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# Aquaponics: A Sustainable Approach to Integrated Fish and Plant Farming

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## ABSTRACT

**Achieving food and nutritional security in East Africa (EA) and the world at large is a global goal. While efforts have been made to improve traditional food production systems, hunger and nutritional insecurity still exist. Aquaponics is a novel technology that holds promising potential to provide food and improve human nutrition by producing both fish and plants. The success of aquaponics is attributed to the beneficial symbiotic relationship among fish, plants, and nitrifying bacteria. Furthermore, independent standalone recirculating aquaculture systems (RAS) and hydroponic systems still face challenges that can be overcome by integrating them into a closed single system. Additionally, alternative economical and ecologically sustainable feed sources are on the rise, with considerable attention being given to black soldier fly larvae (BSFL). For the sustainability of aquaponic systems, water quality parameters such as pH, ammonia, dissolved oxygen, and temperature are critical. This review addresses the ongoing issue of food and nutritional insecurity in East Africa and globally, despite efforts to improve traditional food systems. Moreover, it focuses on overcoming the inefficiencies of standalone RAS and hydroponic systems by integrating them into a unified aquaponics system. Thus, it mainly covers the most used aquaponics systems. Media-filled beds (MFB), deep water culture (DWC), and nutrient film technique (NFT) comprise the hydroponic component, while fish rearing tanks form the remaining part. A total of 90 academic papers were reviewed, with 60 relevant to**

**this study cited herein. These papers provided insights into challenges and innovations in aquaponics design and management for sustainability. In conclusion, scaling up fish-plant production in aquaponic systems is inherently linked to the size of the aquaculture setup and the availability of waste nutrients.**

**Keywords:** aquaponics, food security, nutritional insecurity, recirculating aquaculture systems, water quality.

## INTRODUCTION

In the pursuit of achieving food and nutrition security in East Africa (EA), numerous strategies have been implemented at both household and national levels. Despite these efforts, persistent challenges threaten the well-being of communities in EA. Food security concept, as defined by the U.S. Department of Agriculture, underscores the fundamental importance of ensuring access to nutritious food for all individuals [1]. On the other hand, the Committee on World Food Security expands this definition to encompass not only food access but also the broader socio-economic conditions necessary for healthy living [2]. Despite global commitments, under the Sustainable Development Goals (SDGs), it is stated that food insecurity remains a visible dimension of poverty in Africa [3, 4]. The region is home to nearly one billion food and nutrient-insecure people, about 78 percent of Africa's population [5]. This highlights the urgent need for action and policy solutions.

To achieve the ambitious goal of zero hunger by 2030 set forth by the SDGs [6], several critical actions are required. First, addressing inequalities in resource distribution is essential to ensure that all populations have access to the food they need. Second, restructuring food systems will help make them more efficient and sustainable. Third, investing in sustainable farming techniques like Integrated Aquaculture Agriculture (IAA) can significantly boost food production. Finally, it is crucial to lessen the effects of pandemics and conflict, as these can severely disrupt food supply chains and exacerbate hunger. Aquaponics offers a promising solution to food insecurity. Aquaponics is a novel technology that combines aquaculture with hydroponic plant cultivation in a closed system. This technology presents environmentally friendly benefits and potential solutions to key challenges such as water scarcity and burgeoning food demand motivated by a quickly expanding population. Despite its potential, limited research and data hinder its widespread adoption and economic feasibility.

By 2018, aquaculture employed more than 20.5 million people [7] worldwide, and an estimate of 59.5 million people in fisheries and aquaculture. By 2020, the number increased to 62.8 million people and reduced to 61.8 million people by 2022. FAO [8] reveals that global capture fisheries produced 92.3 million tonnes in 2022 comprising of both marine and inland captures. This figure has stagnated since the 1980s. In addition, the same author indicates that there is a rise in aquaculture production (51%) worldwide and this surpassed capture fisheries, still in the year 2022 [8]. This suggests that aquaculture has the potential to fulfill the food requirements of the growing population. Despite the rising contribution of aquaculture to food security, Africa's potential contribution has not been explored. Africa contributes 1.9 percent globally on the total aquaculture production lagging behind Asia (91.4%), Latin America and Caribbean (3.3%) and Europe (2.7%). According to FAO [8], Egypt (62%) and Nigeria (10%)

are leading in Africa in the regional contribution aquaculture production. Uganda and Ghana follow [9]. The major fish species in these countries are tilapia and African catfish.

