Environmental Technology & Innovation 32 (2023) 103260

Contents lists available at ScienceDirect

Environmental Technology & Innovation

journal homepage: www.elsevier.com/locate/eti

Exploring Insect-based technology for waste management and livestock feeding in selected South and East Asian countries

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ARTICLE INFO

Article history:
Received 20 March 2023
Received in revised form 19 June 2023
Accepted 20 June 2023
Available online 28 June 2023

Keywords:
Black soldier fly larvae (BSFL)
Organic waste management
Livestock
Sustainable developments
Public perception and acceptance
Dependence on subject erudition

ABSTRACT

This paper aimed to investigate the Asian's willingness to use black soldier fly larvae for organic waste management and livestock feed. A random sampling method was adopted based on waste generation and substrate availability. In addition, it contributes to filling gaps in research into public acceptance, social perception, and Attitude towards BSFL-based organic waste management. It has been found that different subgroups in different countries have inconsistent attitudes towards using BSFL technology. Stack group in Afghanistan (3.94 ± 0.90), Pakistan (4.45 ± 0.61), China (4.48 ± 0.54) highly agree, and Bangladesh (3.21 ± 0.57) agree, but the other groups are not sure or show different perceptions. The results of our study indicate that BSFL is a more acceptable feed supplement than conventional food; participants rated their willingness to blend 500 grams of BSFL with conventional feed and preferred to feed livestock, dogs, fish, birds, and cats. It is established that most of the respondents were familiar with the BSFL technology, namely in China (3.58 ± 0.87), Bangladesh (3.55 ± 0.8), Pakistan (3.24 ± 0.82), Afghanistan (2.63 ± 0.5). The waste group with the mean value from Afghanistan (2.87 ± 0.76), Bangladesh (2.74 ± 1.41), China (2.76 ± 1.12), and Pakistan (2.78 ± 1.28). Finally, the article shows a direct relationship between public acceptance of BSFL for waste management and subject erudition.

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https://doi.org/10.1016/j.eti.2023.103260

1. Introduction

Rapid urbanization, demographic changes, consumer behaviors, and unsustainable social and economic developments with environmental repercussions have challenged governments and decision-makers to manage solid waste sustainably and economically (Ma et al., 2022). Today, the world population is about 8.04 billion people, and there is an annual increase in the world's population by more than 90 million people (https://countrymeters.info/en/World). Approximately 2 billion metric tons of solid waste are generated yearly without proper disposal strategies. The world population is expected to be 9.8 billion by 2050, with about 40% living in low- and middle-income countries (Pas et al., 2022). Most waste collection and treatment in developed nations are associated with high costs and are challenging for countries with low and moderate incomes (Ahmed et al., 2023). Different techniques are applied for waste management, including biological treatment, Anaerobic digestion, composting, vermicomposting, and landfilling (Demetrious et al., 2019; Varjani et al., 2021). Thermochemical treatment, incineration, pyrolysis, and gasification (Dong et al., 2018). Each technique has advantages as considered a route for the conversion of terrestrial waste into biogas, biofuels, and other converted products or ways to control waste where it converts into valuable nutrients which can be applied into the agricultural field, along with a chain of and disadvantages, including adverse environmental consequences like greenhouse gases, global warming climatic change and disturbance of flora and fauna of ecosystem (Lau et al., 2023).

The significant lacunae in waste management lie in the inefficiency of present technologies in promoting valuable waste utilization in reuse and recycling systems (Oertel et al., 2016). The current solid waste management policies are restricted to the collection, transportation, treatment, and disposal and lack large-scale valorization of organic-rich waste. Putrescible organic waste represents the most considerable portion of solid waste and is characterized by high nutrient value (Salam et al., 2021; Awasthi et al., 2022). Capturing this inherent organic waste value could alleviate the environmental consequences to a greater extent and simultaneously serve food, fodder, or other products of commercial interest.

Putrescible organic waste can be directly used as feed for livestock and animals (Pinotti et al., 2021). Contributing to reducing the "food footprint" of animal farming, which consumes over a third of global grain production (Sun et al., 2020). Moreover, insects could efficiently bio-process unavoidable food waste into valuable larval biomass suitable for animal feed (Torok et al., 2021). Establishing such a circular food system would simultaneously reduce both the negative environmental impacts of waste going to landfill and intensive livestock production and meet the need for increased livestock feed to successfully establish a waste-to-livestock feed industry (Abdel-Shafy and Mansour, 2018). Using limited resources for food and feed production in an ever-increasing and non-sustainable way, coupled with the generation of large quantities of organic waste, poses many environmental, economic, and public health concerns. A more sustainable, environmentally friendly, and technically feasible approach towards waste management is essential for food and feed production. This is why insect farming on organic waste provides an avenue for waste bioremediation and nutrient-rich feed and organic fertilizer production (Vyas et al., 2022).

