The Economic Cost-benefit Analysis of Black Soldier Fly as an Alternative Animal and Fish Feed Ingredient in Malawi

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P.O. Box 30883 Capital City, Lilongwe Malawi

Dr. Maggie Munthali (m.munthali@mwapata.mw) is a Research Fellow at MwAPATA Institute. Mr. Chilora is a Research Analyst at MwAPATA Institute. Dr. Burke is an Associate Professor of Agricultural, Food and Resource Economics at Michigan State University and Principal Investigator at MwAPATA. Prof. Benbow is a Professor at Michigan State University. Mike Goliath is a Student at LUANAR. Prof. Kang'ombe is a Professor at LUANAR. Dr. Safalaoh is an Associate Professor at LUANAR.

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Executive Summary

Insect farming is a high-potential emerging farming enterprise in sub-Saharan Africa and their production has a relatively small ecological footprint. Black Soldier Fly (BSF), *Hermetia illucens*, is a promising insect species for a sustainable and innovative alternative protein source in animal feed. Little or no evidence exists showing whether BSF is a viable alternative sustainable feed ingredient in aquaculture and animal feed in Malawi or an economically feasible option for farmers. The objective of the study is to evaluate the financial feasibility of BSF farming at various scales of production using Cost-Benefit Analysis (CBA) with data collected from a small-scale pilot BSF farm in Lilongwe. The study addressed the following research questions:

(a) What are the costs and benefits of farming BSF in Malawi for (i) small-scale farming (individual farmers, clubs, and cooperatives), and (ii) large-scale commercial farmers?
(b) What drives variation in the benefit/cost ratio (BCR) of BSF farming across scales?
(c) How could policies improve BCRs of BSF farming to support adoption in Malawi?

The indicators used to assess the economic viability of BSF farming for smallholder and commercial farmers in this study included Net Present Value (NPV) and Benefit Cost Ratio. Results imply BSF farming is viable and feasible across scales of production. Small-scale farmers will generate roughly MK507,100 of gross revenue for one larval cycle and MK2,535,500 (over $2,500) annually. Commercial farmers can generate MK1,536,100 for one larval cycle and MK7,680,750 annually. Sensitivity analysis shows BSF farming remains profitable even within a 10% variation in the cost of production, the price of outputs, and the yield of BSF larvae and frass.

To our knowledge, despite enthusiasm around insects as an alternative protein, this study fills an empirical gap on the viability and feasibility of BSF production across scales. These results also provide a rationale for further development of BSF farming in Malawi, which has received little political attention. These findings will enable the government and other stakeholders to develop strategies and policy actions to promote BSF farming in the country. Based on the findings, we recommend the following:

(a) Invest in building the capacity of farmers and extension workers' education in BSF farming and its use in feed to increase the adoption among the farmers.

(b) Raise awareness among the farmers, entrepreneurs and policy-makers on the socio-economic and ecological benefits of BSF farming to facilitate transitioning from conventional animal protein sources to insect protein sources.

(c) Provide farmers and entrepreneurs access to capital and formal credit to enhance the uptake of BSF farming. This would require supporting formal lending institutions such as commercial banks, microfinance, private sector savings and credit unions to make their interest rates, repayment periods and lending procedures, especially the collateral security, more favorable.

(d) Support more R&D in BSF to enable the development of this emerging industry.

(e) Establish a regulatory framework to build consumer confidence in the safe and effective use of insects as animal and aquaculture feed.

1. Introduction

1.1 Background

The need is growing for innovation around how farmers raise and feed animals. Global population growth, urbanization and increased cost of living are likely to disrupt human and animal nutritional uptake, particularly protein (Henchion et al., 2017; van Huis, 2013). These unfolding changes may reduce access to the land essential for producing feed used in fish and livestock production while coinciding with greater demand for their products in diets. Sustainable insect farming (e.g., BSF farming) in ambient closed or open environments and reared at various scales either on small-scale farms or large-scale rearing facilities offer great economic and financial benefits such as employment and income opportunities. Insects also act as alternative sources of conventional meat products to the growing world population and feed for animals and fish thereby increasing the production of poultry, livestock and aquaculture. (Mottet et al., 2017).

Moreover, livestock production has been associated with numerous detrimental environmental repercussions such as soil erosion, loss of biodiversity, acidification due to leaching of ammonia, depletion of fish, deforestation, desertification, high water footprint, water pollution, eutrophication, and generation of large quantities of waste (Ermolaev et al., 2019; Gerber et al., 2013; Lubkowski, 2016; Mekonnen & Hoekstra, 2012; Mertenat et al., 2019; Sogari et al., 2019; Spranghers et al., 2017; Stamer, 2015; Tacon & Metian, 2008; van Huis, 2015). Further, the livestock industry is responsible for the increased emission of anthropogenic greenhouse gases (GHGs), especially methane and nitrous oxide; for example, 35-40%, 68% and 64% of methane, entheogenic nitrous oxide and total ammonia emissions, respectively are attributable to livestock (Dopelt et al., 2019; Ermolaev et al., 2019; Leytem et al., 2011; Mertenat et al., 2019; Pang et al., 2020).

