Feature Article

Small-scale Black Soldier Fly-fish farming: a model with socioeconomic benefits

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Implications

- While previous research has focused on Black Soldier Fly production on a large industrial scale, our research focuses on economic and social advantages for local economies and small-holder farmers.
- Our findings indicate that Black Soldier Fly provides an important alternative protein source that can be locally produced by small- or medium-scale farmers, and can be combined on farms with fish production.
- Our data show that Black Soldier Fly can provide an economically viable feed component for small-holder farmers
- These results build on existing evidence that a circular approach to insect-fish farming is a viable option that empowers farmers and can contribute to developing the local community through a local value-chain approach in the Global South.

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Introduction

Over the past 20 years, aquaculture has become more integrated into the global food system, with a rapid growth in production and major transformations in feed ingredients, production technologies, farm management, and value chains (Naylor et al., 2021). This growth in production as well as consumption relates almost entirely to countries in the Global South, where almost all (98%) of the world's smallholder fish farmers are located, mostly in rural areas (FAO, 2020). Smallholder fish producers operate across production intensities to cultivate a variety of species, relying primarily on their own labor and relatively small areas of land (Marschke and Wilkings, 2014). In many communities, fish farming has been practiced as a tradition (Bhujel, 2013), and in general, small-scale aquaculture is a peasant activity managed by families, with few employees or operated by a small community (FAO, 2015). Such medium- and smallholder fish farmers are found in countries on different continents, most of them belonging to the Global South where poverty rates are high and high-quality nutrition is needed. Environmental impact of production, scarcity and increasing prices of raw ingredients for fish feed are among the most important challenges for this sector (Tran et al., 2022a), because feed is the largest single cost item for fish production, accounting for 60–70% of the total costs, including smallholder fish farmers (van Huis, 2013).

Therefore, to reduce costs, the exploration of new opportunities is needed. Circular economy (**CE**) may provide these opportunities and may bring innovation into the aquaculture sector (Thorarinsdottir et al., 2011). CE is not a new concept among smallholder farmers because it has been practiced in circular agriculture and agroecology for a long time (Barragan-Fonseca et al., 2022a). However, since aquaculture in the Global South faces similar challenges and opportunities, CE should be implemented by aiming for social equality, promoting a radical change in the creation of wealth and the production, distribution, and consumption of goods and services, and recovering culture (Betancourt Morales and Zartha Sossa, 2020).

Several studies (van Huis, 2013; Dicke, 2018; Chia et al., 2019; Madau et al., 2020; Tran et al., 2022a), have shown how insects may be used to close the loop when referring to serious environmental and social problems that global agriculture is facing. Agriculture is responsible for more than 70% of the water footprint (Pfister and Bayer, 2014) and food production is responsible for more than 30% of overall greenhouse gas emissions from all sources globally (Smetana et al., 2019), aquaculture having a lower impact than livestock (Jiang et al., 2022). Insects provide innovative solutions as an alternative protein source for animal nutrition (van Huis, 2013; Smetana et al., 2019; Tran et al., 2022b), a source to add value and improving health, natural behavior and quality of animals (Foysal et al., 2019; Rawski et al., 2021), and a valuable tool for the transition to a bio-based CE in the agri-food sector, which aims to close the loop of agroproduction through recycling and reuse (Madau et al., 2020). The use of insects as component of fish feed has been recently covered by various reviews focussing on production performance of aquaculture species (Nogales-Merida et al., 2019; Tran et al., 2022b). These reviews indicate that insects such as the Black Soldier Fly (**BSF**, *Hermetia illucens*) are promising components of feed for various fish species including salmonids (Weththasinghe et al., 2022) and tilapia (*Oreochromis niloticus*) (Tippayadara et al., 2021). The BSF can be used in innovations that provide environmental, social, and economical improvements of the performance of agri-food systems (Onsongo et al., 2018; Chia et al., 2019), not only by large-scale, but also by medium- and smallholder farmers (Barragan-Fonseca et al., 2022a). Some initiatives using insects by medium- and smallholder farmers have shown that insects can support several of the Sustainable Development Goals (**SDGs**), focusing on food security, sustainable agriculture, combating climate change, and promoting stability and peace (Dicke, 2018; Chia et al., 2019; Barragán-Fonseca et al., 2020b; Madau et al., 2020).

Currently, it is not clear to what extent circular agriculture, based on producing insects for feed, can foster sustainable livelihoods for peasant families within the fish-producing economy. We recently proposed a theoretical model: Agroecological Insect-Fish Farming (**AIFF**), as a new opportunity to develop a CE by implementing practices such as those related to the agroecological field for crop production and the use of insects, especially the BSF (Barragan-Fonseca et al., 2022a). Here, we present the economic impact of the transition from an industrialized linear economy to a smallholder farmer circular aquaculture, and analyze the feasibility and the conditions under which AIFF might be developed by small- and medium-scale peasant farmers in the Global South based on a case study in Colombia.