The aquaculture sector in Africa has experienced growth by 445 percent since 2000 [8] and according to Jolly, Nyandat [10], aquaculture had grown by 300 % from the 1950s to 2018. This indicates that the aquaculture and aquaponic industries are growing fast in Africa. By 2018, Africa contributed 2.7% to the global aquaculture production [9]. Table 1 indicates the top 10 aquaculture producers in Africa contributing to food security. Egypt tops in Africa with 71.10 percent followed by Nigeria (13.26%), Uganda (4.72%) and Kenya (0.02%) in the seventh position.

**Table 1: Africa's Top 10 aquaculture producers in 2018 [9]**

| No. | Country | Production (metric tonnes) | Regional Share (%) | Global Share (%) |
|---|---|---|---|---|
| 1 | Egypt | 1,561,457 | 71.10 | 1.90 |
| 2 | Nigeria | 291,233 | 13.26 | 0.35 |
| 3 | Uganda | 103,737 | 4.72 | 0.13 |
| 4 | Ghana | 76,630 | 3.49 | 0.09 |
| 5 | Zambia | 24,300 | 1.11 | 0.03 |
| 6 | Tunisia | 21,756 | 0.99 | 0.03 |
| 7 | Kenya | 15,124 | 0.69 | 0.02 |
| 8 | Malawi | 9,014 | 0.41 | 0.01 |
| 9 | Madagascar | 7,421 | 0.34 | 0.01 |
| 10 | South Africa | 6,181 | 0.28 | 0.01 |

Aquaculture in EA is dominated extensively by ponds. This can be attributed to the low cost of infrastructure development and the knowledge gap on intensive systems. Intensive production methods including cages, tanks, etc. are still low in this region [11]. Uganda leads in cage production with 18 percent of inland farm cages followed by Kenya, Tanzania, etc. noting that Lake Victoria hosts the highest caged aquaculture facilities on in Africa [11].

The aquaponic industry holds significant potential for addressing food and nutrition security challenges in EA [12] amidst the backdrop of rapidly increasing population and climate change. Aquaponics offers a sustainable solution by maximizing resource utilization and minimizing environmental impact. As discussed earlier, the percentage growth of the aquaculture sector in Africa reveals that aquaponics can be adopted in EA. Also, having Uganda and Kenya among the top 10 contributors to aquaculture production in Africa gives hope of the success of aquaponics in EA. Despite the hopes, several critical gaps and challenges impede its widespread adoption and contribution to food availability in the area.

### Challenges Faced by Aquaculture/Aquaponics

While aquaponics has demonstrated success in controlled environments [13], its scalability and adaptability to diverse climatic conditions in EA remain uncertain. The region's variable climate, characterized by droughts, floods, and temperature fluctuations exacerbated by climate change, poses challenges for maintaining stable aquaponic systems and ensuring consistent food production. Moreover, the economic viability of aquaponics in EA has not yet been fully demonstrated in its entirety [14]. Effects of climate change are first felt by small-scale aquaculture farmers, despite their little contribution to climate change [15]. These effects are evident through the high global temperatures, alterations in weather conditions, water level reduction, inland water regime alterations, heavy windstorms and increased incidences of flooding and drought [15]. These challenges necessitate the adoption of climate-smart aquaculture practices. High initial investment costs, limited access to technology and training, and uncertain market demand hinder the widespread adoption of aquaponic systems among smallholder farmers [16]. A significant percentage of the population engaged in aquaculture is smallholder farmers. While aquaponics offers the opportunity to grow a range of vegetables and fish abundant in vital nutrients, the accessibility and affordability among these products to vulnerable communities remain uncertain.