Insect farming on various organic wastes, such as food waste and animal manure, represents sustainable and economically viable treatment technology, which can reduce organic waste by 25%–72% (dry matter basis) (Singh et al., 2021). In addition to waste stabilization, black soldier fly larvae (BSFL) *Hermetia illucens* L. metabolize large quantities of organic residues into larval biomass, rich in protein and lipid, which can be used as a source in livestock feed (El Deen et al., 2023).

BSFL technology is particularly appropriate for developing countries, such as Asian countries, due to a lack of funding for safe and environmentally friendly waste management and food shortages; however, whether animal foods made from insects will become established in the coming years depends largely on their public acceptance. Lack of adequate scientific knowledge of insect technology among the population may significantly slow down this prospect, and more efforts are required to improve public acceptance. However, BSF larvae have been considered the most acceptable option for converting organic waste into feed (Mohan et al., 2022; Ordieres and Cultrone, 2022). Public acceptance in the Asian context remains largely unknown, as well as the potential of BSFL technology for the bioconversion of organic wastes into value-added products (Albizzati et al., 2021). Only a few commercial organic waste bioconversion facilities have used the BSFL technology (Wehry et al., 2022).

Previously no studies have been carried out to demonstrate how stakeholders, solid waste management organizations, and residents respond to the application of BSFL in sustainable waste management, biomass production, and use as a feed for livestock as well as its economic and environmental advantage. It is essential to assess public opinion, perception, social acceptance, and willingness towards new technologies like BSFL before implementing them in specialized enterprises in developing countries. The specific objectives of the current study are as follows:

(i) To evaluate the environmental appropriateness, economic advantages, and local acceptance of BSFL as a sustainable waste management technique; To understand the attitudes and practices of diverse communities, particularly in China, Bangladesh, Afghanistan, and Pakistan, towards BSFL-based animal feed; (iii) To identify possible barriers or deterrents to the acceptability and use of BSFL-based feed in different livestock; (iv) To investigate the impact and perception of BSFL as a cost-effective and sustainable waste management solution, and its significant contribution to the animal feed industry, particularly in developing countries; (v) To contribute to future studies on the impact of BSFL-based feed on local market systems and its potential for encouraging business prospects and employment development.

