African Journal of
Agricultural and Resource Economics
Volume 17, Number 1 (2022), pp 64–79

Stakeholders' perspectives on the use of black soldier fly larvae as an alternative sustainable feed ingredient in aquaculture, Kenya

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Received March 2022
Accepted June 2022

DOI: https://doi.org/10.53936/afjare.2022.17(1).4

Abstract

The use of novel feed ingredients from aquaculture is growing globally. However, their contributions to scalable and sustainable aquafeed solutions are unclear. New ingredients for feeds are desired in the framework of sustainability and a circular economy; thus, initiatives for implementing such novel ingredients are of interest to agricultural practitioners. As research continues on the potential contribution of insect-based feeds in aquaculture in Kenya, understanding stakeholders' perspectives about the use of black soldier fly larvae (BSFL) meal is critically important. Given that no such studies have been conducted in Kenya, the overarching goal was to quantify stakeholder perspectives on the use of BSFL meal in aquaculture. Specifically, the objectives of the study were to 1) determine stakeholders' perceived benefits and perceived risks regarding the use of BSFL meal in aquaculture; 2) identify the important considerations when legalising BSFL meal in Kenya; and 3) determine the driving factors to promote the adoption of BSFL in fish production. Purposive sampling was used to select forty (40) experts for a Delphi study, 24 of whom responded. The Kendall's coefficient of *concordance was used to assess the experts' consensus. The results study results suggest that there is agreement among stakeholders regarding the need to use BSFL as alternative protein ingredient in aquaculture. There was a significantly higher perception of benefits of BSFL in aquafeed than of risks, signifying a high degree of acceptance. Sanitary policy and inspection, feed safety, environmental influences and fish quality were given as the top-ranked important considerations when legalising BSFL in aquaculture. Creating and enhancing fish farmers' awareness of the benefits of BSFL in fish production (100%) was ranked as the most important driving factor, followed by identifying pioneer farmers of safe BSFL production and their introduction as the leading farmers. Consequently, the study recommends the need for academia, government and industries to collaborate closely to develop technology on the use of BSFL in aquaculture. If further recommends that the fish farmers and insect farmers should be engaged in the process, as this might increase the acceptance of BSFL in aquaculture upon its legalisation.*

Key words: stakeholders; experts; Delphi technique; black soldier fly larvae; aquaculture, Kenya

1. Introduction

Aquaculture is the fastest growing food production sector globally and is expected to play a key role in delivering future food security. The global prominence of and rapid growth in the size and total annual production of the aquaculture industry have resulted in the need to seek for alternative and pragmatic measures to reduce the cost of feed production and feeding captive fish species, which covers approximately 60% of total annual production (Apraku *et al*. 2017). Aquaculture currently accounts for approximately 50% of fish consumed by humans (Gasco *et al*. 2018). Fed-species aquaculture production is expected to grow to 58.96 million tonnes by 2025 (Tacon 2020). To achieve this growth, the aquafeed industry needs to grow at an average rate of 7.7% per year, as does the supply of feed ingredient inputs (Tacon *et al*. 2020). Aquaculture in Kenya has grown faster than any other food production sector, at an annual rate of 5.8% (Oliveira & Vasconcelos 2020), and this trend is expected to continue.

The protein shortage is a global concern and extensive research to find new sustainable protein sources is ongoing (Gasco *et al*. 2020). Research to find new ingredients to replace fish meal has gained momentum and grown in importance, specifically in the aquaculture field. Because fish need a high protein content in their feed, fish meal made of wild fish has been the main component of farmed fish food (Nogales-Mérida *et al*. 2018). Reliance on a fish meal-based diet affects aquaculture profitability (Olsen & Hassan 2012) and environmental sustainability. Part of the stock harvested is used as fish meal, some of which ends up being used as feed in aquaculture (Arru *et al*. 2019). According to Lang *et al*. (2009), 1 kg of farmed fish is produced from 2 kg to 5 kg of wild-caught fish. More than 90% of the caught fish meal is used to process into fish feed to feed farmed fish, and this leads to negative effects on the natural fish population in oceans, thereby leading to the limited availability of fish meal to feed farmed fish (Stamer 2015). This has led to the overexploitation and consequently the depletion of marine resources. Alternative protein sources of comparable value are therefore indispensable. The potential of insect-based protein in animal feed diets therefore has attracted much attention and the perspectives of stakeholders cannot be overlooked.

Stakeholder engagement is a central tenet of the development of any new product or service to gain understanding, views and perspectives. Stakeholder input is a critical component of setting future directions and goals for research, policy and product innovation that will support the development of insect-based protein as sustainable aquafeed. Stakeholder engagement is thus essential for reaching consensus for effective policy development and implementation, and the process requires sharing and understanding contrasting stakeholders' perspectives to minimise conflicts and to ensure equitable and sustainable outcomes (Brown *et al*. 2020). Recently, the interest of researchers has increased in insect meals such as black soldier fly larvae, and studies have highlighted that they can be used successfully in fish diets (Barroso *et al*. 2014; Henry *et al*. 2015). As such, experts consensus on the use and sustainability of such emerging novel feeds is necessary. Experts consensus studies have been conducted in other fields. Among these are farm animal welfare (Rioja-Lang *et al*. 2020), the practicality and effectiveness of biosecurity measures on dairy farms (Shortall *et al*. 2017), and the benefits of gene-edited crops (Lassoued *et al*. 2019), yet to date there is very little literature on insect-based feed in the aquaculture industry from a wide stakeholder perspective.