Developing countries such as Uganda, Kenya, and Tanzania with growing populations require adequate food supply. A significant portion of the population lives in poverty, with a large share of household expenditure allocated to food [17]. Current food production systems rely on finite resources such as land, freshwater, fossil energy and nutrients [18, 19]. Often, these resources run out faster than they replenish [20], leading to sustainability concerns. Population growth, projected to hit 10 billion people by 2050 [21] and related urbanization come at a cost of deforestation, wetland reclamation and industrialization. However, the greatest fear of humankind is to meet its nutritional needs despite the shrinking arable land as well as the rural labor force [18, 22]. Food production needs to increase by 50% to satisfy growing global demands [23, 24]. Competition amongst food production, urbanization and industrialization intersects at the cost of these finite resources. Expanding arable land for food production encroaches on forested lands and wetlands. Ploughing triggers soil erosion by wind and water, reducing soil fertility. Additionally, increased fertilizer application results in land degradation [25]. This imbalance necessitates innovative approaches like aquaponics and insect farming to enhance resource efficiency and sustainably encourage the production of food. Amidst the urge to increase agricultural output by conventional methods, impactful environmental degradation stemming from deforestation and excessive chemical use including soil salinization, erosion, and nutrient loss have greatly affected the environment [22].

Amidst challenges of population growth, climate change, soil degradation and water pollution which worsen food security, aquaponics presents an innovative and sustainable food production system. The symbiotic relationship between fish and plants in a closed system contributes to food security through providing a stable supply of fish and crops year-round, regardless of seasonal changes. Furthermore, aquaponics combined with other farming practices, such as poultry and insect rearing, creates a synergistic system that maximizes resource use and improves overall food production efficiency. This multifaceted contribution to nutrition security underscores the fish's importance globally, supporting health, livelihoods, and SDGs. Aquaponics, regardless of the climatic conditions can be done indoors (for self-consumption) and/or on non-arable lands near markets. This shortens the distances between producers and markets while reducing on the carbon footprint [26]. This is in agreement with [27] who state that shortened distances significantly reduce carbon emissions.

Addressing these challenges requires multidisciplinary research efforts. These efforts can include, optimizing aquaponic system design, enhancing technical capacity among farmers, and fostering market linkages and policy support. This can form a basis for systems under food production that are sustainable [28]. By addressing these gaps, the aquaponic industry can be pivotal in enhancing nutrition security, promoting climate resilience, and fostering sustainable development in EA [29]. Ensuring a fair distribution of nutrient-dense foods produced through aquaponic systems is critical in addressing malnutrition and improving public health outcomes in EA.

### Food and Nutrition Security

Fish emerges as a significant potential contributor to addressing food and nutrition insecurity in Africa. More than one billion people rely on fish for consumption, globally [17, 30]. Not only does fish serve as an alternative animal protein source, but it also provides essential fatty acids and micronutrients including iron (Fe), zinc (Zn), calcium (Ca), Vitamin A and selenium, crucial for improving the livelihoods of marginalized communities. Micronutrients are critical for pregnant women, breastfeeding mothers and young children. Also, better child growth is highly correlated with higher fish consumption [30]. For instance, fish are the primary source of omega-3 fatty acids, which are critical for infant brain and eye development and help prevent various illnesses, including cardiovascular disease, depression, and other mental health conditions [17]. Furthermore, regular fish consumption has been linked to numerous health benefits, including low risk of chronic diseases like heart disease, stroke, and certain cancers, making them an invaluable component of a balanced diet [31, 32].