The environmental impacts from conventional livestock production and feed demands can be mitigated by shifting from crop-based protein sources to alternatives, without losing important nutritional benefits (Abbasi et al., 2016; Ermolaev et al., 2019; Gahukar, 2016; Lange & Nakamura, 2021; Mertenat et al., 2019; Pang et al., 2020). In this study, we examine the prospect of using insects as livestock and aquaculture feed. For developing countries such as Malawi, insect farming could provide an accessible, cost-effective and sustainable alternative protein source for aquaculture and animal feeds (Chia et al., 2019; Limbu et al., 2022; Pechal et al., 2019). For instance, Munthali et al., (2022) reported that one of the challenges affecting small-scale aquaculture in Malawi is the lack of access to quality fish feed and the commercial feed available on the markets is expensive since it is imported from Zambia, eventually, calling for alternative aquaculture feed. In Malawi, however, insect farming has received little government attention and minimal private investment. In part, this may stem from the dearth of evidence regarding its viability.

In this paper, we aim to fill this gap by providing evidence on the economic feasibility of insect farming, either as a smallholder income-generating activity or as a larger commercial enterprise. Specifically, we consider the farming of Black Soldier Flies (BSF), *Hermetia illucens* L., as an alternative animal and aquaculture feed ingredient in Malawi. We use primary data collected from Bunda college of agriculture's small-scale BSF pilot farm and cost-benefit analysis to answer the following questions:

(a) What are the costs and benefits of farming BSF in Malawi for (i) small-scale farming (individual farmers, clubs, and cooperatives), and (ii) large-scale commercial farmers?
(b) What drives variation in the benefit/cost ratio (BCR) of BSF farming across scales?
(c) How could policies improve BCRs of BSF farming to support adoption in Malawi?

Based on parameters found in the literature and through interviews, we find the benefits of BSF farming likely exceed the costs in most scenarios. There are, however, actions that could be taken to improve the return on investments in BSF. This evidence on the economic feasibility of BSF will be valuable to potential investors and policymakers aiming to better understand and promote BSF as an alternative to animal and aquaculture feed in Malawi.

1.2 Why Black Soldier Fly?

Insects are a promising sustainable protein source for livestock, and fish because of their high nutritional value (the protein content of edible insects ranges from 30% to 65% of the total dry matter), and they emit relatively low levels of GHGs (Bovera et al., 2016; Dobermann et al., 2017; Ermolaev et al., 2019; Halloran et al., 2018; Mertenat et al., 2019; Pang et al., 2020; van Huis, 2013; van Huis & Oonincx, 2017). The authors posit that BSF can be used as an organic waste converter such that total direct GHG emissions from food waste treatment by BSF larva compositing are lower than those from conventional food waste treatment. The use of insects as animal and fish feed has increased exponentially over the past decade, thereby, reducing reliance on traditional feed sources such as soy-based feed (van Huis et al., 2021). The Food and Agriculture Organization (FAO) recommends incorporating insects into animal feed to enhance food security and alleviate poverty (FAO, 2013; van Huis, 2015).

Approximately 40% of global arable land is used to produce fields of grain to feed fish, poultry and livestock (Mottet et al., 2017). Studies have found that insect farming requires significantly less arable land and water for rearing compared to traditional livestock production systems (Espitia Buitrago et al., 2021; Payne et al., 2016; van Huis & Oonincx, 2017). For instance, insect farming uses 50–90% less land per kg of protein produced and 40–80% less feed per kg of edible weight; produces 1.2–2.7 kg less greenhouse gas emissions per kg of live weight gain; and uses 1,000 L less water per kg of live weight gain compared to conventional livestock production systems(Espitia Buitrago et al., 2021; Payne et al., 2016). Hence, promoting the use of insect protein instead of plant-based protein will free up arable land for food production, thereby improving food security.

The Black Soldier Fly (BSF), *Hermetia illucens* L. is an increasingly popular candidate for a sustainable alternative feed source (Chia et al., 2019; Limbu et al., 2022; Pechal et al., 2019). A key difference between BSF and alternatives is the fact that adult flies live entirely off of nutrients stored during the larval stage (adult flies do not even have functional mouths) and can survive up to 4 months (Caruso et al., 2014; Edea et al., 2022; Lu et al., 2022; Makkar et al., 2014). As such, BSF larvae are particularly adept at isolating and storing important nutrients – they must obtain all the nutrients they will need for their full life cycle before pupating. Furthermore, BSF can convert a wide range of organic substrates (from food waste to manure) into a high-quality nutrient source for animals and aquaculture feed thereby reducing waste in landfills (Caimi et al., 2021; Chia et al., 2019; Diener et al., 2011; Nguyen et al., 2015; Shelomi, 2020; Stamer, 2015; St-Hilaire et al., 2007; Veldkamp & Bosch, 2015). The protein content of BSF larvae varies based on the substrates ranging from 37%- 63%; fat content ranges from 7-39% (Table 1).

Moreover, the byproducts of BSF (frass) can be used as organic fertilizer for crop production (Anyega et al., 2021; Beesigamukama et al., 2020; Gärttling et al., 2020;

Table 1: Crude protein (CP) and crude fat (CF) content of BSF larvae reared on different organic matter substrates

