Frontiers in Sustainable Food Systems

TYPE Review
PUBLISHED 10 May 2023
DOI 10.3389/fsufs.2023.1161121

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OPEN ACCESS

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RECEIVED 07 February 2023
ACCEPTED 07 April 2023
PUBLISHED 10 May 2023

CITATION
Hasimuna OJ, Maulu S, Nawanzi K, Lundu B, Mphande J, Phiri CJ, Kikamba E, Siankwilimba E, Siavwapa S and Chibesa M (2023) Integrated agriculture-aquaculture as an alternative to improving small-scale fish production in Zambia. *Front. Sustain. Food Syst.* 7:1161121. doi: 10.3389/fsufs.2023.1161121

Integrated agriculture-aquaculture as an alternative to improving small-scale fish production in Zambia

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Aquaculture is a significant industry in food production, and its contribution to food and nutrition security is well acknowledged. Zambia's aquaculture production has continued to increase significantly, thus playing a key role in supplying animal protein sources for human consumption. However, recent estimates show that 75% of the national aquaculture production comes from large-scale commercial producers despite being by far the minority while the majority of small-scale producers contribute the remaining 25% of the total annual production. This low production by small-scale producers is attributed to insufficient financial resources, poor management and utilization of farm resources, lack of access to competitive markets, and more recently a changing climate. In this research, we examine the viability of integrated agriculture-aquaculture (IAA) as a means for small-scale producers in Zambia to boost their aquaculture output despite the numerous obstacles they face. In addition, the obstacles that could prevent small-scale farmers from adopting IAA have been emphasized. We conclude that IAA has the potential to dramatically boost small-scale aquaculture production in Zambia, but information and understanding must be improved to make it a more feasible alternative.

KEYWORDS

aquaculture, agriculture, integrated agriculture–aquaculture systems, fish farming, small-scale farmers, developing countries, Zambia

Introduction

Currently, fish and its products are the most widely traded food item on a global scale. Aquaculture has been the fastest-growing food production system during the past two decades (FAO, 2018; Muhala et al., 2021a; Maulu et al., 2021b; Ragasa et al., 2022). Diverse forms of aquaculture are essential to the development of the agricultural and farming sector. Aquaculture firms assist in alleviating poverty, mitigating production risks, and reducing food insecurity and malnutrition by providing food products with high nutritional content, generating revenue and employment, and enhancing farm sustainability (Little and Edwards, 2003; Finegold, 2009; Allison, 2011; Little et al., 2016). With the predicted growth of the world population, particularly in emerging nations, it is vital to promote technology that boosts the efficiency of food production systems. Integrated farming systems offer small-scale farmers a one-of-a-kind opportunity to improve resource use efficiency, production, and household income for the sake of food and nutritional security. Several integrated agricultural systems, such as agri-aquaculture, crop-livestock, crop-livestock-fish, and crop-poultry, have been observed among small-scale farmers in some regions, primarily in Asia (Edwards et al., 1988; Waktola et al., 2016).

The agric-aquaculture systems entail the assembly of components characterized by interactions and interdependence, thereby serving human needs in a manner that is compatible with the resource base and the environment (Little and Edwards, 2003). The technology can be implemented in a variety of ways: fish cultured together with livestock, crop, or a combination of the three in the same production system; or fish, livestock, and crop produced independently on the same farm, with wastes from each being utilized by the other, thereby providing a portion of low-cost, high-quality food, employment, and household incomes (Singh et al., 2021). Regardless of the form, synergy exists in an agro-aqua integrated farming system since the sum of the integrated impacts is higher than the sum of the individual effects. The output from one subsystem that would have otherwise been wasted becomes an input to the other subsystem, resulting in better efficiency and optimal usage of outputs of the desired goods from farm resources such as land, farm wastes, and water area under the farmer's control (Edwards et al., 1988; Nagoli et al., 2013; Maulu et al., 2019). Moreover, integration affords farmers the possibility to generate steady revenue from the various components of the farm system (Adugna and Goshu, 2010).

About 80 percent of Zambia's food supply is produced by small-scale farmers. These farmers play a crucial role in household food and nutrition security since a significant portion of their output ends up on the table. Nevertheless, small-scale producers are frequently the most susceptible to several obstacles, such as low financial capacity, lack of relevant technology, absence of market links, and unclear input supply. In addition, climate change continues to destabilize global sectors, with small-scale manufacturers predicted to be the most susceptible to its effects, which threaten their productivity, profitability, and sustainability (Maulu et al., 2021b; Muhala et al., 2021b; FAO, 2022). Small-scale farmers in Zambia primarily cultivate crops, while livestock farming is also prevalent in the majority of regions. The country's immense natural resources, including water (Nsonga and Simbotwe, 2014), land, and people, present a tremendous opportunity for food production to meet local and regional demand. Despite the vast potential of agri-aquaculture output in the country, little attention is paid to it. In Zambia, combinations of integrated fish farming systems to be examined for development include fish and crops, fish and livestock animals, fish mixed with poultry (mostly tilapia), terrestrial crops, ducks, pigs, and goats, to name a few (Maulu et al., 2019). The second system is the integration of crops, fish, and other animals, including, among others, tilapia, carp, pig, goat, sheep, chicken, duck, and fruits. Small-scale farmers and the nation as a whole are unaware of the overall benefits of these systems, and there are few studies on the potential and fundamental obstacles that these farmers face. The objectives of this investigation are therefore:

(a) Reviewing existing studies on the status of the integrated system of Agric-aquaculture practiced by small-scale farmers; (b) Elaborating on its relevance to satisfy nutritional, economic, and food security in the country; and (c) Analyzing some opportunities and challenges faced by smallholder farmers in Zambia.