In the European context, Mulazzani *et al*. (2021) investigated the acceptance of insect meal as a feed component among Italian farmers of trout and seabass. The stakeholders interviewed included farmers, feed producers, and insect meal producers. The findings revealed that feed price and feed conversion ratio (FCR) were the most important drivers of the adoption of new feeds. In a study conducted by Popoff *et al*. (2017), several industry stakeholders of the Scottish insect-feed-aquaculture value chain were interviewed to analyse their awareness, knowledge and attitudes to new feeding possibilities for farmed fish. The study concluded that a consistent quality of feed at a competitive price was required in the supply chain to effectively replace the current protein sources in feed. Only a few studies have investigated stakeholders' perspectives of the emerging topic of using insects as feeds in African countries, namely those by Ssepuuya *et al*. (2019) in Uganda and Pomalégni *et al*. (2017) in Benin.

This study used an expert consensus to identify perceptions and drivers of black soldier fly larvae (BSFL) sustainability in aquaculture in Kenya. According to the authors' knowledge, this is the first stakeholder analysis study with this objective in Kenya. The study defines consensus as a high degree of agreement among stakeholders regarding specific outcomes of BSFL meal, and focuses on consensus because it is an important precursor of collective and equitable guidance within social, economic, policy and cultural systems (Larsen *et al*. 2019). The paper forms part of a larger body of works that identify the perspectives of a range of stakeholders concerning the use of insect-based meals in aquaculture. It is against this backdrop that the present study aims to determine stakeholders' perspectives of the use of BSFL in aquaculture. Kendall's coefficient of concordance was used to assess the level of consensus among the experts.

2. Materials and methods

2.1 Study design and sampling

An online cross-sectional study was set up to assess the opinions of stakeholders on the use of BSFL in aquaculture in Kenya. In a first step, potential participants were selected after a comprehensive review of academic publications and participation in scientific conferences, using broad keywords in an online search engine and through professional networks. The sampling procedure identified experts working or conducting research on issues related to the black soldier fly (BSF) as feed. The group included experts from a multiplicity of disciplines to guarantee a heterogeneous array of opinions. Furthermore, the snowballing method was used for data collection. The researcher first identified some experts and, after receiving the information, further experts were identified, as proposed by Habibi *et al*. (2014). The participants were drawn from government institutes, academia and industry.

2.2 Data collection

The survey instrument was created after taking into account the relevant published and grey literature, informal discussions with experts, and the present status of using insects as feed in aquaculture. The responses of the stakeholders were collected using an online anonymous questionnaire, created, hosted and shared between October 2021 and December 2021 using Google Drive. Since the stakeholders were from different professions and geographic locations, and due to the outbreak of Covid-19, it was challenging to gather all contributors in one place at the same time to discuss and achieve a consensus on the factor of BSFL sustainability in aquaculture. Thus, considering geographical, financial and temporal obstacles, this study employed an online Delphi survey to explore the study objectives. The Delphi method was generated in the 1950s and is now widely used to gain information from professional experts (Rowe & Wright 2011). Previous studies have stated that the Delphi method is a good research method for (i) deriving consensus among experts from wider geographical areas on a particular topic (Imang & Ngah 2012) and (ii) achieving an overall consensus among experts on a complex problem on which knowledge is limited (Hauck *et al*. 2007). The Delphi technique has also been used by several researchers in aquaculture fields to generate consensus (Soon & Baines 2012; Valderrama *et al*. 2014; Marvin *et al*. 2020; Weitzman *et al*. 2021). Experience from other Delphi studies shows that this method is useful for expert judgements by expert respondents, even when obtaining only small sample sizes. Thus, out of the 40 experts invited to take part in the survey, the 24 experts who responded were an adequate representative sample (Mukherjee *et al*. 2018).

An online survey was adopted to improve the efficiency of the questionnaire by facilitating the process and saving time for the participants. The combination of the web-based survey platform and the questionnaire simplified the statistical analysis, avoiding the demands of paper-based surveys and limiting data entry and computing errors. The time required to respond to the questionnaire was approximately 20 to 30 minutes. The questionnaires comprised a combination of open- and closed-ended questions. A draft of the questionnaire was pretested to evaluate the interpretation of the questions, the length of the questionnaire, and the easiness of the online system. The questionnaire was revised following the pilot in terms of a number of questions, wording and emphasis. In the consent section of the invitation to participate in the study, potential participants were informed of the purpose of the study, what it would involve and that they would not be identified by name in any subsequent publications.