Agroecological Insect-Fish Farming

To assess the direct impact of the inclusion of BSF larvae (**BSFL**) as a protein source to decrease the costs related to fish feed, smallholder farmers in Icononzo (Tolima, Colombia) engaged in setting up such novel circular approach of producing tilapia fish (*O. niloticus*) fed with BSFL as an alternative component of commercial feed. These farmers were ex-guerrilla members who had put down their arms in the peace process and started fish production within the frame of the project "Insects for Peace" (**I4P**) (Barragán-Fonseca et al., 2020b). These farmers replaced between 25% and 38% of the traditional tilapia feed with sundried BSFL, fish were fed five times a day during the fingerling phase, three times a day during the juvenile phase and twice a day during the growing and final phase. Fish exposed to traditional production and those exposed to the AIFF model were fed with the same regime and frequency. Italcol´s brand fish feed was used as the commercial feed. Based on this case and information collected from fish and insect producers in Colombia, a CE model called "Agroecological Insect-Fish Farming" (AIFF) was developed (Barragan-Fonseca et al., 2022a). This model conceptualizes the synergies between CE and agroecology approaches as a new opportunity to develop a CE by implementing practices such as the use of insects, especially BSF, producing high value proteins and organic fertilizer (insect waste streams—**IWS**) while empowering small- and medium-holder fish farmers' economies by raising profitability (Figure 1).

Income Generation and Financial Projections

The economic impact and financial projections of partially replacing commercial feed ingredients with BSFL based on a circular approach, used data obtained from insect farmers and fish farmers in Colombia and the case study of Icononzo (Barragan-Fonseca et al., 2022a). This relates to an analysis of the economic impact of the transition to a peasant circular aquaculture to support peasant economy and small- and medium-scale farmers in Latin America according to the AIFF model. To gain insight into the economic effects of using BSF as protein source in fish feed, the income of farmers when including AIFF (circular production) should be compared to a traditional linear fish production (non-AIFF). When producing fish fed with BSF as protein source, two production systems may be used: 1) producing BSF and fish in two different places, as was done in Icononzo or 2) by executing both production systems at the same physical location or production center. *Fish costs:* We used a two-cost structure for fish production. One is based on Icononzo´s case study (AIFF model) and the other is a cost structure without including BSF as fish feed (non-AIFF model). In this way, with BSF and fish cost structures we have a starting point to analyze other market scenarios.

BSF and Fish Costs Structure

In the case of BSF production, the costs incurred by having the BSF production unit and the fish production unit in different production centers (being BSF and fish production of the same owner) or in the same production center are presented. The fish cost structure is subdivided into two, the