Integrated aquaculture agriculture production systems

Integration of aquaculture and agriculture is one of the most effective strategies for enhancing the productivity of small-scale farming in rural areas with limited resources, and it should be encouraged (Yuan et al., 2019). When a farmer diversifies production by combining livestock, fish, tree crops, and vegetables, farm production is steady and efficient in terms of resource consumption and environmental conservation (Lightfoot and Gonzalves, 2001). Integrated farming has been practiced for centuries, primarily in Asia, with rice-fish culture being the earliest approach employed (Halwart and Gupta, 2004). In addition, various countries around the world have recognized the IAA systems' numerous advantages. Despite the numerous favorable results recorded, the prevalence of the technique in Africa has remained relatively low (Table 1).

Over time, the technology utilized in integrated systems around the world has progressed, but the underlying concepts of the systems have remained constant. According to Anschell and Salamanca (2021), typical semi-intensive IAA systems for freshwater include rice-fish farming, integrated fish and animal farming, and integrated garden, pond, and livestock farming. This section examines the three common IAA systems, from which numerous other systems in use around the world are derived.

Aquaculture-crop farming

This system thrives due to the mutual benefit and symbiotic relationship between the crop and fish. Rice and fish farming is the most prevalent aquaculture-crop integration system worldwide, and its benefits have been the subject of numerous research (Table 1). Nile tilapia (*Oreochromis niloticus*) has been the predominant aquaculture species in these systems, with a few reports of African catfish (*Clarias gariepinus*; Miller et al., 2006; Ugwumba, 2010; Lemma et al., 2014; Mohammed et al., 2015; Trinh et al., 2021). Integration of rice and fish farming has been found to greatly increase the productivity of both fish and rice farming systems. In this system, rice typically functions as a filter for potentially hazardous compounds such as nitrates and phosphates, which are necessary for the growth of rice plants (Lemma et al., 2014). In this way, rice fields provide a favorable environment and habitat for fish and other aquatic animals to flourish, while fish contribute to nutrient cycling by feeding on invertebrates and other organic particles created in these flooded rice fields. Rice-fish farming frequently decreases the need for pesticides, hence preserving biodiversity, and it also allows the adoption of native fish species (Soto, 2009). The use of native or indigenous species of fish is

TABLE 1 A summary of findings from studies that have investigated the benefits of integrated agriculture-aquaculture systems (IAA)

Pond size	Component of integration			Major findings reported	References
	Fish spps	Livestock spps	Veg. variety		
2 × 200 m² ponds	Common car (*Cyprinus carpio*)	Pecking ducks	Tomato Spinach Lettuce	- Ducks gained an average of 2.6 kg in 55 days - Fish production surpassed 19.5 tonnes/hectare/year. Ten batches of Peking ducks at a density of 2,500 ducks per hectare of water over a period of 6 months, with an average yield of 32,184 tons per hectare each year - FCR mean of 3.05	Prinsloo and Schoonbee (1987)
20 m²	Redbreast tilapia (*Coptodon rendalli*)	Chicken cattle pig manure		- After 84 days, *C. rendalli* treated with chicken dung were substantially larger and had better net yearly yields than those treated with cattle manure, pig manure, or no manure	Prinsloo et al. (1999) and Kang'ombe et al. (2006)
				- Significantly increased levels of chlorophyll and zooplankton were seen in waters treated with chicken dung	Dey et al. (2006)
	Nile tilapia (*Oreochromis niloticus*)	White leghorn egg-laying chicken		- Increased net present value of the project which enabled its funding by the local national bank	Mohammed et al. (2015)
2 × 42 m² ponds	Nile tilapia, Common carp And African catfish (*Clarias gariepinus*)	Red layers chicken, goats' manure and Rhode Island		- Poultry manure enhanced primary productivity by increasing zooplankton abundance – rotifers >10 individuals/m increased - Fish (*O. niloticus* and *C. carpio*) grown in poultry-manured ponds had significantly better growth performance	Endebu et al. (2016)
150 m²	Nile tilapia	Chicken type; White leghorn	*Red bombey Onion*, Vikima cabbage variety (*ROMA VFN tomato variety*)	- The net profit of the integrated farming significantly improved per given ha	Getu et al. (2017)
150 m²	Nile tilapia, Common carp And African catfish	Pullets of *Lohman brown* chicken	Onion (*Allium cepa*) "Adama red" variety	- The total profit from the integrated system increased to 12,030 ETB compared to what farmers would get from the same plot of land with single systems, estimated at 1300ETB - Additionally, the productivity of fish, eggs, and vegetables (onions) grew dramatically (8 tons of fish/ha/year, 233 eggs/hen/year, 10,800 kg onion/ha/year)	Daba et al. (2017)
200 m²	Nile tilapia	Poultry cattle	Tomato (Cochoro variety) and onion (Bombay red)	- Water physico-chemical properties were kept within the required range for Nile tilapia growth - Nitrate and total phosphorus concentrations were greater in IAA ponds - Comparatively greater soil organic carbon and organic matter levels in IAA ponds than in non-IAA ponds - In IAA plots, both the quantity and size of tomato fruits were increased - The IAA plots produced more onions than the control plots - Expense and income analysis revealed that the integration of vegetable growing using fishpond water alone was more profitable than the standard technique of vegetable cultivation involving the use of fertilizer	Waktola et al. (2016)

(Continued)

TABLE 1 (Continued)