## MATERIALS AND METHODS

A comprehensive review of 90 academic papers on aquaculture/aquaponics was conducted across multiple databases. Peer-reviewed journals (58) that focused on aquaculture, aquaponics, integrated aquaculture-agriculture (IAA), recirculating aquaculture systems (RAS), hydroponic systems, and water quality and food security were included in the study. Studies had to present empirical findings, challenges, system designs, or innovations related to these topics. Other papers (32), lacking significant experimental data, reviews with no original insights, publications not in English, or those focused solely on traditional agriculture without aquaculture integration were excluded from the study. Only relevant, high-quality studies were included after a thorough screening. A synthesis of the results provides insights on the principles of aquaponics, challenges, innovations, designs, and merits of aquaponic systems. It is aimed to contribute to existing knowledge in the aquaponics industry. Also, to identify gaps in research, highlighting areas that need further study to guide future investigations. Additionally, this review serves as a valuable resource for students and professionals who want to learn more about aquaponics.

### Aquaponics

Aquaponics combines aquaculture (fish farming) and hydroponics (soilless plant production) either in a coupled or decoupled design [18, 33]. Simultaneous raising of fish and growing edible plants frontlines aquaponics over the independent RAS and hydroponic systems. Aquaponics utilizes fish excreta and unutilized/uneaten feed as a source of plant nutrients [34] whilst plants set in a function of biofilters that purify the water to keep the fish healthy. The author also argues that biofilters are capable of removing nitrogenous species as nitrogen gas. Plants harbor bacteria that convert ammonia in fish waste to nitrites, then to nitrates. Several studies [33, 35] have provided information on the microbiome involved in aquaponics, rather, it is not exhaustive. Goddek, Joyce [18] describe aquaponics systems as a black box in which inputs, products, and waste are well established but what goes on the inside remains unknown.

The principle of aquaponics lies in the capacity of the participating bacteria including Nitrosomonas sp, and Nitrobactor sp to oxidize ammonia to nitrate [36, 37]. Nitrate is the bioavailable form of nitrogen to plants. Plants require structural, functional as well as macro and micronutrients [27] for proper growth and advancement, primarily, Nitrogen, Phosphorous and Potassium, the so-called NPK. It is a good practice to often visually examine plants for signs of nutrient deficiency. Aquaponic systems may show low concentrations of K, Fe, P or Ca in the water-soluble fraction of the fish effluents [38]. In addition, most aquaponic plant nutrients are obtained from the fish effluent. Stathopoulou, Berillis [36], identify feed loss and fecal waste as the main contributors to solid waste in fish culture. Largely, these contribute to the fish effluent. The feeding frequency in an aquaponic system affects both the fish's nitrogen and energy utilization and plant growth. Results from a study by Stathopoulou, Berillis [36] to evaluate the three feeding frequencies of sea bass showed that the system with the highest feeding frequency outweighed all other systems in plant (lettuce) stem length.

**Decoupled and Coupled Aquaponic Systems**

Decoupled aquaponics have separate aquaculture and hydroponic units in which water flows from the fish to the plants and never returns [39]. This allows for independent management of system parameters including pH, temperature, and oxygen. An advantage of this system is its assumed higher efficiency in water and nutrient use, which is expected to result in higher yields compared to traditional and stand-alone hydroponics systems. On the other hand, the accumulation of nutrients in the RAS part is rather scarce in the hydroponic part which may require periodical discharge of nutrient solutions [40]. In addition, a condition relating to biofouling may exist in hydroponic circulation systems. Furthermore, plants require higher nutrient concentrations than fish, thus, supplementation of nutrients may be required for decoupled aquaponics. To get past these drawbacks, the integration of hydroponic and aquaculture systems into a single coupled system is paramount.

Coupled aquaponics design describes water and nutrient flow dynamics in which water is recirculated in a closed and continuous loop between fish and plants [39]. Its attractiveness to users due to the established fish feed-to-plant ratios, proven system design and documented economic information makes it the most adopted design. The system is merited to be the most efficient in resource use [37]. It combines aquatic organisms, bacteria and plants in a closed loop. Plants are able to receive dissolved nutrients from fish waste, delivered within water which serves a transport medium. In turn, fish gets back clean-filtered water.