Substrate	%CP[1]	n	%CF[1]	n	Reference
Cattle manure	42.1	1	34.8;29.9	2	(Li et al., 2011; G. L. Newton et al., 1977)
Chicken manure	40.1 ± 2.5	3	27.9 ± 8.3	3	(Arango Gutiérrez et al., 2004; Li et al., 2011; Sheppard et al., 1994; Shumo et al., 2019)
Swine manure	43.6;43.2	2	26.4 ± 7.6	4	(Li et al., 2011; Manzano-Agugliaro et al., 2012; L. Newton et al., 2005; St-Hilaire et al., 2007)
Palm kernel meal	42.1;45.8	2	27.5	1	Rachmawati et al., (2010)
Restaurant waste	-		39.2	1	Zheng et al., (2012)
Chicken feed	47.9 ± 7.1	3	14.6 ± 4.4	3	(Bosch et al., 2014; Nguyen et al., 2015; Oonincx et al., 2015; Spranghers et al., 2017)
By-products[2]	41.7 ± 3.8	4	-	-	Oonincx et al., (2015)
Liver	62.7	1	25.1	1	Nguyen et al., (2015)[3]
Fruits and vegetables	38.5	1	6.63	1	(Nguyen et al., 2015[3]; Spranghers et al., 2017)
Fish	57.9	1	34.6	1	Nguyen et al., (2015)[3]

Source: Barragan-Fonseca et al., (2017)

[1] All values are expressed on a dry matter basis. Values are mean ± standard deviation; (n) gives the number of replicates. If n = 2, individual values are stated, separated by a semicolon.

[2] Beet molasses, potato steam peelings, spent grains and beer yeast, bread and cookie remain.

[3] Original values on a fresh matter basis have been converted to dry matter basis using the water content reported.

Lalander et al., 2015; Quilliam et al., 2020). Like nutritional values, the quality and composition of frass vary depending on the substrate used to rear BSF (De Marco et al., 2015; Gebremikael et al., 2022; Klammsteiner et al., 2020; Spranghers et al., 2017). Additionally, BSF farming can offer additional income for rural livelihoods (Beesigamukama et al., 2022; Groeneveld et al., 2021; Mutuku et al., 2022; Onsongo et al., 2018).

In short, BSF larvae are a popular choice among researchers studying insects as feed alternatives because they appear to be particularly effective at isolating and storing the nutritional value of substrates (protein and fat) while separating the remaining content (frass) into component nutrients that can be used for fertilizer. What remains to be seen is how these benefits compare to the costs of BSF farming in real Malawian contexts.

2. Data and methods

2.1 Economic feasibility of BSF farming

We used Cost-Benefit Analysis (CBA) to assess the economic feasibility of BSF at different scales. CBA is a widespread technique for evaluating a project or investment by summarizing the economic benefits and costs of an activity into a single ratio (Shively & Galopin, 2012). In this study, we estimated the Net Present Value (NPV) of benefits and costs to compute the Benefit Cost Ratio (BCR). These indicators would be estimated using Equations 1 and 2 respectively. Model specification (components of costs and benefits) and parameter estimates were determined by key informant interviews and data collected from the Bunda pilot BSF farm. The Bunda BSF farm is by Lilongwe University of Agriculture and Natural Resources (LUANAR). The pilot farm is used as a demonstration, training and research unit for stakeholders and farmers in surrounding communities and Malawi at large.

The Sensitivity analysis was also done to demonstrate the robustness of our conclusions to uncertainty around the parameters used. Sensitivity analysis also illustrates the relative risk of establishing this business due to the price volatility of commodities. In interpreting the investment decision criteria, a proposed investment or project can be reckoned feasible if the NPV is positive or the BCR is greater than 1. Future costs and benefits are discounted to account for inflation, risk aversion, and personal utility (people tend to see less utility in future value compared to the value in the present).

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+r)^t} \qquad (1)$$

$$\mathrm{BCR} = \frac{\sum_{t=1}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{C_t}{(1+r)^t}} \qquad (2)$$

where
T = Investment/project period (years)
t = the time period (year);
B_t= benefits (revenues) of the year t (MK/ha);
C_t = costs of the year t (MK /ha);
r = an annual discount rate (%).

2.2 Key yield and revenue assumptions for CBA for BSF production

Figures from the breeding unit at LUANAR's pilot are summarized in Box 1. The assumptions for estimating BBF larvae production and waste reduction are based on the data from Bunda BSF pilot data. Further assumptions for analysis regarding yield and other factors across scales are presented in Table 2.

Box 1: Estimation of BSF larvae production and waste reduction using pilot data gathered at Bunda - LUANAR BSF Farm

Larval production estimates

With an inventory of 50,000 flies, in a 2:3 male/female ratio;
1 female to lay 450 eggs,
30,000 female BSF > 450 eggs x 30,000 flies = 13,500,000 eggs
With a 75% hatching rate;
0.75 X 13,500,000 = 10,125,000 young larvae
For colony continuation, spare 1% of the 5-day old larvae (DOL) for breeding; (101,250 larvae)
99% of the total 5-DOL will further be fed till they reach harvest stage (day 14 from separation. i.e. at day 5 from hatching and day 19 from egg incubation.
At a 85% survival rate, a total of:
0.85 x 10,023,750 larvae (8,520,187 larvae) will reach harvest stage
At day 14 from separation (14-DOL), a group of 200 fresh larvae weigh approximately 80 grams.
Therefore, a total of 8.5 million larvae will weigh:
(8,520,187/200) x 0.08 kg = 3,408 kilograms fresh larvae
When fully dried, BSF larvae lose approximately 44% moisture;
Therefore, their final dry matter content,
3,408kg x 0.56 DM = 1,908 kg dry larvae

Waste reduction estimates

Waste reduction index depends on a type of substrates used with high SRI (Substrate Reduction Index) in less fibre/cellulose content substrates and low SRI in feed substrates with high fibre/cellulose content. The efficiency of BSF larvae to consume and therefore reduce the waste load of different substrates is determined by the SRI. The higher the SRI, the higher the higher/better the substrate efficiency (Oonincx et al. 2015a)
On average, restaurant/kitchen waste has a SRI of 2.8 - 3.4 (74 - 83% reduction rate)
From 2,000kg waste substrate (kitchen waste), there will be a final residue (BSF Frass) of about 340 - 520kgs that can further be used as organic compost fertilizer for the crop field.