Pond size	Component of integration			Major findings reported	References
	Fish spps	Livestock spps	Veg. variety		
72 m^2	Nile tilapia	Rhode Island Red chicken	(*Allium cepa,* Bombay red onion), Malkashola (*Lycopersicon esculentum Tomato*), and (*Brassica oleracea-Cabbage*)	- Cabbage production for the IAA increased to 221 from 98 q/ha for non-IAA systems - Bombay red onion production grew from 165 to 371 q/ha under the IAA - The IAA raised tomato yield to 458 q/ha, compared to 171 q/ha for the non-IAA system - The presence of poultry dung and wastes in the water boosted primary production in the ponds, and the water was afterwards used as fertilizer for horticulture output	Lemma (2017)
				- An estimated 23–35% decrease in nutrient depletion rates was observed in IAA systems as compared to non-IAA systems - Agricultural production increased by 2–26%, while overall farm food production increased by 22–70%	Muendo et al. (2011)
	African catfish		Yam Maize Cassava	- The net return on investment was 0.5 times greater for crop-fish integrated systems than for crop and fish production systems alone	Ugwumba (2010)
	Nile tilapia		Rice	- There was a 10% rise in rice yield and a more than 50 percent gain in revenue due to rice and fish sales	Miller et al. (2006)
542	Nile tilapia		Rice	- In the paddy-fish plots, dissolved nutrients such as nitrate and phosphate fell from their baseline levels - A decrease in soil nitrogen because of an increase in phosphorus levels - Control plots had greater plankton and benthic populations than paddy-fish plots - The paddy-fish plot produces more rice than the control plots	Lemma et al. (2014)
400	Nile tilapia		Rice	- The production of paddy grain and plant biomass was greater in the paddy-fish integrated plots (112.3 kg) than in the control plots (57.8 kg) (95.65 kg)	Lemma et al. (2015)
				- The number of fish harvested increased; 218 fish of marketable size were caught, with an average length and weight of 17.5 cm and 193.15 g, respectively	
350	Nile tilapia		Rice	- The number of fish and rice harvested through the integrated rice-fish system was enhanced	Mohammed et al. (2015)
915	Nile tilapia		Rice	- The average fish production and mean recovery rate of tilapia were improved, while the total rice yield was reduced in the IAA system compared with the non-IAA system	Rasowo and Auma (2006)

encouraged in this system to avoid problems associated with the introduction of invasive exotic species. Different rice field designs are created and adjusted to allow deeper regions for fish to develop without flooding the rice plants and to restrict rice field escape and access (Halwart and Gupta, 2004).

Aquaculture-livestock farming

Integrated fish farming with animal livestock is a key player in enhancing higher fish production (Gebru, 2021; Mulokozi et al., 2021). This technique incorporates both animal husbandry and fish culture (Shrestha and Pant, 2012; Mulokozi et al., 2021). The integrated animal/fish culture system seeks to recycle all unconsumed organic leftovers and natural organic manure to boost crop, animal, and fish output (Colin, 2018; Kinkela et al., 2019; Gebru, 2021; Mulokozi et al., 2021). Biological and chemical processes such as photosynthesis, respiration, nitrogen fixation, ammonification, denitrification, and decomposition recycle nutrients and minerals in the pond ecosystem (Mukherjee et al., 1992). In turn, these interactions boost the pond's primary productivity, which enhances the availability of natural, nutrient-rich, living food. This system can accommodate a variety of species, including ducks, chickens, pigs, and ruminants such as sheep, goats, and cattle (Table 1). Animal wastes like cow manure, chicken and pig droppings, and goat and sheep pellets are utilized to increase the production of food organisms for fish, hence reducing the cost of expensive feeds and fertilizers (Kapur, 1984; Shrestha and Pant, 2012; Kinkela et al., 2019; Mulokozi et al., 2021; Ibrahim et al., 2023). These systems are predominantly utilized in many Asian nations, including China, Malaysia, Indonesia, and the Philippines, but have also been documented in several African nations, including South Africa, Malawi, Ethiopia, and Kenya (Table 1).

Aquaculture-vegetable farming

This is the integration of the residential property, the garden, the animals, and the fishpond. Almost the bulk of the labor is often performed by family members (Luu, 2021). In this approach, fish pond water is utilized to water vegetables such as onions, tomatoes, and cabbage, hence reducing the farmer's need to buy chemical fertilizers (Luu, 2021). In exchange, vegetable wastes can be utilized as fish food, reducing the need for small-scale farmers to purchase pricey, specially-formulated diets (Maulu et al., 2019). Annually or at the end of each fish growth cycle, pond muck is scraped and used to fertilize vegetable fields and fruit trees; animal excrement is utilized to fertilize plants. This agricultural method is common in Vietnam and is practiced in both uplands and lowlands. The integration of fish and vegetable farming is designed for small-scale deployment, allowing farmers to recycle the majority of agricultural and home wastes inside the system using materials and equipment already on the farm (Anschell and Salamanca, 2021). Such an integrated system allows a farmer to use the pond for fish culture and the pond dykes for growing vegetables (Luu, 2021).

Traditionally, the water gathered in the *de facto* pond is used for domestic reasons and to cultivate aquatic vegetation for animal consumption. The majority of fertilizers are applied to field crops, particularly rice, but as the importance of fish production rises, more is redirected there. The pond is built close to the house so that domestic and cooking wastes can be drained into it. Due to the requirement to fertilize the pond water with organic manure, this method is typically employed in conjunction with other farming systems, such as poultry (Prinsloo and Schoonbee, 1987; Prinsloo et al., 1999; Tugie et al., 2017).