In the two systems, fish habitat is an important part of the welfare and fish growth. Most aquaponic fish are freshwater species (in other words, got from freshwater bodies) . Stathopoulou, Berillis [36] and identifies tilapia species, carp, perch and catfish as mainly cultured freshwater species in aquaponics systems. The aquaponic system must therefore, imitate the native environment conditions for a healthy fish-plant growth as well as for bacteria to thrive.

## Aquaponics Design

Aquaponics, a model of sustainable food production has two main components, the fish-rearing tank (aquaculture part) and the plant growth support media (hydroponic part) [26]. Water-holding vessels (fish rearing tanks) should be large enough to provide sufficient room for fish to move and grow. Conversely, stunted growth results from insufficient space [41]. Also, too much room brings concerns of running expenses and poor space utilization. Fish stocking density is the fuel for running the aquaponic system. Therefore, the key function of fish-rearing tanks is to offer optimum space and growing conditions for a high fish stocking density. Media beds, deep water culture (DWC) also termed as floating raft [42] and nutrient film technique (NFT) are three most commonly used hydroponics subsystems. Media-filled beds are a type of aquaponics system where plants are cultivated in containers filled with materials such as gravel or clay pebbles. Deep Water Culture is a hydroponic growing technique in which plant roots are suspended directly in a nutrient-rich, oxygenated water solution. NFT is a hydroponic method where a thin layer of nutrient-rich water continuously flows over plant roots. The plant roots get essential nutrients while allowing for proper oxygenation. According to Somerville, Cohen [43], fish metabolic wastes in culture water are released from the fish tank to the mechanical filters. Solid waste is removed via a mechanical filter and water continues to a biofilter in which ammonia is oxidized to nitrate. Then, nutrients travel through grow beds where plants uptake them and finally return to fish tanks (Figure 1), purified.

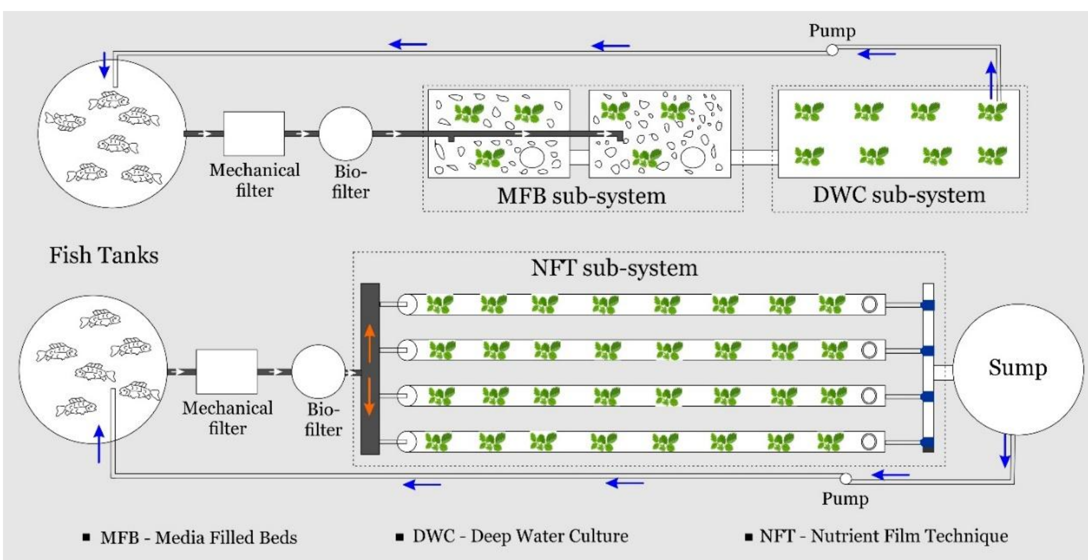


**Figure 1: An illustration of Integration of Aquaculture and hydroponic cultures into a closed recirculating system**

Nutrient uptake by plants removes toxic substances (ammonia and nitrite) and cleans the water. Figure 2 indicates the aquaponic (fish-bacteria-plant) cycle in which the organisms are symbiotically related. All three organisms work in unison to create a healthy growing environment for one another, on the condition, the system is properly balanced.