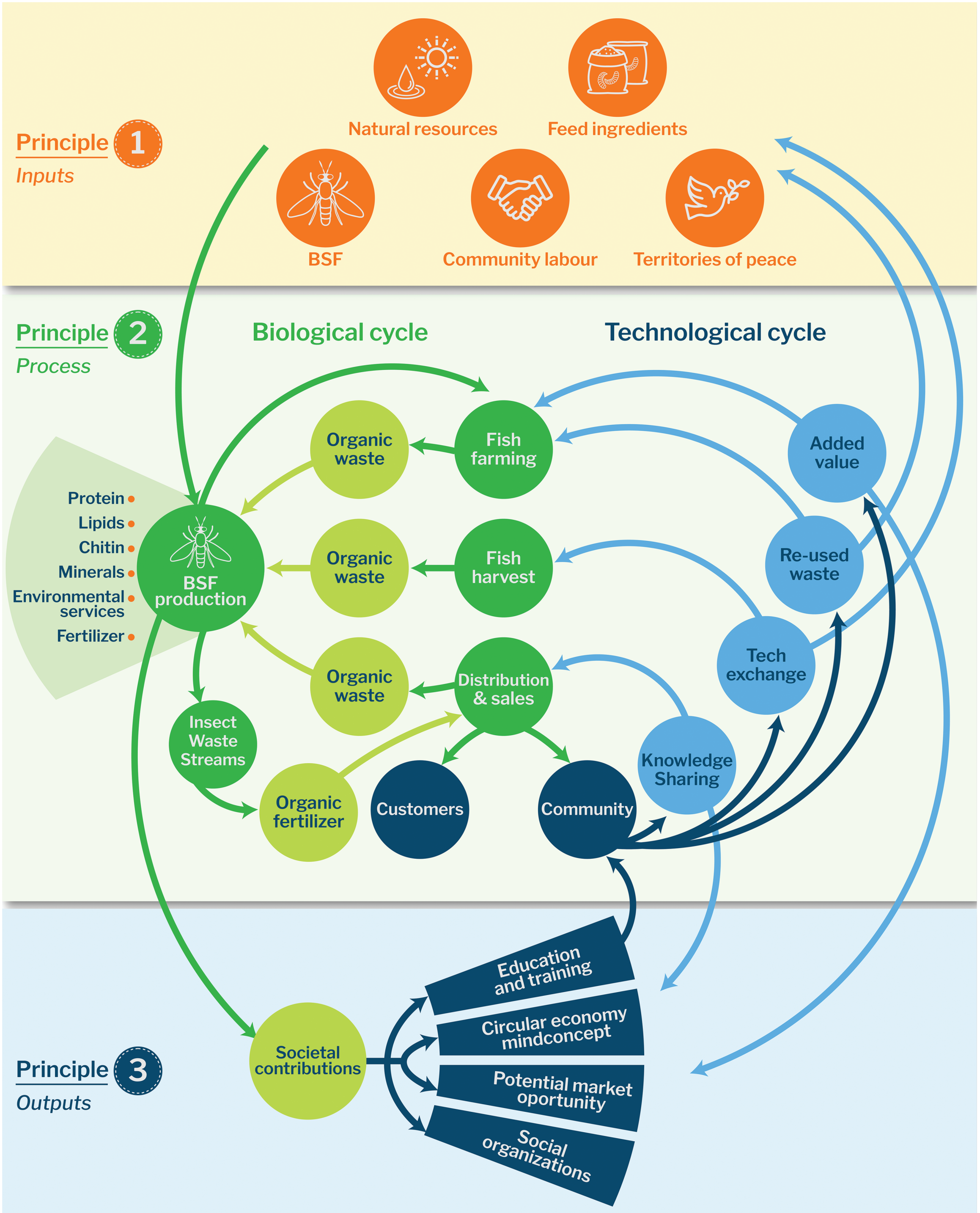

Figure 1. General description of the Agroecological Insect-Fish Farming model—AIFF (adapted from Barragan-Fonseca et al., 2022a). This model conceptualizes the synergies between CE and agroecology approaches as a new opportunity to develop a circular economy by implementing practices such as the use of insects, especially BSF, producing high value proteins and organic fertilizer (insect waste streams—IWS) while empowering small- and medium-holder fish farmers' economies by raising profitability. More than an economy, this is a concept based on the next three principles: Principle 1—Inputs: Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows. Principle 2—Processes: Optimize resource yields by circulating production components and materials in both technical and biological cycles. Principle 3—Outputs: Foster system effectiveness by revealing and phasing out negative externalities.

first structure refers to a fish production system that applies a circular economy production through the AIFF model, which uses BSFL as feed component for fish, thus reducing the use of conventional fish feed and, in turn, their respective total costs. Table 1 presents BSF and fish production costs of Icononzo′s case study. All costs and revenues are expressed for an AIFF with 7,000 fish (2.1 tons of total biomass were produced with an average weight of 300 g/tilapia) and 1,400 kg of

BSF production capacity during a period of 4 months, which represents the duration of the tilapia production cycle. AIFF and non-AIFF production methods had similar responses of the tilapia performance, both had an average Feed Conversion Ratio of 1.3 and mortality of 30% where the tilapia reached the weight target (±300g). *BSFL production*: is done through vertically stacking trays in a facility. Larvae were fed on organic waste streams from community waste and from Icononzo´s local market. Average production of BSF: 15 kg of organic waste (wet weight) to produce ~2 kg (wet weight) of harvested BSFL, or ~0.6 kg of sundried BSFL, and 4.5 kg of frass (wet weight). *Tilapia production*: The facilities for tilapia production consisted of three tanks where the tilapia fingerlings were distributed according to the water volume availability. Tanks 1, 2, and 3 had a capacity of 2,500, 2,500, and 2,000 animals respectively. Each tank had constant water replacement and air flow with a net that covers and protects the fish from natural predators.

Table 1 presents the costs related to both BSF and fish production systems. There are variables such as organic waste transport that only relate to the production of BSF. Land rent, marketing, telephone/internet, and organic waste transport represent those costs of BSF production that, when BSF and fish are produced on the same farm, should not be included for BSF production because they are included in the costs of fish production.

Market Scenarios

We use two variables to propose four different market scenarios, Icononzo´s case being one of them. Variable A: BSF production and fish production are in the same or in different production

Table 1. Structure of BSF production for a 4-month fish production cycle in a different production center or in the same location as fish production, and fish production costs per fish-production cycle (4 months) with AIFF and non-AIFF model