Integrated aquaculture-agriculture systems practiced in Zambia

The IAA system is most prevalent among a small number of smallholder farmers in Zambia, even though it is underdeveloped and poorly utilized. Fish-and-duck, fish-and-crops (mostly vegetables), and fish-and-swine are the most prevalent IAA systems in the nation (Mudenda, 2009). In 2005, the Food and Agriculture Organization (FAO, 2005) claimed that Zambia has more than 6,000 small-scale fish farmers with a total of more than 13,000 ponds, in addition to 15 commercial fish farmers. More than 50% of these small-scale farmers do not entirely depend on fish culture but rather, combine it with either one or more other agricultural activities. In certain households, farmers combine different sub-systems for instance fish together with crops, pigs, birds, goats, and cattle among others. Nsonga and Imelda (2016) in a reference manual for enhancing fish output in the Northern Province of Zambia reported that the small-scale farmers following their training in IAA are practicing the integration of fish with either vegetable (gardening) or poultry (village/local chicken). In certain parts of the country, fish is also integrated with goats, pigs or cattle. Among the Zambian small-scale farmers, the choice of the sub-system to integrate with fish depends on their economic status, social and religious beliefs, technical know-how and environmental factors.

A farmer may combine multiple farming systems based on various reasons and comparative advantages he or she thinks will derive. It could also be due to individual situations or available resources but ultimately the farmer wants to enhance the productivity of the farm in both or among participating systems in order to grow their profits (Nsonga and Imelda, 2016; Maulu et al., 2019). The practice of IAA has more positive benefits to the farmer than negative ones and these include reducing the wastage of resources as they are recycled (Diver and Rinehart, 2010). For instance, the nutrient-rich fish pond water and silt, and other agricultural residues would be considered as wastes. This is more productive per labor and/or land unit (Dey et al., 2006; Mulokozi et al., 2021). In the IAA system, crops will provide food for consumption by humans, fish and livestock; manure and nutrients for the crops and fish ponds are supplied by livestock nutrient-rich water and silt from ponds can be utilized as fertilizer for crops (Prein, 2002; Ndagi et al., 2020; Anschell and Salamanca, 2021). Using the wastes like pig manure and vegetable wastes at the farm, small-scale farmers can have an opportunity of producing quality protein food such as insect fly larvae (e.g., black soldier fly) to feed their fish stock (Nuov et al., 1995; Mafwila et al., 2017; Maulu et al., 2022).

As aquaculture production costs continue to rise due to the rising cost of fishmeal, insects are seen as a more sustainable alternative protein source to replace conventional feedstuffs due to sustainability issues (Maulu et al., 2022). Insects have a high nutritional value and studies show that they have 42–63.3% crude protein on a dry basis (Freccia et al., 2020; Gasco et al., 2020; Alfiko et al., 2022). Furthermore, insects contain a well-balanced essential amino-acids profile like that of fishmeal, and as considerable amounts of lipids between 10% and 30%, vitamins, such as vitamin B12, and some bio-available minerals like iron and zinc (Alegbeleye et al., 2012; Gasco et al., 2020; Maulu et al., 2022). This eventually brings about diversification and a reduction in the cost of production. When the IAA system is well-practiced, it can produce more products and the farmer is likely to rely on fewer external resources for output. Given that the yield is bad from one subsystem (e.g., crops) in a particular year or season, another subsystem will take its place which could be livestock or fish stock subsystems (Nsonga and Imelda, 2016). Therefore, Dey et al. (2010), Béné et al. (2015), and Corner et al. (2020) concluded that there is an optimal exploitation of resources on the farm, including water, agricultural residues, and land, which can promote food security and the production of nourishing food throughout the year.

In addition, Mwaijande and Lugendo (2015) observed that the combination of agriculture and aquaculture offers small-scale farmers in rural locations with limited access to input and output markets an opportunity to increase farm production. Other favorable interactions between farm components in the IAA system include increased land utilization and decreased labor needs, which improve farm management and create an appealing pension plan for the farmer

(Nsonga and Imelda, 2016). Furthermore, Dey et al. (2006) and Diver and Rinehart (2010) concur that the practice of IAA results in increased household income and consumption, which will lead to food security and healthier households among farmers. The main objective of practicing IAA is to have an economic waste-free production (Ahmed et al., 2014; Corner et al., 2020). In the setting of IAA systems, the amount of waste is reduced and pollution is controlled because of less accumulation of animal manure and less utilization of chemical fertilizers and pesticides thus the soil, water and air are less polluted.

Just like any other enterprise, IAA has its strength, weaknesses, opportunities and threats (SWOT; Figure 1) which needs to be taken into consideration.

Enabling environment and policies for aquaculture development

As envisioned in Vision 2030 and the 7th and 8th National Development Plans, Zambia's aquaculture industry may act as a driver of economic growth and poverty reduction. However, the biggest challenge is that the country has not been able to fully leverage its potential over the years. Zambia has the potential to develop aquaculture because of its abundant water resources and several potential indigenous fish species suitable for culture. For example, the country boasts of having 40% of Southern Africa's water resources and good agroecological zones that are good for fish farming (Simuunza, 2022). It also has strong business ties with fish markets in its neighbors, such as the Democratic Republic of the Congo, Botswana, Angola, Namibia, Tanzania, Zimbabwe, Mozambique, and Malawi, as these markets allow back-and-forth trade relationships. Despite these opportunities, the country still lags due to many challenges, some of which are listed below:

Zambia national fisheries and aquaculture growth strategy

Zambia lacks a national fisheries and aquaculture development policy to steer the trajectory of this value chain's development in the country. The sector is governed by many broad policies, such as the Fisheries and Livestock National Policies and Implementation Plan,