Table 2: Key yield and revenue assumptions for CBA for BSF production using data from Bunda Farm

Assumption	Small-scale	Commercial scale
Number of initial BSF	50,000	150,000
Estimated BSF larvae yield (kg) for one (1) larval cycle	1,908	5,783
Estimated BSF larvae yield (kg) for five (5) larval cycles or one year	9,540	28,917
Estimated BSF frass (kg) for one (1) larval cycle	430	1,290
Estimated BSF frass (kg) for five (5) larval cycles or one year	2,150	6,450
Price of dry BSF larvae	MK250/kg	
Price of dry BSF frass	MK70 per kg	
Labour	Family labour	3 minimum wage labourers at Mk50,000/month*.

* Each casual laborer will be receiving Mk88,462 for 46 days (equivalent to 1 larval or production cycle)

3. Findings

3.1 Cost of growing and producing BSF larvae

The summary and estimated costs associated with the growing and producing BSF larvae are presented in Tables 3, 4, A1 and A2. Small-scale and commercial farmers will require MK264,050 and MK3,238,986.00 to set up a BSF farming enterprise, respectively (Table 3). This will carry an operation through the first larval cycle. Each year, a BSF farm can go through a total of five larval cycles. While most of the full first-year costs are in the initial setup, a full five-cycle year will require some additional variable costs. In total, farmers will need MK440,250 (small-scale) and MK5,128,530.00 (commercial scale) to run the BSF business for one year (Table 4).

The fly stage constitutes more than half of the total cost for small-scale BSF farming while in commercial BSF farming, more costs are associated with labour, the fly and larval growth stages.

Table 3: Estimated cost for BSF farming for one larval cycle

Stage	Small-scale		Commercial scale	
	Total cost (MK)	Percent of total cost	Total cost (MK)	Percent of total cost
Establishing the brood stage (attract females)	24,000.00	9.09	120,000.00	3.70
Fly stage (collect larva into a greenhouse)	216,850.00	82.12	1,753,100.00	54.12
Egg stage	4,500.00	1.70	250,000.00	7.72
Hatching stage	7,200.00	2.73	114,500.00	3.54
Larval growth stage	11,500.00	4.36	736,000.00	22.72
Casual labour	0.00	0.00	265,386.00	8.19
Total	**264,050.00**		**3,238,986.00**	

Source: Author's compilation

Table 4: Estimated cost for BSF farming for five larval cycles or one year

Stage	Small-scale		Commercial scale	
	Total cost (MK)	Percent of total cost	Total cost (MK)	Percent of total cost
Establishing the brood stage (attract females)	56,000.00	12.72	120,000.00	2.34
Fly stage (collect larva into a greenhouse)	351,050.00	79.74	2,121,100.00	41.36
Egg stage	14,500.00	3.29	310,000.00	6.04
Hatching stage	7,200.00	1.64	114,500.00	2.23
Larval growth stage	11,500.00	2.61	1,136,000.00	22.15
Casual labour	0.00	0.00	1,326,930.00	25.87
Total	**440,250.00**		**5,128,530.00**	

Source: Author's compilation

3.2 Benefits of growing and producing BSF larvae

Tables 5 and 6 present benefits in terms of projected revenue realized from BSF farming (sales from dry BSF larvae and BSF frass) for one larval cycle (Table 5) and annually (Table 6). Based on the key summary of assumptions described in section 2.4, the small-scale farmers will generate revenue of MK507,100.00 for one larval cycle and MK2,535,500.00 annually. On the other hand, commercial farmers will generate MK1,536,100 for one larval cycle and MK7,680,750 annually.

Table 5: Estimated earnings from BSF larvae for one larval/production cycle

Item	Price/kg	Yield (kg)		Projected income (MK)	
		Small-scale	Commercial	Small-scale	Commercial
Sale from BSF dry larvae	250	1,908	5,783	477,000	1,445,850
Sale from BSF frass	70	430	1,290	30,100	90,300
Total				**507,100**	**1,536,150**

Source: Author's compilation

Table 6: Estimated earnings from BSF larvae for five larval/production cycles (annually)

Item	Price/kg	Yield (kg)		Projected income (MK)	
		Small-scale	Commercial	Small-scale	Commercial
Sale from BSF dry larvae	250	9,540	28,917	2,385,000	7,229,250
Sale from BSF frass	70	2,150	6,450	150,500	451,500
Total				**2,535,500**	**7,680,750**

Source: Author's compilation

3.3 Economic viability indicators

Two indicators (BCR and NPV) were computed to assess the economic viability of BSF production for smallholder and commercial farmers. A detailed analysis of the NPV for BSF production is presented in Tables 7 and 8. The results show that BSF production for both smallholder and commercial BSF farming at 12%[1] discount rate is positive. At the end of 10 years, NPV for small-scale and commercial BSF farming was estimated to be MK12,886,439.64 (US$15,629.78[2]) and MK27,582,340.68(US$33,454.23), respectively.

Table 9 provides estimates of the profitability and economic viability of BSF production at various levels using NPV and BCR Similarly, the BCR for small-scale BSF farming was approximately 3 times (10.0) than that of commercial BSP production (2.7) which are both greater than the accepting range of BCR>1 based on decision-making criteria (Table 9). This shows that BSF production at various production scales is economically attractive, viable and feasible. Based on the results, BSF farming could have potential and impact on poverty alleviation by building sustainable livelihoods and improving food security.