Costs[a]		BSF production: Different production centers[b] (BSF Cost A) (€)	BSF production: Same production center (BSF Cost B) (€)	Fish production: AIFF model (with BSF)[b] (€)	Fish production: Non-AIFF model (without BSF) (€)
Fixed	Labor payment[c]	400	400	500	500
Fixed	Consultation	100	100	60	60
Fixed	Land rent[d]	<u>140</u>	<u>0</u>	200	200
Fixed	Marketing[d]	<u>20</u>	<u>0</u>	80	80
Fixed	Telephone/internet[d]	<u>60</u>	<u>0</u>	60	60
Fixed	Bank payment	200	200	320	320
Fixed	Organic waste transport[d]	<u>80</u>	<u>0</u>	N/A	N/A
Variable	Electricity	16	16	N/A	N/A
Variable	Water	16	16	N/A	N/A
Fixed	Machinery depreciation	89	89	N/A	N/A
Fixed	Machinery maintenance	60	60	N/A	N/A
Variable	Materials and equipment	40	40	N/A	N/A
Variable	Raw materials	80	80	N/A	N/A
Variable	Distribution	N/A	N/A	200	200
Variable	Animal feed	N/A	N/A	<u>1,500</u>	<u>2,700</u>
Fixed	Services	N/A	N/A	20	20
Fixed	Innovation	N/A	N/A	50	50
Fixed	BSF cost[e]	N/A	N/A	<u>1,301</u>	0
Total fixed costs		1,149	849	2,591	1,290
Total variable costs		152	152	1,700	2,900
Total costs		1,301	1,001	4,291	4,190

Underlined figures represent costs that differ between scenarios. All costs in euro's based on Colombian conditions. N/A, not applicable.

[a]Cost structure includes: *Fixed costs* that do not depend on production volume; they are constant in time; *Variable costs* which depend on the production volume. The sum of the fixed and variable costs equals *Total costs*.

[b]Icononzo market scenario.

[c]The type of peasant family economy applied in this context recognizes working conditions where the producer families exchange working hours with neighboring farms and family members, which is why it is optional to pay wages in cash or in working hours. For cost accounting purposes, it is calculated that an average worker dedicates 3 to 4 h of work per day in each of the two activities, with an average payment of 1.2 Euros for each hour of work (higher than the payment of 1 h of work stipulated by the legal minimum wage in force in Colombia in 2023).

[d]Costs that are reduced in BSF's cost structure by incorporating both production systems (BSF and fish) within the same production center.

[e] This cost relates to both cost structures, because variation in the costs of BSF production affects the cost structure of fish production, because for circular fish production (AIFF), the production of BSF is previously incurred.

centers or farms. Variable B: The sales price of fish produced in a linear economy (non-AIFF) is the same or different from that produced in a circular economy (AIFF). We selected these variables based on the actual situation in Iconozo for small and medium-scale fish farmers. A difference in fish prices for the circular and linear production systems was selected because there is a tendency toward the consumption of food with better nutritional quality and benefit for human health due to the management and type of complementary feeding used (Feldmann and Hamm, 2015). Both variables combined generate four different market scenarios. The market scenario of Icononzo's BSF production is based on the following principles: different sales prices (€1.00/ fish produced in a circular system [AIFF] vs. €0.71/fish produced in a linear system [non-AIFF]) and production systems in different production centers. After analyzing Icononzo's market scenario (hereafter Scenario 3) we assessed the consequences of changing variables A and B. The prices were obtained by the local sales market experience. In the local market, traditional tilapia price was € 0.71/fish, compared with a different market price of € 1.00/fish, based on the Porter's five tendency force: threat of substitution, where the customers prefer a more sustainable product on their dish (from farm to fork).

Table 2 presents four market scenarios based on the two variables: Variable A—BSF and fish produced in the same or in different production centers, and Variable B—fish produced in a circular and linear production system are sold at the same or different prices. Variable A only affects the cost structure of the AIFF model, reducing or maintaining costs; while variable B only affects the income of the non-AIFF model (linear economy). Therefore, there are four market scenarios each with two cost structures: under the AIFF model and the non-AIFF model, and we can calculate the profit differences between fish production with AIFF and non-AIFF models.

In scenarios 1 and 3, higher fixed costs are generated by the obligation to pay rent for the land, marketing, telephone, and transport of organic waste to the BSF farm, which are unavoidable when the BSF production plant is located in a different location than the fish production plant. Hence, in this first case, the difference between operating profits when producing AIFF compared to non-AIFF is 200 euros. In Scenario 2, the costs are lower than in Scenario 1, because here the advantage is that both BSF and fish production systems are in the same place, which reduces AIFF fixed costs by €300 for each production cycle: total fixed costs are €2,291 for AIFF in the same production center and €2,591 for AIFF in different production centers. Therefore, fixed costs like marketing, internet and telephone, land rent, and organic waste transport are not present. As a result, the difference between Operating Profit between

Table 2. Fish production with (AIFF) and without (non-AIFF) the use of Black Soldier Fly as feed component