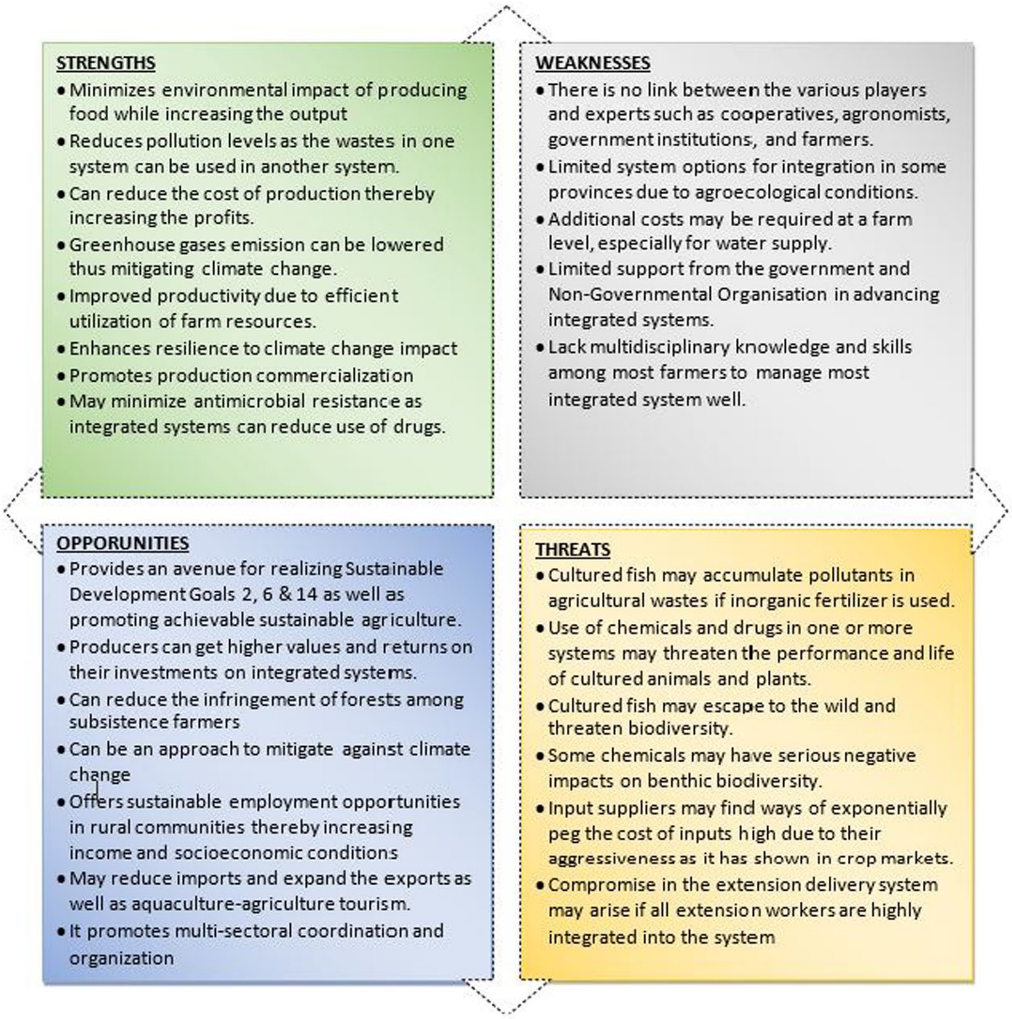

FIGURE 1
SWOT analysis for IAA.

which have a big impact on both how the policies are put into action and the financial resources allocated for the fish and livestock producers. Before the livestock and fisheries policy was put in place, the sector relied on the Second National Agricultural Policy (SNAP, 2016) whose program puts more emphasis on crop production and cattle. In addition, the fisheries and aquaculture industries do not have a complete regulatory framework. Rather, they are managed by a legislative framework comprised of various regulations that regulate various aspects of cattle-based development. This makes it difficult for the government to regulate and coordinate the nation's fisheries and aquaculture industries. A proposed policy will aid in elucidating how the fisheries and aquaculture sector may develop sustainably through the adoption of suitable technology.

Additionally, this measure will equalize the aquaculture segment weight in terms of national budget allocation and implementation, which is currently being overshadowed by other politically motivated and supported departments like the Department of Veterinary Services (DVS). Therefore, Zambia's aquaculture could benefit from better coordination and organization through a clear national policy, thanks to a proposed Fisheries and Aquaculture National Development Policy that will be linked to a plan for implementation that will include full-fledged activities like marketing and developing entrepreneurs. This is anticipated to promote the expansion and growth of aquaculture integration in Zambia.

Private partnerships and support

Given the numerous problems facing the aquaculture business in Zambia, government and private sector activities must be coordinated. Stakeholder partnerships are used to solve industry-based challenges that a standalone partner may not be willing to invest in. Partnership platforms engage in dialogue to address industry challenges. They mobilize resources to supplement government efforts. Table 2 shows the private partners working in the aquaculture market space. It also shows the partnerships with government institutions and the disclosed and undisclosed funds allocated to each commercial relationship. The African Development Bank Group (AfDB) provided the most funding for aquaculture through the Ministry of Fisheries and livestock on the Zambia Enterprise Development Project (ZAEDP) worth $50.89 million, followed by the Lake Tanganyika Development Project (LTDP): fisheries management, fish stock assessment, and piloting cage culture projects worth $29.62 million, for a total of $77.51 million.