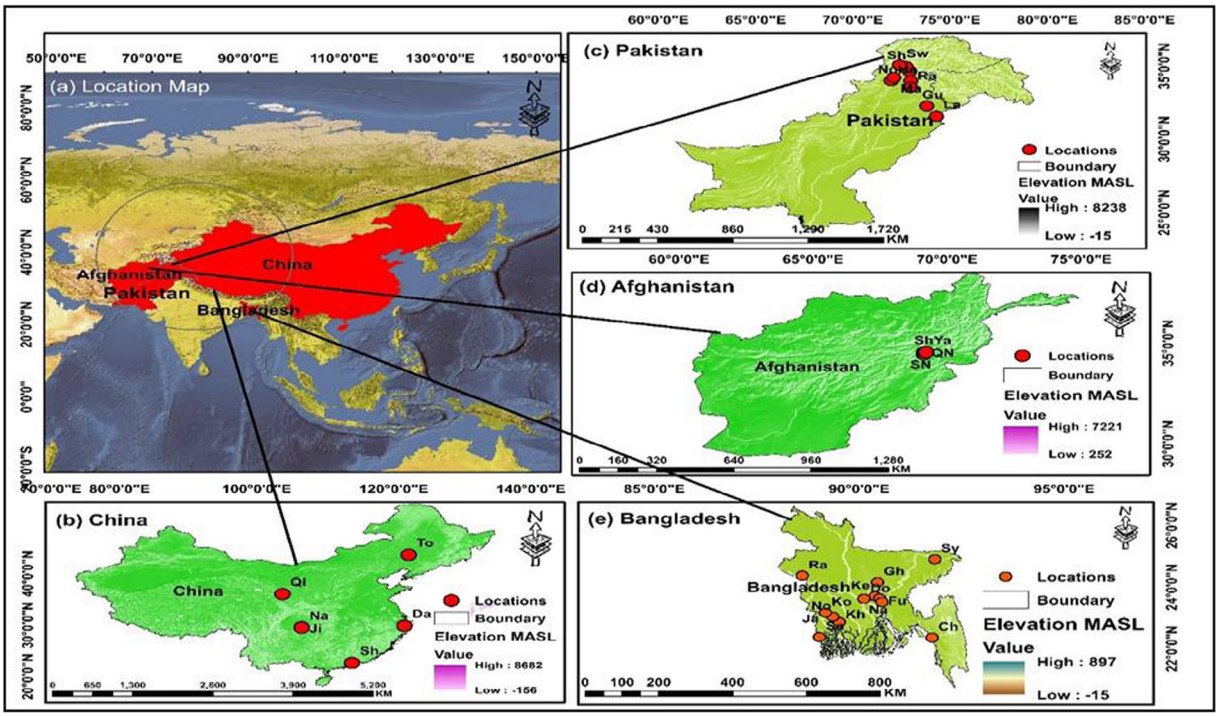

Fig. 1. Map representing the four study areas (countries) in Southern Asia.

2. Materials and methods

2.1. Methodology

This study was conducted in four countries, including China and three South Eastern countries: Pakistan, Afghanistan, and Bangladesh (Fig. 1), where BSFL can play a significant role in resolving the problems of waste mismanagement, livestock feed at their low operating costs, required minimum place, easy handling, and public requests Chongqing (China) was selected among the study areas because two factories were recently established to treat 10 tons of waste daily. Afghanistan and Bangladesh were also chosen because the location and temperate appear suitable for BSF farming to treat waste and produce biomass.

A random sampling method was adopted based on waste generation and the availability of adequate waste management strategies (Sohoo et al., 2021), keeping the significance of random sampling ensures that results obtained from the sample should approximate what would have been obtained if the entire population had been measured, to assess general knowledge of BSFL farming and the engagement of Stack, Local, and Waste groups in the research region (China, Pakistan, Afghanistan, and Bangladesh). The term 'Stack' refers to persons concerned in livestock management and feed handling, whereas 'Waste' refers to individuals or businesses involved in waste management or production, while the 'Local' resident keeps animals in their house for different purposes. The selection of these countries was based on their varying conditions, which renders them suitable settings for evaluating the overall knowledge of Black Soldier Fly Larvae (BSFL) farming. The criteria for sampling were based on ten years of environmental conditions (temperature, humidity, substrate availability) and substrate characteristics. Sampling involved local animal food dealers, shopkeepers or industrial managers, entrepreneurs, farmers or workers, and solid waste management organizations. Participation in the study was restricted to persons responsible for waste management, aged 18 years, and familiar with organic waste, livestock, and food facilities. A total of two thousand four hundred (2400) persons (600 per country) were recruited into the study as respondents. Data were collected using structured questionnaires and interviews designed to document perception, attitude, social acceptance, and willingness to use (WTU) the BSFL as feed for livestock and were assessed on a five-point Likert scale from point 1 (Highly disagree) to 5 (Highly agree). The five-point Likert scale is one of the most reliable ways to measure a person's opinions, attitudes, and behavior. It gives a more precise answer than the simple Yes/No result by providing different opinions.

During the survey, the BSF, eggs, and adults were photographed and shown to the participant with a brief introduction (translated into each participant's preferred language). Participants were compensated with a modest sum in each country for their time.

2.2. Statistical analysis

Data were classified and analyzed qualitatively (interviews and surveys) and quantitatively (close-ended questionnaires). To determine whether or not the results of the questionnaires had any significant statistical bearing, data were subjected to a statistical analysis using the statistical package for social science" (SPSS, V21.0). Prisms from Origin and GraphPad were used to create the graphs.

2.3. Ethical consideration and limitations of the study

This study sort participants' consent and ensured that all personal information was protected. Participation in the interviews and questionnaire studies was voluntary, and each participant's safety was assured. COVID-19 restrictions limited face-to-face interviews, and some language barriers were encountered. However, this did not affect the data quality because appropriate measures, such as online-based interviews, were conducted where physical meetings were impossible. Furthermore, Native speakers were recruited in each study area to translate interview and questionnaire questions.

3. Results

3.1. Participant perception of BSFL technology

The familiarity with BSFL technology varies significantly across countries and subgroups of countries. The question "Are you familiar with BSFL" generates respondents average responses and is analyzed by measuring standard deviation (SD). Table 1, 2 and 3 (SI). The familiarity with BSFL technology, Pakistan's local group responded to an understanding with a mean value of (4.24 ± 0.84) while Stakeholder groups (4.35 ± 0.71) gave highly agreeable responses. Residents are familiar with the BSFL but are questioned about its benefits, whereas stakeholders know its economic value. The Waste group was also friendly to familiarity (3.86 ± 0.08) and experience (4.17 ± 0.77) as they know there may be positive benefits to using it as a product.