2.3 Data analysis

A five-point Likert scale was used to solicit responses from the experts, with a scale ranging from (1) strongly disagree, (2) disagree, (3) neutral, (4) agree and (5) strongly agree on the perceived benefits and risks of using BSFL in aquaculture. Experts were also asked to rank 11 indicator variables on a Likert scale of 1 to 5, with 1 being the least important and 5 being extremely important. The Kendall coefficient of concordance was used to evaluate the level of agreement in the scores of the indicator variables ranked by the experts (Legendre 2010). Kendall's coefficient of concordance is a measure of the extent of agreement or disagreement among the rankings. The value of W is positive and ranges from a value of zero (which means there is maximum disagreement) to a value of one (which means there is perfect agreement).

$$W = \frac{12[\sum T^2 - (\sum T)^2/n]}{nm^2(n^2-1)}, \quad (1)$$

where T denotes the sum of ranks for each item, m denotes the number of experts sampled, and n denotes the number of items being ranked. In addition, Cronbach's alpha was employed to assess the consistency and reliability of the results based on the Likert scale estimation. Data from each of the experts was stored in a database on a web server. After completing the study, the data was exported to Excel, where initial data processing and quality checking were undertaken.

3. Results and discussion

3.1 Sample characteristics and participation

In this study, 24 experts took part in the survey, representing a response rate of 60% of those from 15 organisations who received the invitation, as in Table 1. The participants were from professional backgrounds, including research officers/scientists (n = 41.7%), fish farmers/fish cage managers (n = 29.2%), academia/lecturers (n = 12.5%), fisheries officers (n = 24.2%) and other professions (n = 12.5%), as illustrated in Figure 1. The majority of the experts were males (62.5%, n = 15), while females constituted 37.5% (n = 9). There were more male participants than females (possibly reflecting a bias in the expert population). The average years of professional experience were 10.58 years (range = 3 to 38), with little variation in years of experience between the fields of competence.

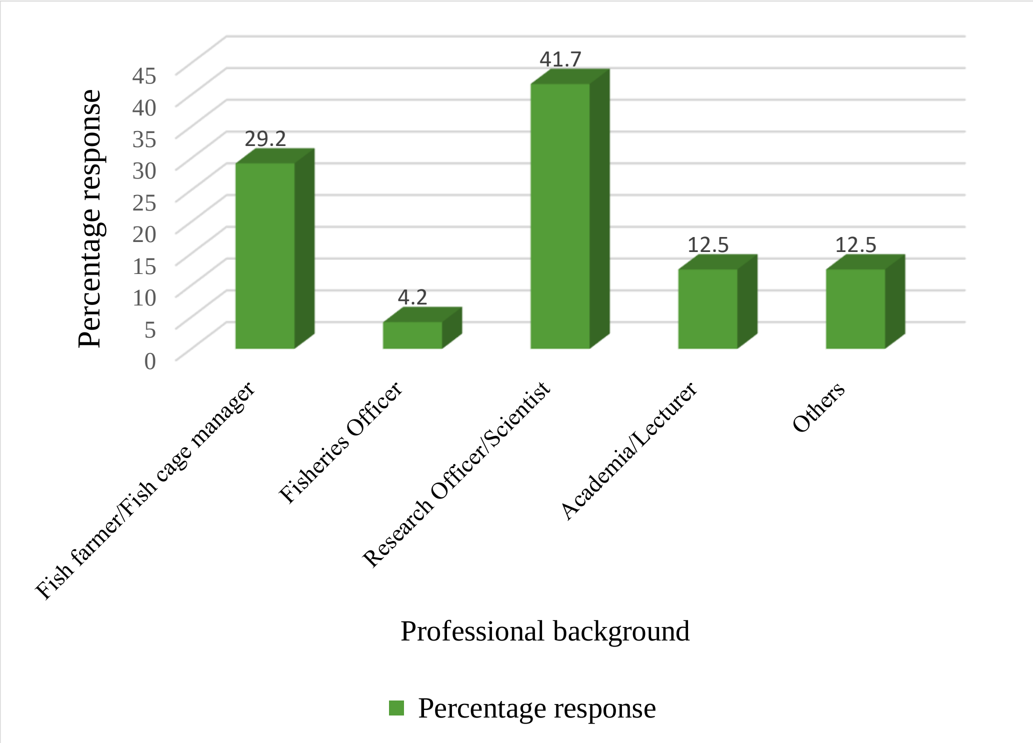

Figure 1: Professional background of the selected experts

3.2 Experts' opinions on fish feed challenges and their severity

The experts ranked the high cost of feed (87.5%) to be the most serious fish feed challenge, followed by lack of access to feed (50%) (see Table 2). A shortage of ingredients, a lack of knowledge about feed formulation and poor feed-processing technologies were ranked third (33.3%) in terms of severity. Poor feed quality and high transport, storage and handling costs were ranked the lowest among the very serious challenges, at 29.2% and 16.7% respectively. The challenges of high costs and lack of access to feed have been reported in previous studies done in Kenya as main challenges facing the fish and aquaculture industry (Munguti *et al*. 2014). Shitote *et al*. (2013) concur that the lack and cost of commercially produced feeds and use of low pond-management practices has resulted in the stagnation of fish farming, leading to household food insecurity and a small contribution to livelihoods in Kenya. Munguti *et al*. (2021a) state that the utilisation of inappropriate formulations is a common problem in Kenya. Their findings note that, in some cases, the fish farmers use commercial grow-out formulations that contain a more elevated level of dietary protein than is required, while others provide grow-outs feeds that are designed for other species. Other findings by Munguti *et al*.