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[1] Reserve Bank of Malawi' discount rate at the time of our calculation was 12%

[2] US$=Mk824.48 as of 25 February 2022. Source: Reserve Bank of Malawi

Table 7: Economic viability of Small-scale BSF farming over 10 years

	Cost	Benefit	Discount @ 12%	Discounted Cost	Discounted Benefit	NPV
Year	(i)	(ii)	(iii)	(i/iii)	(ii/iii)	(ii – i)/(iii)
1	440,250.00	2,095,250.00	1.12	393,080.36	2,263,839.29	1,870,758.93
2	220,000.00	2,315,500.00	1.25	175,382.65	2,021,285.08	1,845,902.42
3	220,000.00	2,315,500.00	1.40	156,591.65	1,804,718.82	1,648,127.16
4	220,000.00	2,315,500.00	1.57	139,813.98	1,611,356.09	1,471,542.11
5	220,000.00	2,315,500.00	1.76	124,833.91	1,438,710.79	1,313,876.88
6	220,000.00	2,315,500.00	1.97	111,458.85	1,284,563.21	1,173,104.36
7	220,000.00	2,315,500.00	2.21	99,516.83	1,146,931.44	1,047,414.61
8	220,000.00	2,315,500.00	2.48	88,854.31	1,024,045.92	935,191.61
9	220,000.00	2,315,500.00	2.77	79,334.21	914,326.72	834,992.51
10	220,000.00	2,315,500.00	3.11	70,834.11	816,363.14	745,529.03
Total	**2,420,250.00**	**25,355,045.00**		**1,439,700.85**	**14,326,140.49**	**12,886,439.64**

Source: Author's compilation

Table 8: Economic viability of Commercial BSF farming over 10 years

	Cost	Benefit	Discount @ 12%	Discounted Cost	Discounted Benefit	NPV
Year	(i)	(ii)	(iii)	(i/iii)	(ii/iii)	(ii – i)/(iii)
1	5,128,530.00	7,680,750.00	1.12	4,579,044.64	6,857,812.50	2,278,767.86
2	2,361,930.00	7,680,750.00	1.25	1,882,916.14	6,123,046.88	4,240,130.74
3	2,361,930.00	7,680,750.00	1.40	1,681,175.12	5,467,006.14	3,785,831.02
4	2,361,930.00	7,680,750.00	1.57	1,501,049.21	4,881,255.48	3,380,206.27
5	2,361,930.00	7,680,750.00	1.76	1,340,222.51	4,358,263.82	3,018,041.31
6	2,361,930.00	7,680,750.00	1.97	1,196,627.24	3,891,306.98	2,694,679.74
7	2,361,930.00	7,680,750.00	2.21	1,068,417.18	3,474,381.24	2,405,964.05
8	2,361,930.00	7,680,750.00	2.48	953,943.91	3,102,126.10	2,148,182.19
9	2,361,930.00	7,680,750.00	2.77	851,735.64	2,769,755.45	1,918,019.81
10	2,361,930.00	7,680,750.00	3.11	760,478.25	2,472,995.94	1,712,517.69
Total	**26,385,900.00**	**76,807,500.00**		**15,815,609.85**	**43,397,950.53**	**27,582,340.68**

Source: Author's compilation

Table 9: Economic viability of BSF farming at various production scales over 10 years

Economic indicator	Small-scale	Commercial scale
NPV	12,886,439.64	27,582,340.68
BCR	10.0	2.7