Tilapia production (7,000 fish/4 months)	Scenario 1 Different production centers (A) and same prices (B) AIFF	 Non-AIFF	Scenario 2 Same production centers (A) and same prices (B) AIFF	 Non-AIFF	Scenario 3[a] Different production centers (A) and different prices (B) AIFF	 Non-AIFF	Scenario 4 Same production centers (A) and different prices (B) AIFF	 Non-AIFF
Sales price per individual fish	1	1	1	1	1	0.71	1	0.71
Fish production revenues	7,000	7,000	7,000	7,000	7,000	5,000	7,000	5,000
By-products revenues	500	200	500	200	500	200	500	200
Total revenues	**7,500**	**7,200**	**7,500**	**7,200**	**7,500**	**5,200**	**7,500**	**5,200**
Variable costs	1,700	2,900	1,700	2,900	1,700	2,900	1,700	2,900
Fixed costs	2,591	1,290	2,291	1,290	2,591	1,290	2,291	1,290
Total costs	**4,291**	**4,190**	**3,991**	**4,190**	**4,291**	**4,190**	**3,991**	**4,190**
Break-even point (quantities)[b]	3,422	2,202	3,025	2,202	3,422	4,362	3,025	4,362
Operating profit	**3,209**	**3,010**	**3,509**	**3,010**	**3,209**	**1,010**	**3,509**	**1,010**
Difference in operating profit for a four-month production cycle	199		499		2,199		2,499	

All costs in euro's.

Costs, revenues, and break-even point for four different market scenarios per fish-production cycle (4 months) including and excluding the AIFF model based on two variables (A and B).

Fish production revenues are derived directly from the total sales of fish (at the farm gate), and by-products' revenues are the income obtained from the sales of the by-products generated by the fish production. In the case of AIFF production, by-product revenues refer to the fertilizers obtained after harvesting the BSF (frass, i.e., non-consumed substrate, insect manure, and moulting skins), which are sold to neighboring crop farmers (Barragán-Fonseca et al., 2022a); in the case of non-AIFF fish production by-products' revenues (leftover fish parts) refer to the surplus fish marketable in the area. Break-even point refers to the level of sales (in quantities sold) where the revenues obtained cover both fixed and variable costs, and that from these values profits start to be generated. Operating profit is the difference between Total Revenues and Total Costs, being the profits obtained from the total sale of fish, after discounting the costs. Difference in Operating Profit for a 4-month production cycle represents the difference between the fish production systems (AIFF and Non-AIFF) of each of the cases, for a period of 4 months, a value that will allow be projected to some future periods, as we will see later.

Bold values indicate the main values, that are calculated on the basis of several lines above the value.

[a]Icononzo´s market scenario.

[b]*Break-even point* represents the point at which total revenues equal total costs. At this point there is no profit or loss. In the table they are presented as the number of units sold.

producing with AIFF and without AIFF increases from €200 to €500. Scenarios 3 and 4 differ considerably in income from scenarios 1 and 2, mainly generated by the differentiation of sales prices of fish (€0.71 and €1 for non-AIFF and AIFF, respectively). The differences in break-even point between AIFF and non-AIFF models, regardless of scenario, show that the AIFF model presents better income to the farmer, with the best market scenarios being 3 and 4.

Income Generation When Adopting AIFF

In the Icononzo case (Scenario 3), where BSF production is not located at the fish farm, the final price of fish produced with BSF as feed ingredient (€1.00/fish) at the farm gate is higher than without including BSF (€0.71/fish). This result is achieved because local consumers are willing to pay more for fish locally produced through an AIFF model by ex-combatants, based on the experience with local consumers in Icononzo. However, this principle may or may not be fulfilled in other communities because it depends on the preferences of consumers that may change over time, depending on their situation and economic stability. If their economic situation deteriorates, consumers may prefer a lower price over quality. This is why it is important to recognize other possible sources of economic sustainability, which do not fundamentally depend on the sales price of fish produced through AIFF compared to the non-AIFF model. For instance, when there is a cost structure where both production systems (fish and BSF) are on the same land or within the same production center, the BSF production cost is lower than when both production systems are in different places. The AIFF model provides opportunities to yield up to 44% higher revenues, and to reduce the costs up to 23%.

The AIFF and non-AIFF approaches in scenarios 3 and 4 differ considerably in income compared with the two approaches in scenarios 1 and 2, mainly caused by the differentiation of sales prices of fish (€0.71 and €1.00). It is a strong assumption considering economic crises that farmers (local consumers) have in relation to the commercialization of their products or basic services access. Reduced income of these local fish consumers may make them decide to choose cheaper fish. However, the wish for healthy and environmentally friendly food encourages consumers to make decisions where quality prevails over price, which is why they decide to opt for fish produced through a circular-economy approach. The differences in break-even point between AIFF and non-AIFF models, regardless of scenario, show that the AIFF model presents better income (Operating profit) to the farmer, with the best market scenarios being 3 and 4.