It is against this background that the government should continue working on strengthening private-public partnership instruments to foster dialogue, which is a prerequisite to the growth of the aquaculture market among smallholder farmers. We are aware that the government, through the Ministry of Finance and National Planning, has launched this plan. On the other hand, a localized private-public partnership forum for fisheries and aquaculture would focus on specific sector goals rather than a broad one (Table 2).

NAIP II (2022) reports that to improve aquaculture production there are more than 23 privately owned and managed fish hatcheries and eight fish feed companies producing and supplying feeds to fish farmers mainly commercial fish farmers along the line of rail. The number of feed-producing companies is still small causing a rise in fish feed costs which the government needs to step up to offer business incentives that will promote high production of cheaper and accessible year-round feed by all the farmers.

According to Mario et al. (2018) and Otoo et al. (2016), policies, plans, and regulations; trade agreements; institutional setups and strength; access to finance and subsidies; technology; matching partners and land availability; and local infrastructure all have an impact on businesses and can aid or hinder their sustainability and scalability, which is beneficial for all stakeholders in the aquaculture and fisheries value chains. Most significantly, knowledge sharing would allow everyone in the sector to collaborate more and utilize new technologies.

Climate-smart policy

Several investigations have been carried out to show that aquaculture and fisheries are vulnerable to the impact of climate change (Musumali et al., 2009; Maulu et al., 2021b; Muhala et al., 2021b). The factor that the sector relies on water for its main input is enough to deduce that water quality and quantities get affected by drought and rise

TABLE 2 Summary of aquaculture-related projects implemented in Zambia by cooperating partners.

Aquaculture and fisheries development partners	Program/project title	Project status	Implementing agency	Budget (Million USD)
AfDB	Zambia Aquaculture Enterprise Development Project (ZAEDP)	Active	Ministry of Fisheries and Livestock	50.89
BMZ-GIZ	Sustainable Fisheries and Aquaculture Programme (Fish for Food Security) Zambia	Active	Ministry of Fisheries and Livestock/ DOF	Undefined
AfDB	Lake Tanganyika Development Project (LTDP): fisheries management, fish stock assessment, and piloting cage culture	Active	Ministry of Fisheries and Livestock/ DOF	29.62
European Union (EU)	Lake Tanganyika Fisheries Management (LATAFIMA) for Zambia, Tanzania, Burundi, and DR Congo.	Active	Riparian Countries	2
European Union (EU)	Lake Tanganyika Water Management Project on Water Quality (Zambia, Tanzania, Burundi, and DR Congo)	Active	Riparian Countries	6
FAO/EU/Fish 4CP	Value Chain on Small Pelagic (Kapenta)	Active	Ministry of Fisheries and Livestock/FAO	Undefined
World Bank	Transformation Landscapes for Resilience and Development (TRALARD)	Active	Ministry of Fisheries and Livestock	Undefined

Source: National Agricultural Investment Plan draft (NAIP II) (2022).

in temperatures. In recent times, studies have shown that water quality compromises the quality of fish produced and bred in terms of diseases and other mineral deposits (Hasimuna et al., 2020b; Nong et al., 2021; Hasimuna et al., 2021b; Khalil et al., 2022). Management of water resources for present and future use should be a call for every fish farmer, and this calls for climate-smart management strategies that need to be adhered to. Climate-smart aquaculture calls for using fish species that are environmentally, socially, and economically friendly while attaining sustainability for future and present benefits (Zougmoré et al., 2016). Working with the Ministry of Green Economy and Environment, Land and Natural Resources, the Department of Fisheries which is in charge of aquaculture should aim to train fish farmers on how to preserve the natural resources that are responsible for the rain cycle and reduce water and air pollution which could be detrimental to the growth of the sector (Maulu et al., 2021b). Béné et al. (2016), Genschick et al. (2018), and Maulu et al. (2021c) found that irresponsible management of water resources and fish genetics leads to poor production and productivity. Therefore, technologies that attempt to reuse water resources within a circular economy and also utilize clean energy have been shown to be climate-smart technologies that mitigate climate change and improve people's livelihoods (Shikuku et al., 2019; Balasubramanian et al., 2021; Siankwilimba et al., 2021, 2022).

Challenges faced by farmers using integrated aquaculture-agriculture systems

Although IAA could be a profitable and sustainable approach to fish production, there are critical challenges that could affect the majority of the farmers if not well practiced. When preparing to improve or double the production of the farm, the farmer must also be equipped to double the responsibility. It is essential to thoroughly understand what the farmer is about to venture into and acquire appropriate technical know-how of every subsystem. In IAA, it is cardinal not to combine the subsystems that contradict each other, for instance, the type of plants (crops) to be grown should not be harmful or poisonous to birds or animals (fish and livestock). Lack of proper management and care could also bring more harm than good which could be a downfall of the farm. Below are some challenges that farmers can encounter when practicing IAA:

Inadequate technical ability to manage both fish and crops/livestock

A large number of small-scale farmers practicing IAA lack the technical capabilities to handle both the fish and livestock or crops in terms of proper nutrition, disease control and general husbandry and this greatly affects their productivity (Respikius et al., 2020). This can be attributed to ineffective extension services (Maulu et al., 2021a), as well as a lack of access to knowledge and the required technologies.

Lack of access to information

Integrating aquaculture and agriculture aims to maximize the favorable interactions or synergies between the constituents. This occurs when a subsystem's output becomes an input to another subsystem in an integrated farming system (Edwards, 1998). This, in turn, increases the efficiency with which desired products are manufactured. Most farmers do not seem to understand the working principles of IAA systems and end up designing systems that are not very efficient. This can be linked to a lack of information about IAA systems partly because of ineffective extension services both by government and private institutions (Edwards, 1998; Maulu et al., 2021a).