(2021b) assert that many of the feed ingredients that are used in farm-made tilapia feeds are poorly milled and fail to conform to the recommended standards. The ingredients therefore have poor binding properties, which lead to low ingestion rates and high economic feed conversion ratios. Moreover, Beveridge *et al*. (2010) have noted that the success of small and medium-enterprise fish farming is due to strong markets, access to feed, credit and transport, and a focus on profits.

Table 1: List of the respondents' organisations/institutions

Name of organisation/institution	No. of experts interviewed	Percentage
Kenya Marine and Fisheries Research Institute (KMFRI)	7	29%
Jaramogi Oginga Odinga University of Science and Technology (JOOUST)	3	13%
Masinde Muliro University of Science and Technology (MMUST)	1	4%
Jomo Kenyatta University of Agriculture and Technology (JKUAT)	1	4%
African Institute for Development Policy (AFIDEP)	1	4%
Bundesinstitut für Risikobewertung (BfR)	1	4%
Kings Beta Fish Farm	1	4%
Lebed Cash Marine Enterprise Ltd	1	4%
Micro Enterprises Support Programme Trust (MESPT)	1	4%
World Bank	1	4%
University of the Highlands and Islands (UHI)	1	4%
Muga Fish Farm	1	4%
Rio Fish Ltd	1	4%
Lake View Fisheries Ltd	1	4%
Aquaculture private sector	1	4%
Agunja Hatchery	1	4%
Total	**24**	**100%**

Table 2: Experts' opinions on fish feed challenges and their severity

Fish feed challenges	N	Severity			
		Not a problem (%)	Minor problem (%)	Big Problem (%)	Very big problem (%)
High cost of feeds	24	0	4.2	8.3	87.5
Lack of access to fish feeds	24	16.7	12.5	20.8	50.0
Shortage of ingredients	24	8.3	4.2	54.2	33.3
Lack of knowledge about feed formulation	24	8.4	33.3	25.0	33.3
Poor feed-processing technologies	24	8.3	20.8	37.5	33.3
Poor feed quality	24	8.3	8.3	54.2	29.2
High transport, storage and handling costs	24	8.3	50.0	25	16.7

Experts were asked for their opinion on what fish farmers consider as key when purchasing fish feed, giving a choice between ingredient, cost and quality. The results are as displayed in Figure 2. Of the 24 experts. 79.17% were of the opinion that farmers chose cost as the key deciding factor when buying feeds, 12.50% were of the opinion that quality was the key determinant, while only 8.33% mentioned ingredients. This may be because most of the fish farmers do not know the ingredients of existing fish feeds. The statistical tests showed that the experts were in agreement on the key factor that fish farmers consider when purchasing fish feeds ($\chi^2 = 8.515$; P = 0.744).

3.3 Familiarity with insect-based feeds

The respondents were asked about their familiarity with insect-based feeds in Kenya. The results show that the majority (95.8%) had heard of the use of insect-based feeds in aquaculture in the country. The results were consistent among the respondents across the different professional backgrounds ($\chi^2 = 2.534$, P = 0.639). Further tests showed that there was no significant difference in awareness of insect-based feeds in Kenya based on the experts' years of professional experience (χ^2 = 11.478, P = 0.404). The participants in this research were thus very aware of the concept of BSFL meal in aquaculture, indicating high levels of knowledge on the topic being examined. Ssepuuya *et al*. (2019) found that familiarity with the use of insects and knowledge or awareness of their use significantly contributed to fish farmers' and traders' positive perceptions about their use in aquaculture. More than 50% of the experts agreed that feeding fish with insects is a traditional farming practice, while over 10% felt that using insect-based feeds is an unnatural feeding practice in fish farming. Similarly, previous studies indicate that insects are a natural food source for marine and freshwater fish species, including Nile tilapia (Njiru *et al*. 2004; Howe *et al*. 2014; Whitley & Bollens 2014) (see Figure 3).