In relation to the break-even point, in Scenario 1 and Scenario 2, the main difference between the production systems with AIFF and Non-AIFF is that feeding fish from BSF production requires higher fixed costs and lower variable costs due to the constant production of BSF which is required, unlike the case of opting for the traditional production system where costs depend to a large extent on the purchase of concentrate that varies according to the level of production. In scenarios 3 and 4, the main difference in break-even point of both production systems is due to the price difference, which is ahead of the production system with BSF where comparatively a point of zero losses can be reached sooner than in the case of producing by the non-AIFF model. In all cases, the constant sales level of 7,000 fish would allow reaching and exceeding the break-even point in the first period of application.

Additional to that, as mentioned before, the AIFF model has the possibility of generating a by-product in the transformation process: organic fertilizer from BSF frass, which can be used for crops (Poveda, 2021; Barragan-Fonseca et al., 2022b) and can improve profits for farmers as was reported, for example, Kenya (Beesigamukama et al., 2022; Tanga et al., 2022). This fertilizer is generated without increasing the costs of fish production and also increases the family income by supplying the inputs that a peasant family needs to increase the quality of other products that they grow on their farm. With the sale of these, an increase in the family income is estimated at 500 euros. Therefore, the AIFF model may produce a return rate up to 45% considering that total sales are €7,500 and the costs associated to its production are around 50% of it.

However, there are some risks to consider for the proposed market scenarios. For instance, there may be a previous unproductive stage typical of the application of the BSF production system, which may vary among production centers which could affect each of the models contemplated because in this time there would not be income. On the other hand, the aforementioned market models do not consider monetary inflation fluctuations or eventual cases of increases in the prices of inputs in the local area, which is why it is important when evaluating scenarios that require more detail to consider the need to add to the final sale price the inflationary percentage that allows projections more faithful to reality. Thus, the evaluation of more precise AIFF scenarios is needed according to different geographic and socio-economic factors in the AIFF implementation.

Income Differences in the Short, Medium, and Long-term

The income projections are based on the calculation of the operating profits of both production systems (AIFF and non-AIFF models) presented in each of the four scenarios analyzed. The projections are made for the short (2 years), medium (5 years), and long-term (10 years), where each year of production contains three production cycles of fish, each lasting 4 months. The difference in accumulated earnings is bigger in the AIFF model than in the non-AIFF model in all four scenarios and in the long-term projection. The income differences (Difference Operating Profit for 4 months) in the short, medium, and long-term between AIFF and non-AIFF models of the four scenarios (Figure 2) shows that even in the least profitable scenario (Scenario 1) the income based on AIFF is higher than for the non-AIFF situation. Even with this small income difference and starting from a moderately profitable scenario (Scenario 1), when projecting the income over several years into the future after 10 years the income difference between both systems is €5,970.

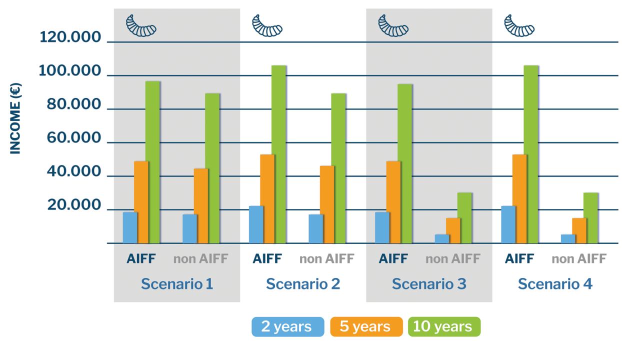

Figure 2. Income of farmers using the AIFF and non-AIFF models in four market scenarios (see Table 2 for details on the four scenarios). The income differences (Difference Operating Profit for 4 months) are based on the calculation of the operating profits of both production systems (AIFF and non-AIFF models) presented in each of the four scenarios analysed. The projections are made in the short (2 years), medium (5 years), and long term (10 years), where each year of production contains three production cycles of fish. The income differences between AIFF and non-AIFF model of the four scenarios shows that the income based on AIFF is higher than for the non-AIFF situation.

Enabling Aspects to Promote AIFF

The transition to a sustainable organic waste management with insects should establish the best ways to put AIFF into practice in a local scenario. Experience shows that this transition cannot be merely technological. By nature, it is multidimensional and requires active participation by different actors through an inter- and transdisciplinary approach (Chia et al., 2019; Barragán-Fonseca et al., 2020a,b). Here, we analyze success and risk factors and we present a strengths, weaknesses, opportunities, and threats (**SWOT**) analysis of an AIFF model to identify enabling aspects to implement AIFF schemes in developing countries. For this SWOT analysis all observations and inferences suggested are based on the previously documented literature, Icononzo´s experience, insect production with small-holder farmers in Kenya (Chia et al., 2019), workshops with ex-combatant communities in Colombia (Barragán-Fonseca et al., 2020a), and private and public institutions in Colombia regarding the use of insects as feed (Dicke et al., 2020), and the authors' experience.

SWOT analysis for AIFF

Pros and cons of the use of insect farming in aquaculture in countries of the Global South are assessed through a SWOT analysis to identify key factors that could support or impair the development of AIFF in those countries as protein source for the aquaculture sector. In Table 3 we present the SWOT of implementing the AIFF model in the Global South.