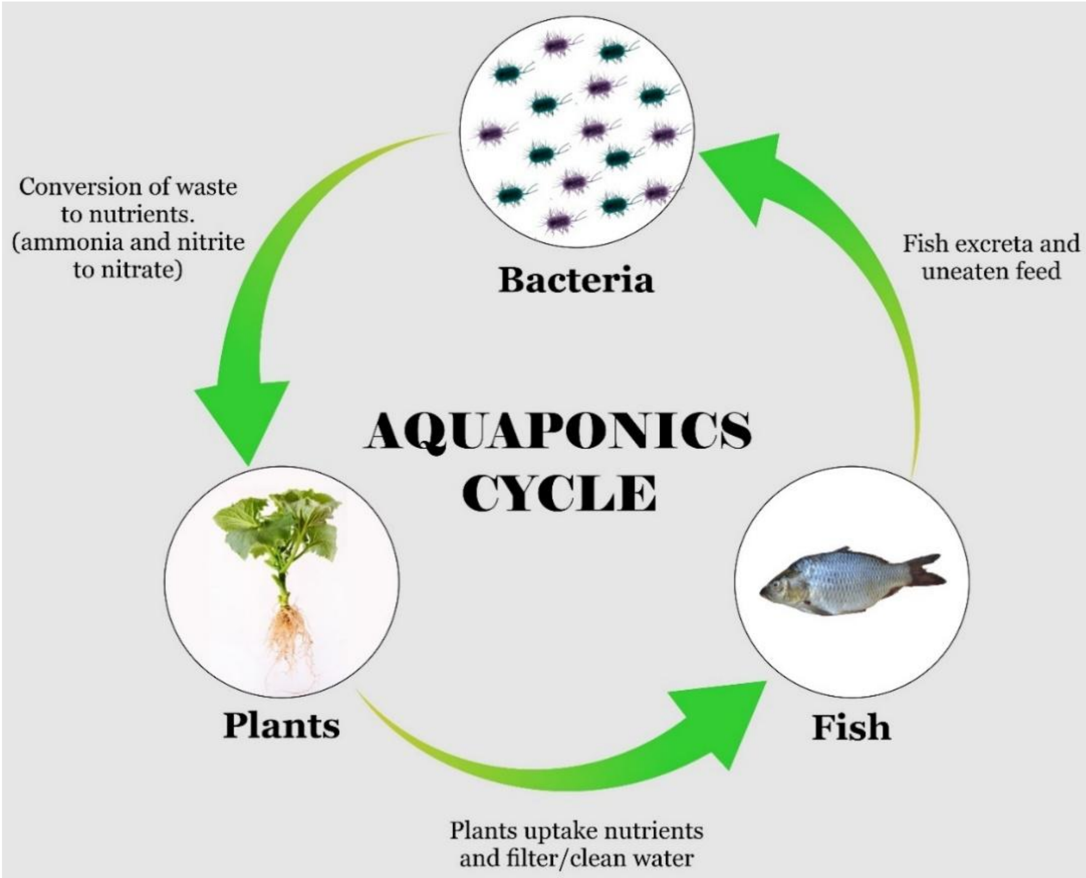


**Figure 2: The Aquaponics Cycle (Fish-bacteria-plant symbiotic relationships)**

## Media-Filled grow beds

Tórz, Burda [20] states that media filled beds (MFB) are the easiest and most prevalently used by small-sized and medium-sized systems. The ability of the media-filled beds to 1) firmly anchor plant roots, 2) facilitate solid filtration, and 3) effectively drain nutrient-rich water underscores their importance to aquaponics systems. Several media types are employed to the task, mostly locally available ones. Kamauddin, Ottoman [42] qualifies them into commercial ones and locally available alternatives. Many researchers have identified and carried out experiments on different MFB. For instance, gravel is the mostly mentioned [44-47]. In addition to gravel, other materials such as ceramist or pumice are used [20], Lightweight Expended Clay Aggregate (LECA), lava rock gravel and river gravel. Alternatives such as cocopeat and rice husk and a mixture of the two were studied by Kamauddin, Ottoman [42]. In addition, Oladimeji, Olufeagba [48] identified clay balls, sand, gravel, perlite, sphagnum peat moss, and coconut fiber. In addition, studied Palm kernel shells (PKS) and Periwinkle shells (PWS) can as well be used conventionally as growth media. This list is by no means exhaustive, but rather a small mention of a few of the many MFBs that are used/studied.