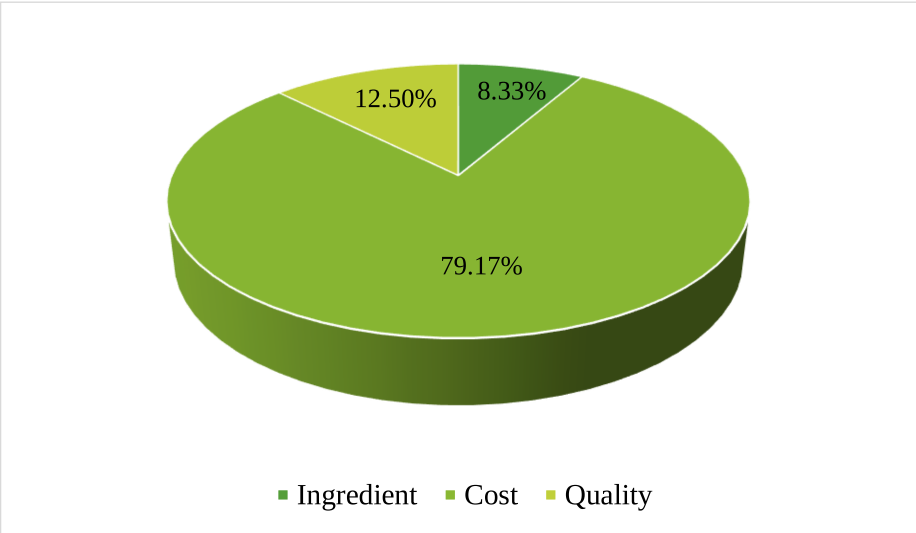

Figure 2: Key factors that fish farmers consider when purchasing fish feeds

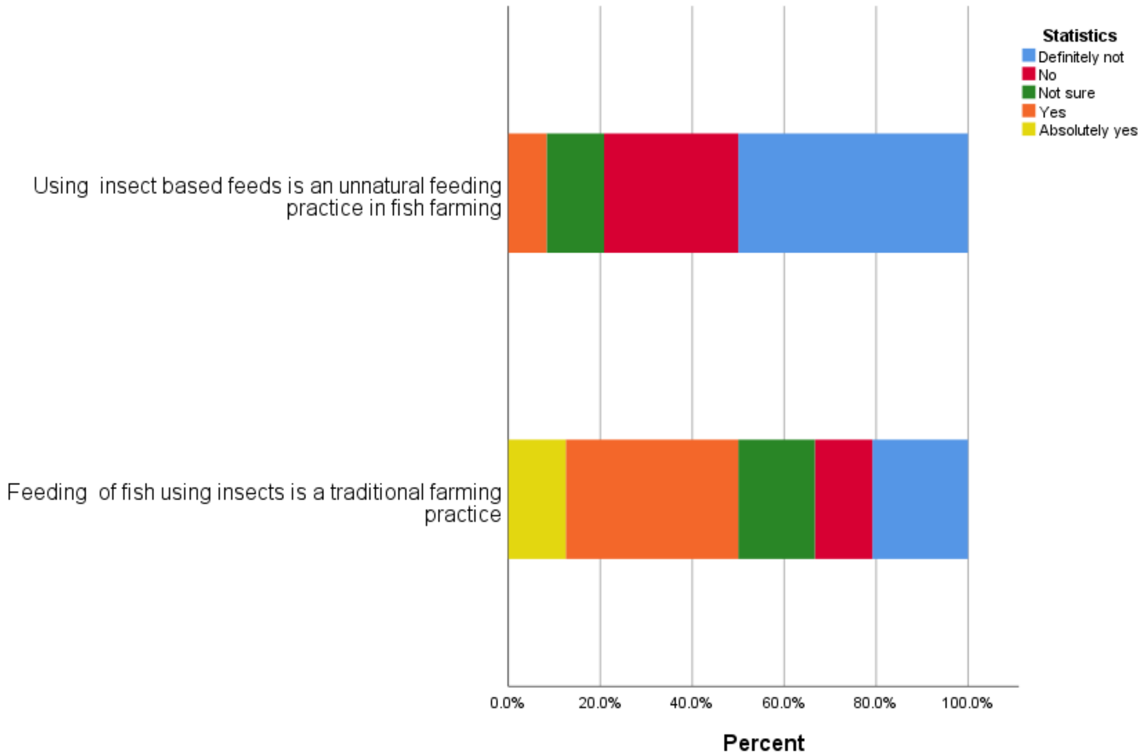

Figure 3: Experts' opinions on feeding insect-based feeds to fish

3.4 Perceived benefits and perceived risks of the use of black soldier fly meal in aquaculture

Table 3 provides a summary of the results of the means of various statements showing perceived benefits and risks relating to the use of BSFL in fish feed. A Likert scale was used to solicit responses from the experts, with a scale comprising (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree.