Aspects to Promote AIFF in Countries of the Global South

The transition from linear to circular aquaculture by smallholder farmers in low-income countries requires a local analysis of the value chain and the actors (stakeholders) involved, that can potentially intervene so that the system is successful and that it adjusts to specific conditions at each place. A value chain of the AIFF model consists of four main segments: 1) The substrate segment, aimed at providing organic waste for insects, 2) the insect segment, aimed at production of insects, 3) the feed production segment, aimed at products resulting in resources for fish feed, and 4) the fish production, valorization, and consumption segment (Dicke et al., 2020). Each segment has specific stakeholders. We propose four main aspects to promote the AIFF model in developing countries: 1) socio-economic, 2) technical, 3) communication and marketing, 4) education, research, and innovation, and 5) policy-making and legislation.

Socio-economic aspects

Peasant family farming has traditionally been more focused on self-consumption of food and other goods to satisfy their own needs and on the selling of surpluses rather than on cash crops (van der Ploeg, 2008). Entrepreneurial farming in the Global South usually engages small- and middle-scale farmers in business models addressed to big, national, international, or highly profitable markets, that normally require high inputs of innovation, capital, knowledge, and skills and a fruitful economic environment which, in some developing countries, are currently difficult to achieve. Value chains and business models promoted through public policies and cooperation programs in the Global South usually fail due to the lack of understanding of the local economic environment. Most of the time, the local economic environment lacks public support and infrastructure, is embedded in criminal activities, involves high levels of land concentration and is managed by violent power structures, among others. In this context, promoting peasant and family farming within the AIFF model, would be a more realistic approach to provide sustainable livelihoods to peasants, increasing local knowledge, safeguarding culture, conserving nature, feeding themselves, and being autonomous, among other benefits (van der Ploeg, 2014).

As a corollary of the former aspect, we propose to concentrate efforts, at a starting stage, in building local markets and zero-level channels, where farmers can sell fish products directly to final customers. Further efforts to achieve more complex markets and added value to innovative products can be made in contexts where the support of the state or international cooperation is well organized and concentrated on peasant and small- and middle-scale farming where there are more certainties regarding possible and realistic markets. Cooperatives also can serve to support the AIFF model by reducing costs of agricultural inputs, negotiating better prices in the market, sharing knowledge and supporting strategies of production among others (Gibson-Graham et al., 2013). Therefore, AIFF initiatives could be developed by combining extended and niche markets. It means selling large quantities of fish produced at the lowest possible cost and producing and selling a lower amount of fish but with a higher added value (e.g., healthy and agroecological food concept) in specific niche markets.

Table 3. Strengths, weaknesses, opportunities, and threats (SWOT) analysis of implementing AIFF model in the Global South

Strengths	Weaknesses
•Favorable climatic conditions for insect rearing in low-income countries in the Global South •High biomass production in these regions generates a wide availability of substrates and organic waste as input for insect production •Easy access to cheap and local materials to build infrastructure •Support from academia in some of the countries (e.g., Colombia and Kenya) •Constant growth of fish-production sector •Relevant indigenous and traditional knowledge available among small-scale and peasant farmers	•Limited insect production at present •Lack of specific regulations •Lack of processing technology for insect farming •Gaps of knowledge in insect production: rearing, processing, animal feed formulation •Lack of access to funding sources, especially for small- farmers •In many cases, lack of governmental support •Poor transportation infrastructure •Lack of access to technical, information technology (IT) and scientific knowledge in rural areas •Depeasantization of some regions in the Global South due to violence, dispossession of land, internal migration and so on, that reduce farmers´ willingness to work as farmers.
Opportunities	**Threats**
•Improvement or generation of income for small-scale farmers •Improving livelihood and food security of peasant communities •Development of novel animal production systems with high added value •High willingness of peasant farmers to be involved in insect farming and innovative business •For war-torn countries: peace construction scenario in the territories which could allow the engagement of communities in innovative productive initiatives. •Current focus of public policy on CE and agroecology. •Current inflation in the Global South economies that leads to excessive costs of commercial feed which may be reduced by insects as components of fish feed •High costs associated to other technologies oriented to implement CE alternatives and reducing organic waste in comparison with those which include insects. •Growing market for healthy food and sustainable consumption. •Reduced costs of fish production would be attractive for local consumers in villages and small cities where sustainable consumption is minimal or nonexistent. •Future economic crisis and climate change perspectives demands circularity and agroecological approaches in order to reduce fish production costs, improve peasant livelihoods and provide food for the poor.	•Social and cultural stigma hampering the use of insects •Social resistance to replace traditional fish feed •Excess of legislative regulations in the global north addressed to undermine artisanal ways of production and in favor of intensive and industrial production or that would not be adjusted to local realities •In some countries: Existing war and illegal activities in rural areas with gangster-like control over territories •High possibility of monopoly of the insect farming sector. •Aggressive economic structure in some countries for entrepreneurial farming •Consumer food safety