Mostly, two techniques are employed in media beds and include Flood and Drain (FAD) and Continuous Flow Technique (CFT). Under FAD, media beds are periodically flooded with nutrient-rich solution [49]. This decline and regrowth (flood and drain) is termed as ebb-and-flow (EAF) [48]. It is dried to allow certain products be delivered to the bacteria. In this regard, the system allows for nitrifying and heterotrophic bacteria to work in tandem and thus, does not require biofilters since the media allow nitrification. Sufficient oxygen is directly added to the plant root zone by use of a siphon. Another technique employed in aquaponic media beds is the Continuous Flow Technique (CFT) [41]. The plant root-zone is continually flooded with water; thus, additional oxygenation is required to maintain high DO levels to sustain the system. Regardless of the developments, clogging and oxygen deficit remain a major concern in MFB [27].

**Nutrient Film Technique**

Nutrient Film Technique hydroponic system takes the form of cultivation of plants in a long narrow plastic channel slanted at 1% slope [20] with the flow of a continuous thin layer of water, so-called film from which plants draw nutrients. This ensures plant roots remain moist while receiving adequate oxygen. Nutrient-rich solution from the fish tank flows over plant roots, they absorb these nutrients and grow strongly. According to Shreejana, Thapa [27], Small-sized plants with limited/low root growth are supported by this system. The author's argument is that strong root system block recirculating thus only small plants are preferred.

At present, NFT utilizes less labour whilst maintaining balance of water and energy in addition to investment cost; thus, regarded the most effective of the three systems of hydroponics. [37]. Further, it is important to take caution at plant selection as not most plants do well in this system. It is best advised to use NFT in coupled systems at small/semi-commercial systems and large-scale systems.

**Deep Water Culture (DWC)**

Deep water cultures are widely used in aquaponic systems. They are usually constructed tanks with a 30 cm depth [20] with continuous water flow. Plants roots are allowed to freely absorb nutrients from water [27]. Deep water culture subsystems are less labor-intensive and require less maintenance, therefore can have plants on a large area [37]. Whilst being fit to large-area-planting, they are often found on small scale or in domestic systems. In large commercial DWC systems, they happen to be labour intensive and at a high maintenance cost.

**Biofilter Establishment**

Biofilter establishment is a process involving the seeding of nitrifying bacteria cells or building up bacterial ecosystems during system setup in aquaponics [33]. This process can be done with or without the presence of fish. Using intact biofilter media (medium designed to house beneficial bacteria), the nitrification process can take up to two months to start [50], after which ammonia and nitrite levels should remain safe for fish.

**Water Quality**

Water quality management is critical for the growth and survival of fish [50]. Important parameters include water temperature, pH, dissolved oxygen (DO), and ammonia [51]. Huang, Lu [52] includes electrical conductivity (EC), oxidation-reduction potential (ORP) while Ruiz, Scicchitano [35] added nitrites and nitrate content. Other factors including, fish stocking density, feeding rate, fish growth rate and environmental conditions [51] influence system water quality. Whilst high stocking density increases productivity per unit volume, it can heavily deteriorate water quality. Stunted growth and reduced health can therefore result from a high oxygen consumption by heavy organic load. Reduced system productivity and a reduced feed conversion ratio (FCR) will arise from understocking.