Lack of security of land tenure

Most of the farmers practicing IAA do not formally own the land on which they do this type of fish farming. Aquaculture has proven to be unprofitable for rural poor people who lack secure access to land, either because they are landless or because they possess land under insecure tenancies. The lack of land tenure security discourages long-term investment (FAO, 2014). This is one of the reasons that deter small-scale fish farmers from investing significantly in their businesses.

Input provisions and market development

Market and Input provision and market development

Farmers will only engage in IAA if it is economically viable. This may depend on the availability of inputs (seed, fertilizer, and feed) and local and regional market conditions, which dictate the price of fish and the incentive to produce. In turn, market circumstances are connected to physical access in the form of infrastructure and economic access in the form of consumers' purchasing power. Due to the limited and dispersed availability of inputs such as feed and seed, costs are high, which may hinder the development of aquaculture, particularly in rural areas. The markets in rural areas are not uniform. Numerous consumer groups exist, each with its own purchasing power and consumption habits. This hinders the adoption of cutting-edge technology and ideas intended to improve rural residents' standard of living.

Aquaculture species cultured in Zambia

The majority of Zambia's populace has adopted five tilapia species, one foreign and four indigenous (Maulu et al., 2019; Hasimuna et al., 2020a; Siavwapa et al., 2022). These are the Nile tilapia (*Oreochromis niloticus*), three-spotted Tilapia (*Oreochromis andersonii*), Green-headed Tilapia (*Oreochromis macrochir*), Red-breasted Tilapia (*Coptodon rendalli*), and Tanganyika tilapia (*Oreochromis Tanganicae*) species (Maulu et al., 2019; Hasimuna et al., 2020a, 2021a). However, *O. niloticus* farming is only permitted in some sections of the country, such as south of the Itezhi-Tezhi dam on the Kafue River; in other areas, a licence from the Director of Fisheries is required as prescribed in the Fisheries Act number 12 of 2011 (Hasimuna et al., 2020b). This exotic fish is mostly cultivated in Southern Zambia's Lake Kariba in cages controlled by large-scale firms such as Yalelo and Lake Harvest (Hasimuna et al., 2019), as well as a significant number of cooperatives financed by the Zambia Aquaculture Enterprise Development Project (ZAEDP). Furthermore, *O. tanganicae* is cultivated mostly in the Northern Province, especially areas with streams leading to Lake Tanganyika where it is an endemic species. *O. macrochir* is cultured in Luapula provinces, Copperbelt, Central, Lusaka, Southern, Western and Muchinga Provinces as this species is found in most rivers and lakes except in Lake Tanganyika.

C. rendalli is farmed in every province due to its wide distribution across the country while *O. andersonii* is grown throughout the southern half of the country, particularly in the Eastern, Lusaka, Central, Copperbelt, Southern, Northwestern, and Western Provinces. But it must be stressed that *O. andersonii* is the species which is adopted by the Department of Fisheries as a species of culture in the country except for the northern part where it is not endemic (Bbole et al., 2018).

Aquaculture–agriculture

Small-scale farmers in Zambia frequently combine fish and ducks, fish and pigs, and fish and crops (vegetables), with fish and pig being the most prevalent combination. It has been determined that integrating *O. andersonii*, *O. niloticus*, and *O. macrochir* with pigs is technically and economically feasible (L'Heureux, 1985; Gopalakrishnan, 1988). However, among the three native fish species, only *O. andersonii* has successfully proved the technical and economic viability to be cultivated (Gopalakrishnan, 1988).

Potential species of culture

Apart from the species mentioned above being the main ones cultured in the country, there are a number of potential species for aquaculture that may be used in aquaculture–agriculture integration. Notable indigenous species which are potential candidates for aquaculture include *Oreochromis mortimeri* (Trewavas, 1966), *Labeo altivelis* (Peters, 1852), *Clarias gariepinus* (Burchell, 1822), *Heterobranchus longifilis* (Valenciennes, 1840), but surprisingly the viability of these species in the aquaculture industry have not been investigated fully (Mudenda, 2009). In addition, *Cyprinus carpio* (Linnaeus, 1758), *Procambarus clarkii* (Girard, 1852) and *Auchenoglanis occidentalis* (Valenciennes, 1840) have demonstrated remarkable promise for aquaculture in the country.

Cyprinus carpio

Several researchers have investigated the food and feeding behaviors of the common carp in its native habitat in order to comprehend its feeding behavior (Hana and Manal, 1988; Magalhaes, 1993; Adámek et al., 2003; Ali et al., 2010; Rahman et al., 2010). This fish has exhibited a great deal of variety in its eating behavior, which has been related to changes in its position during specific times and for specific feeding goals (Ali et al., 2010). The presence of benthic invertebrates, detritus, and mud throughout the year in its digestive tract demonstrates that the species eats at the bottom of the body of water (Magalhaes, 1993; Ali et al., 2010; Dadebo et al., 2015). *C. carpio* is an omnivore fish in terms of its diet. Detritus, insects, and macrophytes are the primary food sources, whereas phytoplankton, ostracods, zooplankton, and gastropods are of lesser importance.