Technical aspects

In the case of BSFL as feed component for sustainable fish production, the main concern is the variability in bioconversion due to the changeability of the substrate used to feed BSFL (Onsongo et al., 2018). Several studies show that insect meal can be used to substitute fish meal in fish diets and can be used to as novel aquafeed component for sustainable aquaculture (Tippayadara et al., 2021). The use of live or sun-dried larvae may provide both a nutritional advantage and cheaper protein source for freshwater and tropical fish found in the Global South, which are mostly herbivorous/omnivorous (Henry et al., 2015), such as for tilapia that does not have such high protein requirements. The use of a mixture of different protein sources (different insects, with plant-derived proteins or with other animal proteins) could reduce the potential nutrient deficiencies and better balance the amino acid profiles of aquafeeds incorporating insect meal (Henry et al., 2015) and insect meals may also be mixed with other protein sources to improve tilapia performance (Mohd Din et al., 2012) to reduce lack of full diet balancing. Experiences in the Global South show that the implementation of integrated agri-aquaculture systems and aquaponic systems might allow smallholder fish farmers to develop local adaptations and generate synergies (Barragan-Fonseca et al., 2022a).

Communication and marketing

Considering the labor-intensive aspect of the production of healthy and agroecologically produced food (including healthy fish) which is usually more expensive than highly industrialized food, a strong communicational effort is needed to show the advantages of consuming AIFF products and healthy and agroecological food. Such advantages are not only about the promotion of healthy behavior, but also about the provision of fair income to peasant farmers and the protection of nature. Additionally, because sustainable consumption of food requires high levels of mental construal (van Dam, 2016) which problematizes making decisions in favor of health, environmental protection, fair income to producers, there is an additional challenge in terms of communication that strengthens current efforts in promoting and improving sustainable and responsible consumer behavior.

Education, research, and innovation

Small farmers need to be aware of the advantages of circular economy practices. This can be done by sharing knowledge and recovering traditional peasant practices, on the use of side-products from their farms to reduce costs and to profit from part of these side-products. On the other hand, the adoption of agroecological practices also implies the conscientization of circularity among farmers. Because many countries in the Global South are located in the tropics, this provides a comparative advantage compared to countries that have seasons because it has greater biodiversity, such as insect species and species of tropical forages that can be included in diets of these insect species (Espitia-Buitrago et al., 2021). New insect species that may be amenable to large-scale rearing and new feed alternatives and substrates for them are important to explore as it represents an additional advantage of rearing these species in the Global South. Finally, if we aim to achieve the "zero hunger" SDG, consumers with low incomes should be able to afford access to food from AIFF producers. Thus, efforts addressed to reduce production costs and to connect producers with consumers would serve to produce healthy fish at the lowest production cost and with a fair profit for peasant farmers.

Policy-making and legislation

Future attempts to regulate AIFF practices must consider specific contexts. While in some countries—e.g., with a strong conflict around land ownership—regulation would help to support small- and medium-scale farmers practicing AIFF initiatives, in others it would reduce their possibilities. On the one hand regulation might ensure food quality and good practices of production, but on the other hand, it can serve to strengthen the concentration of land in a few hands and to reduce the adaptability of its practice by peasant communities who will be at a disadvantage with those who can invest in the achievement of an existing regulation. The involvement of the public sector, if possible, could be concentrated on redistribution of land, the improvement of current infrastructure to reduce costs of transportation of agricultural inputs and food products, the provision of basic services, training in entrepreneurship to build capacities, and the support in creating innovation and more markets among others.

Conclusion

Aquaculture rapidly gains importance in providing nutritious food to the growing human population. Small- and medium-scale farmers are important fish producers in the Global South. Yet, they face high costs of imported feeds, especially related to soy and fishmeal as protein sources. Current aquaculture especially follows a linear production. Insects such as BSF provide an important alternative protein source that can be locally produced by small- or medium-scale farmers. Moreover, BSF production can be combined on farms with fish production. This leads to a circular approach to fish production where residual streams can be used to improve the sustainability of fish farming. In addition to the extra income using insects, helping communities become independent from external inputs should be a priority. In this way, the AIFF model promotes the independence of the community from external and increasingly expensive inputs, a CE concept that can be expanded to other livestock as has been seen in different countries in the Global South (Chia et al., 2019). Here we show, based upon experiences in Colombia, that a circular approach to fish farming is a viable option that empowers farmers and can contribute to developing the local community through a local value-chain approach. We identified several aspects that deserve to be developed to support this sustainable aquaculture approach that contributes to the livelihood of small- and medium-scale farmers.

Authors' Contributions

All authors significantly contributed to the manuscript and all authors approve the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

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