According to Pattillo, Hager [39], water source properties such as the physical, chemical and biological composition impact the security of food, dietary dynamics and production. Uneaten feed, bacterial biomass, fish excrement [52], and flocculants [37] are the major origins of solid waste in aquaculture system. These solid wastes contribute to nutrients fit for plant growth. According to [53], nutrients from fish manure, decomposing fish feed and algae, can accumulate as contaminants, potentially increasing toxicity and deteriorating water quality, which is detrimental to the fish population. In addition, solid wastes increase the Biochemical oxygen demand (BOD) while reducing water quality together with oxygen avail-ability to both fish and plants.

Metabolism is the major ammonia source released through the fish gills into water. The ammonia is oxidized to nitrite and then to nitrate. Atique, Lindholm-Lehto [50] argues that nitrite conversion to nitrate is possible with a well-established biofilter. Even in low concentrations, ammonia and nitrite significantly affect the welfare and fish growth whilst nitrate rather, is safe to fish even at concentrations less than 100 mg/L. Nitrates can be seriously toxic at a high level that is 300–400 mg/L [51]. Also, long-term exposure to nitrite and total ammonia nitrogen (TAN) can be lethal for fish if these substances exceed acceptable concentrations. Ideally, their levels should be close to 0 mg/L and must remain below 1 mg/L. To wrap up, inability to maintain water quality parameters especially pH [53] and ammonia may jeopardize the aquaponic cycle. Also, effective solid waste removal is a pre-requisite in the design of fish rearing tanks.

**pH**

Plants and fish require different pH environments for optimal growth and health. Plant species require a pH range from 6.0 to 6.5 while fish grow best at a pH range of 6.5 to 9.0 [51]. Additionally, bacteria growth in the biofilter (best at 7.0–8.0) and thus, the pH range ideal for the whole aquaponic system is 6.0 – 8.0 [52]. Thus, a pH of 7.0 is suitable for fish, bacteria and plant.

## Benefits of Engaging in Aquaponics

Aquaponic food production systems are gaining attention particularly in urban settings and water stressed areas such as arid and semi-arid areas, for their potential to enhance food security. The system not only yield organic high-quality vegetables but also, is a source of sustainable proteins, addressing food security and water conservation problems [54].

- Water use efficiency (WUE): Aquaponics systems use 90-99% less water than traditional agriculture, crucial for areas with water scarcity (Ibrahim et al., 2023).
- Sustainability in production: Aquaponics systems prove to be ecologically friendly food production systems. Being closed-loop systems reduces the need for fertilizer and pesticide making them environmentally sustainable (Ahmed & Turchini, 2021). Also,

being recirculating aquaponics systems enables them to be a reliable food source (fish and vegetables) all year-round (Medina et al., 2016).

- Space optimization and local production: Aquaponic systems do not require large tracts of land. They can be set up in diverse environments indoors or outdoors for example, urban areas, rooftops, basements and unused spaces (FAHIM, 2021). Since food production is done locally, fresh supply is made available at a reduced cost, as transport costs are eliminated or minimized.

## CONCLUSIONS

Food insecurity is a growing global challenge, and aquaponics presents a promising solution. The interlinked nature of aquaponics allows for a sustainable relationship among fish, bacteria, and plants, where nutrients harmful to fish are beneficial for plants. The scalability of aquaponics systems relies on the size of the aquaculture setup and waste nutrient availability. Enhancing fish growth can be achieved by incorporating protein-rich food sources, such as black soldier fly larvae (BSFL), while maintaining optimal water quality is vital for system success. To establish aquaponics as a sustainable industry, there is a need to improve adoption processes, enhance entrepreneurial knowledge, and bridge the gaps between research and development. Collaborative efforts in East Africa can drive expansion and intensification of aquaculture and aquaponics, prioritizing equity, safety, and efficiency. Furthermore, optimizing system design to improve water quality management, water reuse efficiency, and nutrient recycling with minimal energy input is essential. Interdisciplinary partnerships among aquaculture, agriculture, and engineering sectors will enhance the cost-effectiveness of aquaponic systems, making them more accessible for farmers. Finally, localized training programs and feasibility studies should be implemented to ensure successful adoption and long-term sustainability of aquaponics technologies.

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