Table 3: Perceived benefits and risks regarding the use of black soldier fly meal in aquaculture

Perception statements	Mean	Std deviation	Cronbach's alpha
Perceived benefits			
Could allow organic waste to be better valorised	4.17	.917	0.911
Could allow sustainability to be improved	4.29	.908	
Could allow the production of enough fish for the world population	3.92	1.060	
May reduce the price of feed and fish production	4.42	.929	
Can improve society's acceptance of fish production	3.50	1.103	
Reduction in reliance on fishmeal	4.33	1.007	
Better nutritional value of fish	4.04	1.083	
Perceived risks			
May cause allergic reactions in humans	2.29	.859	0.748
May cause allergic reactions in fish	2.00	.780	
Can affect biodiversity if the BSFL are released accidentally	2.71	1.268	
May introduce microbiological contamination in fish feed supply chain	2.46	1.141	
BSFL farming can increase competitiveness with other agricultural activities	3.04	1.268	

Source: Survey data

The Cronbach's alpha for the benefit statements was 0.911, showing that the scores for the various benefit statements can be summed up in an overall score. The overall mean benefit score computed was 4.104, which was significantly higher than the average point of the scale ($t = 25.045$; $P < 0.000$). The strongest perceived benefits were that the use of insects in fish feed may reduce the price of feed and fish production (mean = 4.42), could reduce overreliance on fishmeal (mean = 4.33), could cause sustainability to be improved (mean = 4.29), could allow organic waste to be valorised better (mean = 4.17) and could improve the nutritional value of fish (mean = 4.04). The study participants were least convinced that BSFL would allow the production of enough fish for the world population (mean = 3.92) and could improve society's acceptance of fish production (mean = 3.50); however, these were still positive agreements.

The Cronbach's alpha for risk statements was 0.748, showing that the scores for the various risk statements can be summed up in an overall score. The overall mean risk score computed was 2.500 and was significant ($t = 16.022$; $P < 0.000$). The strongest perceived risks were that BSFL farming could increase competitiveness with other agricultural activities (mean = 3.04) and that the use of BSFL could affect biodiversity if the they were released accidentally (mean = 2.71), which generally indicated that, on average, the experts neither agreed nor disagreed that the issues constituted a potential risk. All other mean risk perceptions were below the mid-point scale, indicating that, on average, the study participants disagreed that the issues constituted potential risks.

A paired sample t-test ($t = 6.350$; $P < 0.001$) revealed a significant difference between the scores. Therefore, the researchers concluded that fish farmers have a significantly higher perception of the benefit of BSFL in aquafeed than they do of the risk. In conclusion, the perceptions of benefits were generally stronger and more outspoken than the perceptions of risk. Thus, there was a high degree of acceptance of BSFL meal among the experts. These findings are congruent with those of Verbeke *et al*. (2015), who found the perceived benefits of using insects as feed outweighed the perceived risks and concerns as determinants of insect feed acceptance. Similarly, Oppong (2017) found that the perceived benefits of BSFL-based fish feed outweighed the perceived risks among farmers in Ghana.

3.5 Important considerations when legalising BSFL meal in Kenya

In an attempt to assess the perceived importance to be placed on different considerations when legalising the use of BSFL meal in aquaculture in Kenya, Kendall's coefficient of concordance (W) was used to evaluate the level of agreement among the identified and ranked considerations of the experts, as in Table 4. Overall, the coefficient of concordance (W) was estimated at 0.156 and was statistically significant at 1%, showing agreement among the experts. This means that there was sufficient evidence that there was an agreement among the experts on the identified considerations. Consequently, this justifies the ranking of the important considerations as presented by the experts.

Table 4: Ranking of important considerations when legalising BSFL meal in Kenya

Variables of importance	Mean rank	Rank position
Sanitary policy and inspection	7.25	1
Feed safety	7.23	2
Environmental impacts	6.69	3
Fish quality	6.65	4
Feed prices	6.48	5
Traceability	6.06	6
Profitability	5.65	7
Fish farmers' acceptance	5.25	8
Efficient use of resources	5.17	9
Labelling of the end product	5.15	10
Perception of the fish industry	4.44	11

Kendall coefficient of concordance (W^a) = 0.156; Chi-square = 38.254; DF = 10, $P < 0.001$; Cronbach's alpha (α) = 0.839. The rankings were in terms of relative importance on an ordinal scale from 1 (not important at all) to 5 (very important).

Sanitary policy and inspection were ranked the number one (1) most important consideration, followed by feed safety in second place, and environmental impacts and fish quality as third and fourth ranked most important considerations respectively. The perception of the fish industry was ranked as the least important consideration when considering legalising BSFL in aquaculture. Similarly, previous studies indicate that the production constraints associated with insects as feed include the possibility that insects may contain anti-nutrient properties, food safety concerns (Van Huis 2016; Dobermann *et al*. 2017), may be pathogen carriers or may contain residues of pesticides (Makkar *et al*. 2014). Insect farming also requires standardisation and quality control, a goal that requires government legislation and regulations (Han *et al*. 2017).

Feed manufacturers are willing to include insects in their feed formulation, given favourable legislation and marketplace acceptance (AllAboutFeed 2014). According to a study in Malawi by Mulumpwa (2018), the incorporation of insect meal in fish feed could replace soybean and fish meal, hence turning the fish industry in the country around by making it more productive. Since insect meals are considered processed animal protein (PAP), they must comply with the respective legal constraints associated with PAP legislation to guarantee their safety for use as fish feed ingredients (Belghit *et al*. 2019).