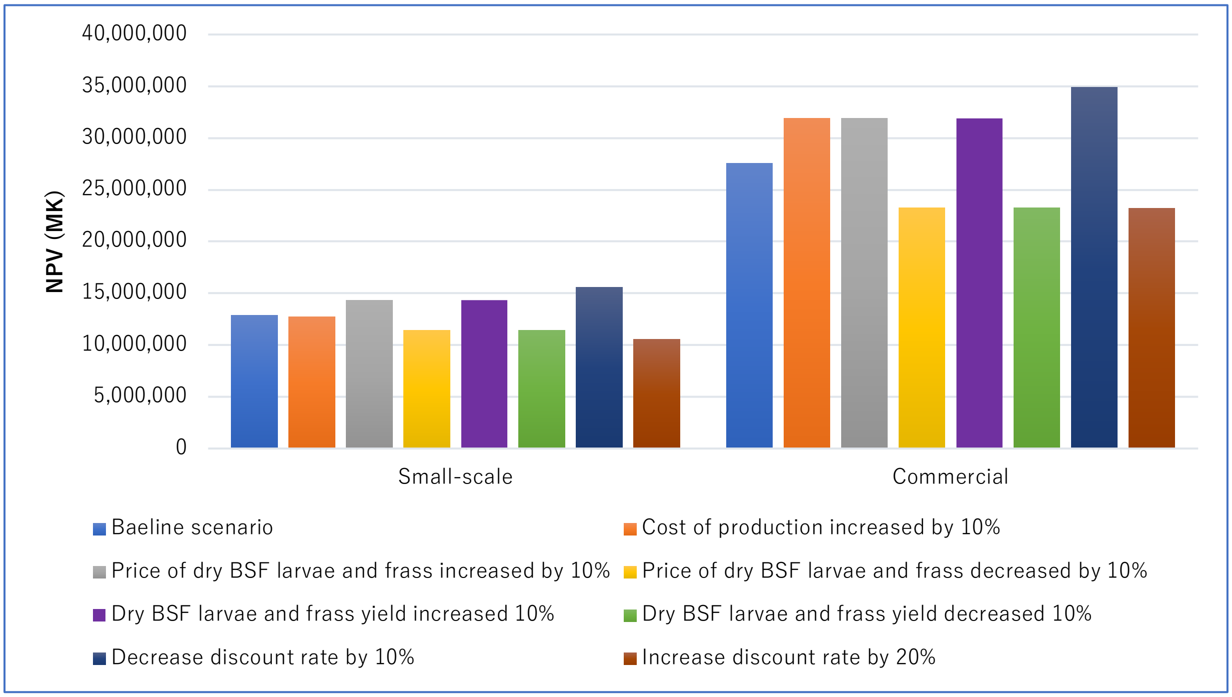
Source: Author's compilation

3.4 Sensitivity analysis

An investment decision can also be made when an investor understands how sensitive (risky and uncertain) the investment is when subjected to various economic and financial environments, e.g., the cost/price of commodities and interest rates constantly fluctuating over time. Results of the sensitivity analysis based on pessimistic (worst) and optimistic (best) scenarios based on the key economic variables such as discount rate, cost of production, price of dry BSF larvae and frass and yield changes are presented in Figures 1 and 2.

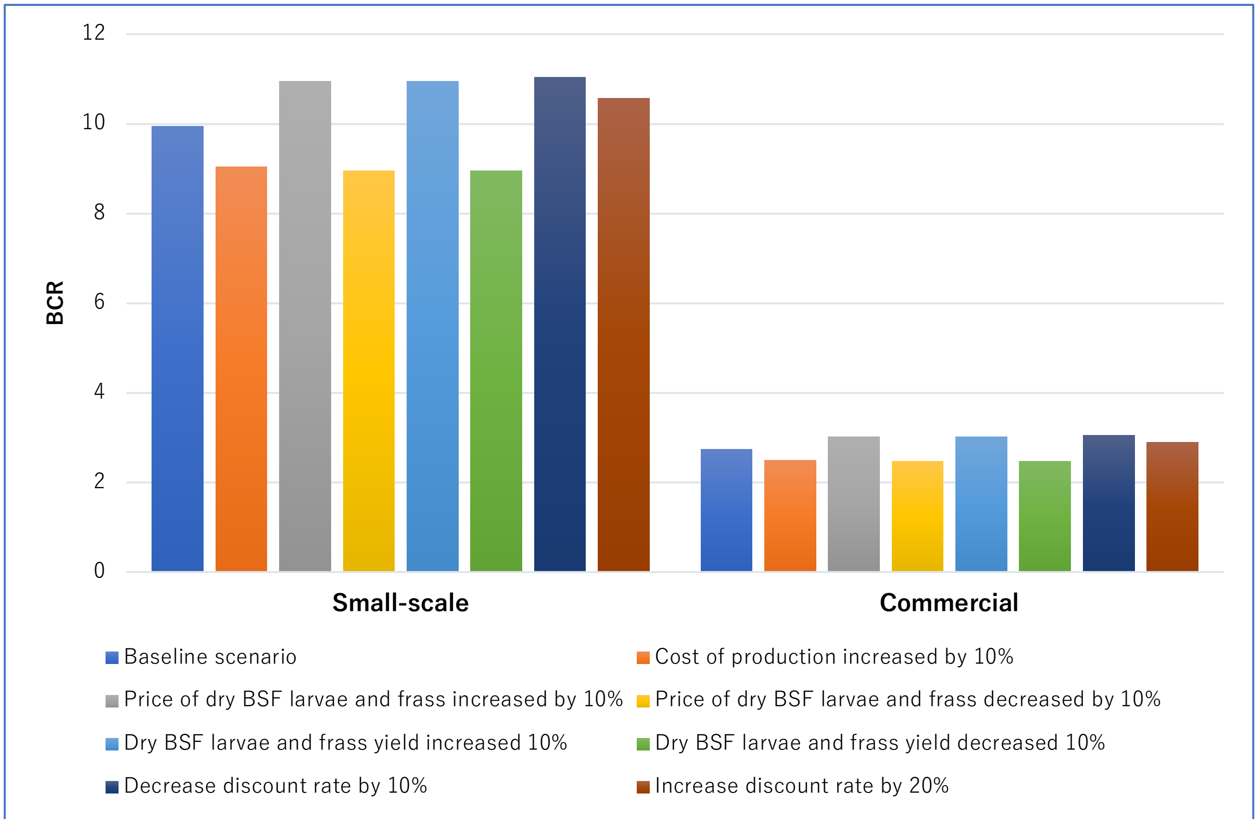
Our findings reveal that BSF farming is still profitable even if you increase the cost of production and reduce the price and yield of BSF larvae and frass by 10% (Figures 1 and 2). However, increasing the cost of production reduces NPVs by 1.1% and 2.4% for smallholder and commercial BSF production, respectively. As shown in Figure 1, increasing/reducing the prices and yield of BSF larvae and frass by 10% increases/reduces the NPVs by and 11.1% (smallholder) and 12.4% (commercial). Further, BCR is sensitive to changes when subjected to changes in the cost of production, discount rates, prices and yield of BSF larvae and frass (Figure 2).