Clarias gariepinus and *Heterobranchus longifilis*

The African catfish (*Clarias gariepinus*) and the Vundu (*Heterobranchus longifilis*) graze on a variety of foods based on their environment, and in Zambia, these are widely spread at the confluence of the Zambezi and Kafue Rivers (Hecht and Lublinkhof, 1985). These species are opportunistic and omnivorous feeders, consuming a wide variety of foods, including algae, macrophytes, zooplankton, zooplankton, insects, fish prey, detritus, amphibians, and sand grains (Dadebo, 2000; Abera and Guteta, 2007; Dadebo, 2009; Admasu and Debessa, 2015). In addition, their dietary composition may vary based on the season and geographical circumstances of their surroundings, as well as the fish's size, maturity, and habitat differences (Houlihan et al., 2001; Kamal et al., 2010). During the dry season, insects, zooplankton, and fish prey are the favored dietary sources. During the rainy season, detritus, zooplankton, insects, and macrophytes are primarily devoured, whereas the tiniest fish consume more insects than their larger counterparts, who primarily consume zooplankton and smaller prey fish.

Oreochromis mortimeri

Kariba Tilapia *or Oreochromis mortimeri* (Trewavas, 1966) is an indigenous species found in Zambia whose natural habitat ranges from Cahora Bassa Gorge to Victoria Falls (Marshall, 2011; Zengeya et al., 2015). The feeding behavior of this fish species is omnivorous feeding on diets such as algae, especially diatoms, detritus, plant material, insects, and zooplankton (Skelton, 2012). This feeding behavior is similar to that of *O. niloticus* a commercially farmed species. Comparative research on the two species indicated that the types of food consumed were comparable and that there was no significant variation in eating behavior (Chifamba, 2019). Furthermore, it was reported that this species of fish breeds throughout the year and its breeding is triggered by temperature and rainfall. The ability of *O. mortimeri* to breed throughout the year is one feature which makes it a good candidate for aquaculture species as it can lead to a continuous supply of fingerling throughout the year (Chifamba, 2019). This species has great potential for commercial aquaculture in Zambia and there is an urgent need to utilize the various biological factors that favor its commercial farming as well as a conservation strategy.

Labeo altivelis

This fish species is also known as the Rednose labeo, and similar to other Labeo species, it is herbivorous. This species feeds on the substratum's algal development, grazing on algae and aufwuchs from rocks (Skelton, 2012). Besides diatoms and plant fibers, they consume Bdelloid-type rotifers and cladocerans. In addition, this type of fish possesses a unique feeding adaptation consisting of a sucker-like mouth with folded lips and a sharpened edge (Skelton, 2012). In addition, their intestines are exceedingly lengthy and tightly coiled, and they do not have a separate foregut or stomach (Reid, 1985).

Auchenoglanis occidentalis

The Giraffe catfish (*Auchenoglanis occidentalis*) locally known as Mbowa is an omnivorous fish which is common in large rivers and lakes in the lakes northern Zambia (e.g., Chambeshi and Luapula Rivers and Lake Bangweulu, Mweru and Tanganyika). This species and its lineage are reported to be widely distributed in most African Lake such as Lake Turkana, and Lake Chad and it is also found in rivers including the Chambeshi in Zambia, Anambra River in Nigeria, White Nile and Niger Rivers among others (Okwiri et al., 2018). According to Chukwuemeka et al. (2019), Ikongbeh et al. (2014), and

Abobi et al. (2019), *A. occidentalis* primarily feeds on insects, insect larvae, protozoans, phytoplankton, sand particles, crustaceans, and fish scales in the wild, and it tends to prey on insects and smaller fish species within its reach. This species prefers shallow waters with muddy bottoms from an ecological standpoint. The male is the only guardian of the eggs and the nesting, and it spends a great deal of time fanning its pectoral fins and swaying its posterior body to prevent oxygen deprivation (Ochi et al., 2001).

Recommendations

It is evident that the practice of IAA could have numerous benefits and potentially improve the efficiency of food production systems. Therefore, we recommend that further studies should focus on the urgent need to investigate the viability of culturing most of the potential local species. There is also a need to study the breeding and nutrition of *A. occidentalis* under aquaculture conditions. It is necessary to encourage the integration of agriculture and aquaculture, particularly among small-scale fish farmers to capitalize on the existing synergies. However, achieving this will require improved extension services to provide knowledge to the producers. Researchers must investigate the optimization of production from IAA systems (i.e., determining the right ratios and size of animals and fish per unit area); there is a need to promote the use of aquaponics as they are perfect IAA systems that can easily be practiced by people living in urban areas where land is scarce; we also recommend studies on various components of the aquaponics system, e.g., use of indigenous vegetables, and fish species as well as the use of baked clay instead of lava rock as a growing medium. More research on the technical efficiency and economic viability of integrated fish farming systems is required if farmers are to reap some benefit. Furthermore, we recommend that a study must be done to document the various types of IAA that are being employed in the country.

Conclusion

Integrated aquaculture is founded on the notion that "there is no waste" and that waste is a misdirected resource that may be repurposed as a valuable component of another product. The fundamental concepts of integrated agriculture are the utilization of the synergistic effects of interdependent farm activities and conservation, which includes the complete utilization of farm wastes to fulfil the tenets of the circular economy. It is assumed that all system components would benefit from such a combination. However, the primary beneficiaries are fish, which utilize livestock and agricultural wastes as direct or indirect food sources.

Author contributions

SM came up with the concept, outlined the objectives, and conducted a thorough analysis of the paper. OH aided in the definition of the objectives, coordinated the production of the text, and contributed to the composition of the book. MC and ES evaluated the manuscript critically and contributed significantly to it. The manuscript was written by KN, BL, JM, CP, EK, and SS. All authors contributed to the article and approved the submitted version.

Funding

This research was funded by the Copperbelt University Africa Centre of Excellence for Sustainable Mining (CBU ACESM Project No. 5803-ZM).

Acknowledgments

The authors would like to thank all the institutions they represent for collaborating toward a common aim.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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