Sanitary policy and inspection are very critical in aquaculture. Embaby *et al*. (2015) note that, during processing, a feed can be contaminated with fungal spores in cases where grains are ground and feed pelleted. Some feed storage practices and processing methods include environmental temperatures of greater than 27°C, humidity levels higher than 62%, and moisture levels in the feed above 14%, which may result in mycotoxin production (Mahfouz & Sherif 2015). The exposure of fish to mycotoxigenic fungi may subsequently reduce their growth rate, reduce immune responsiveness, damage the liver and lead to a steady and gradual decline in the quality of reared fish stock, thereby posing serious challenges to aquaculture (Fallah *et al*. 2014).

A key consideration of any new feed product is the safety and acceptability of the product, which needs to be free of contaminants such as pathogens, bacteria, chemicals, toxins and heavy metals (DiGiacomo & Leury 2019). These considerations need to be made specifically for each species of insect reared and for each species that is to be fed the insect diets. BSFs are not disease vectors as they do not lay their eggs on decaying organic materials and the adults do not eat decayed materials (Van Huis *et al*. 2013). BSFL larvae reared on substrates spiked with heavy metals (As, Cd, Pb, Hg, Cr and Ni) accumulated Cd and Pb in significant quantities, while As in larvae was at the same concentration as that found in the rearing material (Cai *et al*. 2018). BSFL larvae have demonstrated the ability to consume feeds containing mycotoxins and pesticides and remove these toxins so that the resultant larvae/mealworms do not accumulate the toxins (Cai *et al*. 2018, Van der Fels-Klerx *et al*. 2018). In addition, pesticides were not accumulated in BSF larvae reared on substrates spiked with pesticides (chlorpyrifos, chlorpyrifos-methyl and pirimiphos-methyl) (Purschke *et al*. 2017).

Marijani *et al*. (2017) note that, although fish feed quality standards exist in the East African countries, including Kenya, standards for the manufacture, distribution, storage and handling of ingredients are either non-existent or not strictly regulated by law. Proper screening of substrates for their protein content can also contribute to improved larval protein quantity and quality (St-Hilaire *et al*. 2007; Tschirner & Simon 2015). The type of insect-rearing substrate affects the insects' amino acid composition. For example, black soldier fly larvae raised on swine manure had a different amino acid composition compared to those raised on cow manure (Newton *et al*. 2005).

Feed prices are also an important consideration. The market price of dried BSFL range from US$ 1.1 to US$ 1.4 per kg (Tanga *et al*. 2021). Comparing break-even sales prices of feeds that include BSF meal as a protein source with prices of conventional feeds in West Africa indicates that insect meals are competitive with feeds based on fishmeal as a protein source (Roffeis *et al*. 2018).

Environmental impacts were also considered by the experts to be a key factor when considering legislating BSFL. The breeding of insects for feed is considered to be more environmentally friendly than the soybean meal and fishmeal protein sources used as feed in aquaculture. This is in tandem with previous findings, such as those of Smetana *et al*. (2019), who showed that the production of 1 kg of BSFL resulted in less land use, less CO_2 production, and less water use than the production of both soybean meal and fishmeal. However, there are some concerns about the effect of edible insects possibly escaping into the environment and becoming invasive to natural and production systems in non-native countries. This concern is similar to that raised by Thrastardottir *et al*. (2021) in Iceland, where an environmental risk assessment for BSF was performed before receiving a licence from the Icelandic authorities for import and trials. Their results show that BSF posed no threat to the local insect environment and that it was highly unlikely that a wild population could form if they did manage to escape, possibly because BSF is a tropical species and cannot survive in the cold climate of Iceland.

3.6 Factors driving the adoption of BSFL in fish production

The study sought opinions about the possible factors driving the adoption of BSFL in fish farming. The summary of rankings of the possible driving factors is shown in Figure 4. When the ranks of those who agreed and strongly agreed are summed, the most important driving factor was found to be creating and enhancing fish farmers' awareness on the benefits of BSFL in fish production (100%), followed by identifying pioneer farmers of safe BSFL production and their introduction as leading farmers (95.9%), and reasonable pricing of BSFL-based feeds to motivate producers and fish farmers (95.9%). These findings confirm those of Khaemba *et al*. (2021), whose research demonstrates that increased awareness creation and evidence-based demonstration of the benefits of BSFL-based feed would improve consumer perceptions and foster uptake of this emerging and rapidly growing technology. Consequently, campaigns on the creation of awareness of the potential role of insects as an innovative food or feed resource to supply the needs of an ever-increasing human population have gained momentum (Van Huis *et al*. 2013). Feed costs account for up to 80% of a farmer's total production costs (Van der Poel *et al*. 2013), leaving the resource-poor farmers with very small profit margins. Thus, reasonable pricing of BSFL will play a critical role in reducing the cost of production and improving the profitability of small-scale farmers.

