salt bath may be done for fish in combination with antibiotics to remedy the situation. **Figure 13** depicts a tail rot bacterial infection on an African Catfish juvenile.

Non-infectious diseases (systemic diseases) are caused by non-living factors. The diseases are either congenital (such as genetic anomalies or neo plastic conditions) or iatrogenic (induced by external conditions such as environmental or nutritional problems). Non-infectious diseases are not contagious, and medications are generally not required. However, iatrogenic condition can usually be reversed by removing (or adjusting) the cause. Non-infectious diseases of fish include diseases due to environmental, nutritional, and genetic anomalies.

Apart from the application of appropriate (approved) remedial actions and/or treatments for fish diseases, a change in management is necessary in most cases. However, as a rule of thumb, it is advised to consult the nearest aquaculture/fisheries extension office for technical assistance in remedying the situation before things get out of hand. As a precautionary measure, it is advisable to not feed fish with bare hands, as that could be a point for introducing infection into the pond. Either wear gloves or use a small cup to fetch and throw fish feed when feeding.

4.7 Fish harvesting and processing

Harvesting is one of the most important and labour-intensive activities in aquaculture but is often overlooked. In raised ponds, harvesting may be achieved either by using a two-man drag net (**Figure 14**) or by fully draining the pond water (**Figure 15**) and scooping the fish out with a basket or a harvesting scoop net (**Figure 16**). The scoop net and the two-man drag net can be helpful in fish sampling purposes. Harvest fish during the cool hours of the day; preferably, early morning or at sunset, where possible. To keep the harvested fish fresh, especially where long distance transportation is involved, place iced blocks on the fish.

Figure 14.
Fish harvest in pond using a two-man drag net.

Figure 15.
A fully drained pond prior to harvest.

4.8 Handling and processing

The handling, processing, and marketing of fish are essential complementary functions. The marketability of fish is an important constraint in the development of the fish industry. Processing and marketing offer the greatest opportunities for employment within the sector. A rule of thumb is that the timing of harvest must be tailored to meet the local supply and demand patterns. This is because fresh fish cannot be held for long periods of time without serious losses. The transport of fresh or live fish requires: (a) location of ponds close to the market to minimise handling and to limit transportation time (b) early morning harvests to transport fish at cool temperatures and (c) markets equipped with ice facilities or water tanks (cement or small tin containers) with aeration devices and a drainage system. For

Figure 16.
Fishing scoop net.

Figure 17.
African catfish preservation by smoke drying.

these reasons, simple but efficient preservation and processing methods have been employed over the years by fish farmers.

The processing methods used can vary greatly and are dependent on consumer taste, availability and costs of the processing material, technical knowledge, time needed for processing, price of the final product, storage facilities, marketability and seasonal fluctuations [18]. The most predominant fish preservation method is smoking, which comes in varied forms. In smoke drying of fish, the use of barrels, roofing sheets, cement blocks and kilns are common (**Figure 17**).

5. The Brazilian Sisteminha story

In 2002, researchers from the Federal University of Uberlandia, Minas Gerais State of Brazil developed an integrated food production system. The Brazilian Agricultural Research Cooperation (EMBRAPA) have, since its successful patent in 2006, disseminated the integrated food production system, popularly known as *Sisteminha*, across almost all the regions of Brazil. The project helps low-income families to meet their nutritional needs by producing their own quality foods, with low levels of pesticides and with the use of all available resources around their homes. The project also assisted in fostering entrepreneurship and financial

Figure 18.
Sisteminha fishpond systems using different materials.

independence in regions with low family income. Currently, various aspects of the Sisteminha have been adopted in some African countries including Ghana, Uganda, Ethiopia, Cameroon, Angola, Mozambique through donor-funded projects or own initiative.

The technique of constructing the fish tank in the fish farming module presented itself as the most versatile and therefore underwent more modifications. Initially the tank was designed to have its structure supported by wooden stacks tied with PET bottle wires, cardboard sides, coated with plastic film of 150–200 micron thick [19]. Currently, the tank can even be designed with prefabricated concrete slabs. These EMBRAPA Sisteminha fishponds have been well adopted in Brazil and can be adapted to meet existing local conditions. **Figure 18** provides an illustration of the various Sisteminha tanks.

6. Building on success stories: Wontesty Ventures, Ghana

The recirculating tank culture system was first introduced to Ghana in 2014 through a joint donor-funded project with Scientists from Embrapa Mid-North, Brazil [20]. The closure of the Ghana-Brazil collaborative research and dissemination project on aquaponics-based food production systems in 2016 sparked an interest for recirculating aquaculture ponds, which led to the establishment of a private agri-business venture to meet this demand.

Wontesty Ventures is a start-up business at Kumasi in the Ashanti Region of Ghana specialised in the construction of recirculating aquaculture systems, provision of general aquaculture services including training, production, processing and marketing of Catfish, Tilapia, and other farm produce. With a vision to pond every household in Ghana by 2040, Wontesty Ventures has been working hard through the provision of tailor-made research-based solutions to fish farmers, families and aqua-preneurs across the country. Currently with over 150 established ponds across the country and more than 50 clients since 2017, the business strives to erase the notion that fish farming is possible only with the traditional earthen ponds and cages. The system has since been adapted to Ghanaian conditions through research

Figure 19.
The evolution of the recirculating tank culture system.

and currently available on the market for consumers. These tanks have evolved over the years and now there are even collapsible (mobile) tanks made of industrial-grade canvas tarpaulin material. The mobile tanks come in handy for potential adopters who have plans to relocate after a couple of years. **Figure 19** shows the evolution of the recirculating tank culture system since 2014.

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