Similarly, the Stack group in Bangladesh was highly familiar (4.24 ± 0.8), agreed to have experience with BSFL consumption response, and showed a mean (3.57 ± 1.19). The local group in Bangladesh also showed a mean value of (3.55 ± 0.8) with an agreed familiarity response. Still, the Waste group responded with a (3.13 ± 0.75) mean value for familiarity and a statement regarding experience with a mean value (3.91 ± 0.91). The suppressed mean generated by the waste group was due to the perception of some adverse effects of using this technology. However, only the Stack group with a mean value (3.82 ± 0.87) of the three groups in Afghanistan agreed with the familiarity of BSFL technology. Neither the Local (3.1 ± 0.7) nor the Waste group (3.08 ± 0.78) was sure of their understanding of BSFL because they were uneducated and primarily unaware of new technologies' lack of knowledge and resources. The response of the local Chinese group to the same question has a mean value (3.7 ± 0.82), Stack group (4.42 ± 0.6), and Waste group (4.2 ± 0.79). Almost identical results emerged for the statement 'I know the importance of BSFL technology,' with only slightly changing the question scores' ranking as presented in Table 1, 2 and 3 (SI). This means that those familiar with BSFL technology also acknowledge the importance of BSFL technology. None of them responded as agreed to the question 'I practiced/eaten BSFL technology made food for animals, but the ratings were ranked overall high in China (3.58 ± 0.87) followed by Bangladesh (3.55 ± 0.8), Pakistan (3.24 ± 0.82) and Afghanistan (2.63 ± 0.5)

This indicates that familiarity with the BSFL technology is not necessarily correlated with past practices indicating that people are advancing and exploring new food techniques to meet the required food demand. Various subgroups in various countries have inconsistent attitudes towards using BSFL technology to make food for animals and give it to the animals they raise. The Stack group in Afghanistan (3.94 ± 0.90) and Pakistan (4.45 ± 0.61) highly agree, but the other two groups in Afghanistan are unsure. The Stack group in China (4.48 ± 0.54) and Bangladesh (3.21 ± 0.57) highly agrees and agree, but the other two groups, local (3.58 ± 1.1) and waste (4.28 ± 0.77), show different perception.

3.2. Important issues concerning the consumption of BSFL-based feeds

The question "The important factors regarding the BSFL-based feed consumption" had the lowest mean rating of (3.22 ± 1.06) from the Pakistan local group and the highest mean rating of (3.94 ± 1.01) from China. Important factors influencing the consumer's behavior to opt BSFL as feed source. These factors may include price level, nutrition demands, pathogenic behavior, and available substrate values. Pakistani locals responded positively about the dietary benefits of BSFL-based animal feed, ranging from (3.63 ± 1.14) for the Stack group to the Waste group (3.0 ± 0.99). Respondents broadly agreed upon the nutritional qualities of BSFL-based feed products in Bangladesh and China. In Bangladesh, local groups (3.22 ± 1.06) and the waste groups (3.52 ± 0.9) are more concerned about the usage of BSFL as a feed source due to its nutritional benefits, with a mean value of (3.66 ± 0.97) among the waste group while in the local group (3.42 ± 0.94). The stack group is more concerned about the cost of the BSFL rearing system (3.22 ± 1.06), but by providing awareness to them about the cost and benefits of BSFL technology and the use of this technology as a business while progressing towards the SDGs mentioned in Fig. 4. could satisfy their disquiet. While in China, the Local group is more inclined to use

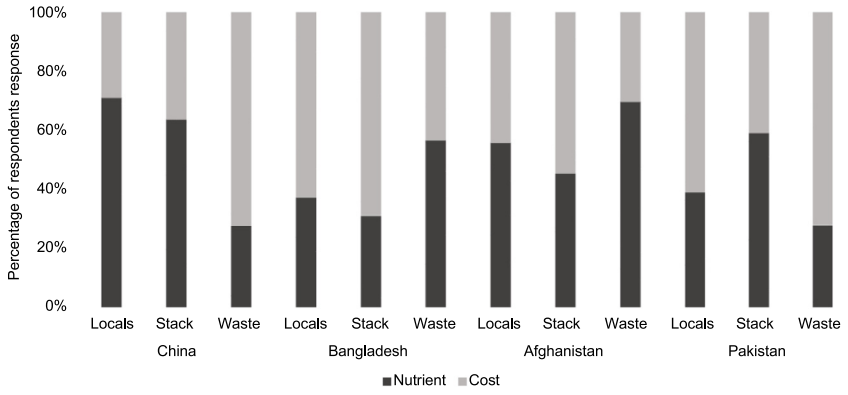

Fig. 2. Important factors concerning the consumption of BSFL-based feeds.