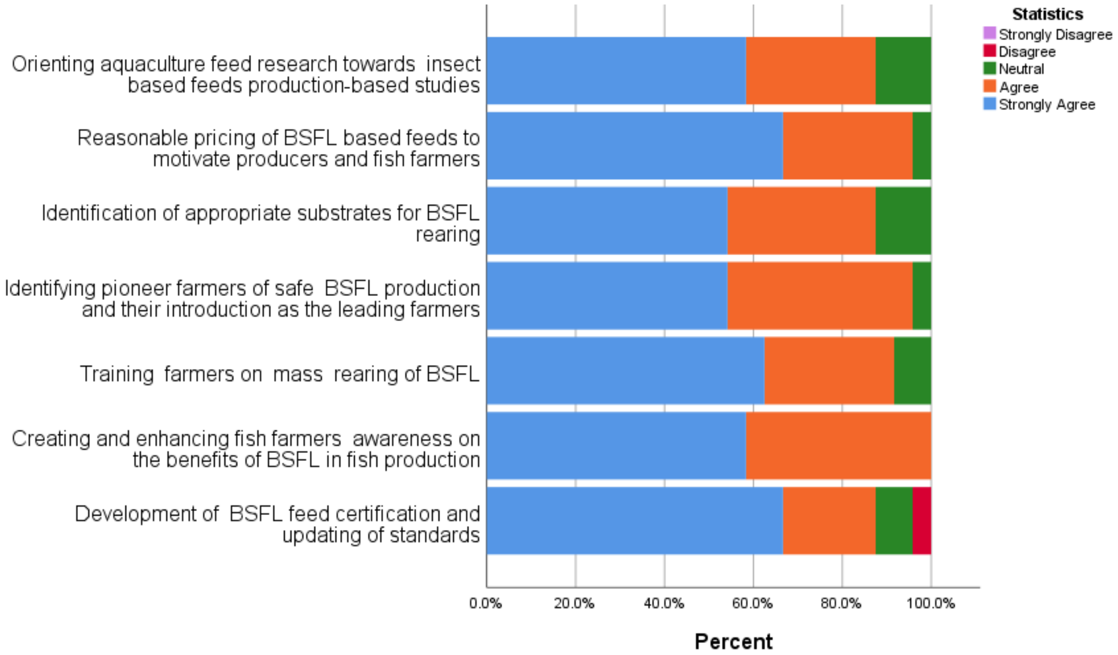

Figure 4: Factors driving the promotion of adopting BSFL in fish production

4. Conclusions and policy recommendations

The importance of investigating and using insect meals as alternative sources of protein ingredients in aquaculture is increasingly gaining relevance. This study is one of the first to report on stakeholders' opinions on the use of BSFL as an alternative sustainable ingredient in aquaculture in Kenya, including stakeholders from different fields of competence and stakeholder groups comprising aquaculture and insect value chain experts. The primary findings of this research are that there is consensus among experts on the potential use of BSFL in aquaculture in Kenya. A majority of experts indicated that the high cost of feeds (87.5%) and lack of access to feeds (50%) are the most serious fish feed challenges in Kenya. Furthermore, a majority of the experts (79.17%) were of the opinion that farmers choose cost as the key deciding factor when buying feed. In terms of awareness of the use of insect-based feeds, the majority of experts (95.8%) had heard of the use of insect-based feeds in aquaculture in Kenya. In terms of perceived benefits and risks of using BSFL in aquaculture, the perceptions of benefits were generally stronger and more outspoken than risk perceptions. Thus, from these results, it would appear that there are consistently positive attitudes exist towards BSFL in aquaculture, regardless of stakeholder group or field of competence.

The findings of this study can inform policymakers to support BSFL integration into large-scale commercial feed manufacturing and enhance sustainable intensification of aquaculture production, thereby contributing significantly to food and nutritional security in the country. Awareness of these perspectives is expected to promote the exchange of ideas and knowledge among policy and decision-makers and to support the development of BSFL as aquafeed.

Academia, government and industries should collaborate closely to ensure further research on and the development of technology for the use of BSFL in aquaculture, and fish farmers and insect farmers should be engaged in the process. This might increase the acceptance of BSFL in aquaculture. Legislative decisions on the introduction of this alternative feed source have to be based on the results of studies investigating sanitary policy and inspection, and the safety of BSFL meal for farmed fish. Although the results are promising, BSFL meal is not common in the market, and therefore further work to promote its rearing using locally available substrates and various processing methods and commercialisation is needed to achieve the full potential of its use as a protein ingredient in aquafeeds.

The use of an online platform to elicit opinion provides both advantages – in its potential to maximise coverage of diverse stakeholder groups given limited resources, and disadvantages – in the collection of relatively superficial information using a survey-type approach, which can have limited response rates in certain groups and hence has the potential for bias. To overcome these limitations, this study should be viewed as a scoping investigation. The study recommends that future research should use these findings as a baseline to delve further. This work preferably should be followed up by a form of in-depth interviews or workshops with key representatives, and with a focus on sustainability aspects.

Acknowledgements

The collection of data for this study was funded by Jaramogi Oginga Odinga University of Science and Technology (JOOUST) through the African Centre of Excellence in Sustainable Use of Insects as Food and Feeds (INSEFOODS) project funded by the World Bank. Additional research funds were received from Feed the Future/University of Pretoria, South Africa.

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