Figure 1: Net Present Value of Black Soldier Fly farming based on different scenarios



Source: Calculations by Authors

Figure 2: BCR based on various scenarios at different production levels



Source: Calculations by Authors

4. Conclusion and policy implications

The use of BSF as alternative animal and aquaculture feed has gained increasing attention around the globe. Knowledge of the economic viability of BSF farming in Malawi is scarce despite being perceived as an emerging and profitable farming enterprise. The use of insects such as BSF is increasingly relevant in SSA as it offers numerous tangible benefits including high-quality animal feed, food and nutritional security, job creation, poverty reduction and environmental sustainability. Malawi has high unemployment levels, especially among the youth and women; government investment in BSF farming could contribute to the economic empowerment of these vulnerable groups, although, further research is needed to test if BSF farming could be a realistic and viable venture for women and youth in Malawi. Insights into the economic viability of BSF farming at different scales is thus crucial for facilitating adoption by farmers, designing policy interventions that will drive the BSF farming growth and ensuring its sustainability. However, further research is needed to if BSF farming could be a realistic and viable venture for women and youth.

We utilized data from a small-scale pilot BSF farm at Bunda in Lilongwe to assess the farm-level economic feasibility of BSF farming at various scales of production in Malawi using Cost-Benefit Analysis. The results shows that BSF farming appears to be viable and feasible across scales of production. Based on the assumptions described in Section 2.4, the small-scale farmers will generate revenue of MK507,100.00 for one larval cycle and MK2,35,500.00 annually. At a larger scale, commercial farmers will generate MK2,535,500 for one larval cycle and MK7,680,750 annually. This implies that BSF production has greater implications on household food and nutrition security and can also act as a livelihood diversification strategy among farmers to minimize risks of on-farm activities while ensuring environmental sustainability. Both the Net Present Value of investment returns and the long-run Benefit Cost Ratio suggest BSF farming is profitable across scales.

The study also performed a sensitivity analysis and find viability to be robust to up to 10% changes in the price and yield of BSF larvae and frass. These results have significant implications that will inform the government and other stakeholders to develop strategies and policy actions that will promote BSF farming in the country. However, our study did not conduct probabilistic sensitivity analysis to account for multiple different scenarios given the uncertainties associated with agricultural production.

Based on our findings, the study, therefore, recommend the following be considered to promote BSF as an alternative animal and fish feed in Malawi:

(i) Invest in farmer's and extension worker's training in BSF farming

Adopting and promoting new business ventures or technologies is always challenging for reasons that vary across farmers, extension agents, entrepreneurs and policy-makers. It will require a collaborative effort from the government and other stakeholders to train more farmers and extension workers to increase the capacity of Malawians to take up BSF production. Some of the extension models that have proven successful include farmer-led demonstration plots, farmers' field schools, farmer field days and training and visits. Strong advisory and extension services will be crucial to overcoming the knowledge regarding BSF farming, facilitating the transition from conventional animal feed to insect feed, and increasing adoption among farmers.

(ii) Invest in research and development of BSF

Research and development (R&D) play an important role in the adoption of new technologies and solving complex issues affecting the agriculture sector. Although our analysis sheds some light, exploration of BSF as an alternative sustainable feed ingredient in aquaculture and animal feed in Malawi is still at the infant stage. Further investment towards BSF R&D will help develop the emerging industry. For example, our findings should be validated (or not) by newer data as it becomes available. Further empirical research is also needed to understand the perceptions, views and perspectives of farmers and stakeholders towards BSF as an alternative sustainable feed ingredient as well as the substrates BSF is reared on. Other research areas to be explored include determining the safety and acceptability of utilizing BSF raised on various substrates. This information is critical for effective policy development, implementation and uptake of BSF farming in Malawi.

(iii) Provide farmers, entrepreneurs and industries with access to capital and formal credit

Lack of access to financial capital and credit, especially from the formal lending institutions or high-interest rates where access is possible are major impediments to new business ventures in Malawi. This is also true for BSF farming. Improving access to formal credit will enable the adoption of BSF production among farmers, other potential entrepreneurs and industries. Although there are several formal credit institutions in Malawi, they are usually concentrated in urban areas; whereas most farmers prefer to borrow informally, for example, from village bank savings loan associations (VSLA), money lenders, neighbours, friends or relatives. To enable farmers to access formal credit, policy makers could employ subsidies, public-backed guarantees, or incentives to encourage formal lending institutions to offer lower interest rates, longer, more flexible repayment periods and lending procedures more attuned to collateral-poor potential borrowers. Additionally, there is a need for the government and other stakeholders to encourage the institutions to establish branches in rural areas to serve the specific credit and savings needs of the farmers and also avoid farmers walking very long distances just to access the credit.

(iv) Raise awareness among the farmers, entrepreneurs and policy-makers on the socio-economic and ecological benefits of BSF farming

Although BSF farming is apparently profitable, the low levels of adoption may be due to limited awareness or misconceptions amongst potential entrepreneurs and their potential consumers. This could be overcome via information exchange through smart dissemination channels targeting different actors, including farmers, other potential entrepreneurs, planners, local communities and policy-makers.

(v) Develop a legal framework or guidelines to regulate the production of BSF and other insects for feed in Malawi

Safety and effective promotional use of insects as animal and aquaculture feed requires conducive and supportive policies, standards, laws, legislations and a regulatory environment. Currently, Malawi has no regulatory framework to support and govern the development and production of insects for feed. The effort to promote insect farming such as BSF as an alternative feed ingredient to animal and aquaculture feed cannot be successful if there is no appropriate legal framework or guidelines to ensure the quality and traceability of BSF. The present study has provided a foundation for various stakeholders including governments, academia, industries, the private sector, donors and policy-makers to initiate debate on the development of a clear and comprehensive regulatory framework to govern insect farming including BSF. Other countries in SSA (e.g., Tanzania, Kenya and Uganda) have made progress in regulating insects as feed; Malawi can learn from these examples.

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Appendix

Table A1: Cost of small-scale production of BSF larvae

Stage	Item	Qty	Unit	Price	Total
Step 1: Establishing the brood stage (attract females)	Buckets (medium)	4	No.	4,000	16,000.00
	Substrate (kitchen waste, pig manure (to be mixed with another substrate, chicken +pig manure)	2	90l bucket	1,000	2,000.00
	90 l bucket (Mbiya)/oil plastic buckets (used for storage)	2	No.	3,000	6,000.00
Subtotal					24,000.00
Step 2: Fly stage (collect larva into a greenhouse)	Greenhouse construction (greenhouse sheet, timber, etc.)				42,500.00
	Love cage (nails, timber, labour, net)	4	various	20,000	80,000.00
	broom for cleaning	1	No.	150	150.00
	Face mask (cloth)	2	No.	500	1,000.00
	Work coat	1	No.	15,000	15,000.00
	Lab gloves	2	Box	15,000	30,000.00
	Rubber boots	1	No.	6,000	6,000.00
	face shield	1	No.	2,000	2,000.00
	Scrubbing brush	1	No.	2,000	2,000.00
	Attractant light (torch)				-
	Attractant box	4	No.	1,000	4,000.00
	Attractant Media (substrate)				-
	Ant trap	16	No.	50	800.00
	Akheri chemical	1	No.	3,000	3,000.00
	Precision scale				-
	Eggies (Laying site for BSF)/big cartons,	2	No.	200	400.00
	Water container	4	No.	500	2,000.00
	Cotton wool	8	No.	3,500	28,000.00
Subtotal					216,850.00
Step 3: Egg stage	Tweezers				-
	Precision scale				-
	Chicken feed (23%CP), soya beans maize mixture	5	Kgs	500	2,500.00

	Hatching Container	4	No.	500	2,000.00
	Egg holder			-	-
Subtotal					4,500.00
Step 4: Hatching stage	Residual container (recycle water containers)			-	-
	Scoop				-
	Precision balance				-
	Plate	4	No.	300	1,200.00
	Cups (500ml)	5	No.	300	1,500.00
	tray	3	No.	1,500	4,500.00
Subtotal					7,200.00
Step 5: Larval growth stage	Nursery larvero rack (holds containers)	3	No.	-	-
	Nursery larvero (hatching container) recycle those in the egg stage	4	No.	-	-
	Spade				-
	Bulk scale	1	Box	11,500	11,500.00
	Bin recycle 90l buckets in stage 1		90l bucket		-
	Chicken feed (23%CP), soya beans maize mixture/ use substrate in step 1		Kg	-	-
Subtotal					11,500.00
GRAND TOTAL					**264,050.00**

Table A2: Cost of commercial production of BSF larvae

Stage	Item	Qty	Unit	Price	Total
Step 1: Establishing the brook stage (attract females)	BioPod	2	No.	45,000	90,000
	Attractant media	5	No.	-	-
	BioPod rack	2	No.	15	30,000
Subtotal					**120,000.00**
Step 2: Fly stage (collect larva into a greenhouse)	Greenhouse	1	No.	1,200,000	1,200,000
	Love cage	4	No.	20,000	80,000
	Dust pan	3	No.	1,500	4,500
	Face mask	2	No.	7,500	15,000
	Work coat	2	No.	15,000	30,000
	Latex/lab gloves	4	Box	7,500	30,000
	Face shield	2	No.	2,500	5,000
	Rubber gloves	4	No.	8,000	32,000
	Scrubbing brush	2	No.	2,000	4,000
	Rubber boots	2	Pair	15,000	30,000
	Attractant light	5	No.	45,000	225,000
	Attractant box	4	No.	500	2,000
	Attractant media	4	No.	-	0
	Ant trap	32	No.	300	9,600
	Eggies	40	No.	1,500	60,000
	Precision scale	1	No.	20,000	20,000
	Water container	4	No.	1,500	6,000
Subtotal					**1,753,100.00**
Step 3: Egg stage	Tweezers	5	No.	1,000	5,000.00
	Precision scale	1	No.	-	-
	Chicken feed (23%CP)	15	Kg	1,000	15,000.00
	Hatching container	50	No.	4,500	225,000.00
	Egg holders	10	No.	500	5,000.00
Subtotal					**250,000.00**
Step 4: Hatching stage	Sieve	3	No.	6,000	18,000.00
	Residual container	15	No.	4,000	60,000.00
	Scoop	3	No.	2,500	7,500.00
	Precision balance	1	No.	17,500	17,500.00
	Plate	5	No.	300	1,500.00
	Cups and tray	10	No.	1,000	10,000.00
Subtotal					**114,500.00**
Step 5: Larval growth stage	Nursery larvero rack	6	No.	50,000	300,000.00
	Nursery larvero	50	No.	4,500	225,000.00
	Spade	2	No.	2,500	5,000.00

	Bulk scale	1	No.	56,000	56,000.00
	Bin	2	No.	25,000	50,000.00
	Chicken feed (23%CP)	200	Kg	500	100,000.00
Sub total					**736,000.00**
Grand total					**2,973,600.00**