the BSFL as a feed source as they believe that BSFL can provide nutritional benefits with a mean value of (3.53 ± 0.82). The stack and waste group know that BSFL is a cost-effective process; therefore, they agree to use the BSFL as a feed source with the mean value of (3.61 ± 1.06) and (4.05 ± 1) as shown in Fig. 2. Locals of Afghanistan (2.83 ± 1.06) to initiate the BSFL rearing system to make feed for their animals. Still, they are highly concerned with essential factors with a mean value of (3.73 ± 1.2) to the nutritional benefits of BSFL as a feed as compared to the conventional feed products, including wheat straw, grasses, and seasonal straw hay and for stack, and waste scored mean value (3.56 ± 1.08) and (3.73 ± 1.2) respectively.

The primary issue of the local group of all countries regarding BSFL-based feed is the cost compared to conventional food. Locals of China and Bangladesh are most concerned about prices, while Pakistan and Afghanistan showed underrated responses. Following the locals, the stack group of all countries showed vital concern, indicating their choices can be significantly influenced due to price factors.

3.2.1. Attitude towards the advantages of BSFL

Many attributes can influence food acceptance, such as nutritional value, quality, substrate nature, beneficial health effects, and the expected taste and geographical origin. The researchers also asked respondents about their attitudes towards the advantages of the BSFL itself and its by-products and the ability to optimize the environment and reduce organic waste. Table 2 presents the data for questions including I will go for BSFL fat or proteins if they are extracted and used as manufacturing ingredients for cattle/poultry feed and "I would mainly select to feed" presents choices, feedback and attitudes of respondents. In all four countries, there were no 'Disagree' responses, but 'Not sure', 'Agree,' or 'Highly Agree' towards the advantages of BSFL. The local group in Afghanistan and Bangladesh are unsure due to a lack of knowledge about using BSFL as an animal feed with mean values of (3.1 ± 0.43) and (3.37 ± 0.77). At the same time, the local groups in China (3.57 ± 0.76) and Pakistan (3.99 ± 0.89) are pleased with the benefits of BSFL. Local groups in China and Pakistan will switch from their traditional feed source if provided with good instruction and information about BSFL. The question "The acceptable form of BSFL reared on other waste was in favor of food waste according to the survey results. In All countries, subgroups who responded to the survey were enthused about possibly employing food and animal waste to grow BSFL to manufacture animal feed. The question statement 'BSFL reduces organic waste, will impact my BSFL feed buying choice for livestock", all three groups in Afghanistan with the mean value for the local group is (4.29 ± 0.57) for the stack group (3.84 ± 1.34), and the waste group (4.29 ± 0.57) with highly agree on the result.

While the local, stack, and waste groups in Bangladesh (4.38 ± 0.66; 3.5 ± 1.42; 4.38 ± 0.66), China (4.21 ± 0.84, 3.78 ± 1.13, 3.36 ± 1.51) and Pakistan (3.5 ± 1.42, 3.85 ± 1.31, 3.88 ± 1.3) are agreed on the usage of food waste. The waste group in China only preferred animal waste to rear BSFL because they believed that food waste is more acceptable among all three groups.

3.2.2. Social acceptance towardsBSFL as food for livestock

Our results show that respondents' preferences for BSFL made into animal feed differ across subgroups in different countries. In the question statement 'we like some BSFL-mediated food product after growing on waste,' Afghanistan ranked stack (2.9 ± 1.16), local (2.83 ± 1.06) and waste group (2.83 ± 1.06) with a moderate rating and were not significantly positive when faced to trials of BSFL-made food for their animals. The same question was rated as agree in the rest of the countries. The response in Bangladesh was seen as a stack (3.15 ± 1.27) local (3.82 ± 0.57) and waste (3.82 ± 0.57), while the mean response for stack (3.13 ± 0.99) regional (3.34 ± 1.12) and destruction (3.26 ± 0.96) recorded in Pakistan. The stack group in China responded as (3.31 ± 0.92) locals with a mean (3.63 ± 0.75), and the waste group as (3.22 ± 1.06) also showed an agreed-on response as shown in table 3 (SI)

In response to the question, "My preferred animal to feed with BSFL-based ingredients",. The waste group with the mean value from Afghanistan (2.87 ± 0.76), Bangladesh (2.74 ± 1.41), China (2.76 ± 1.12), and Pakistan (2.78 ± 1.28)

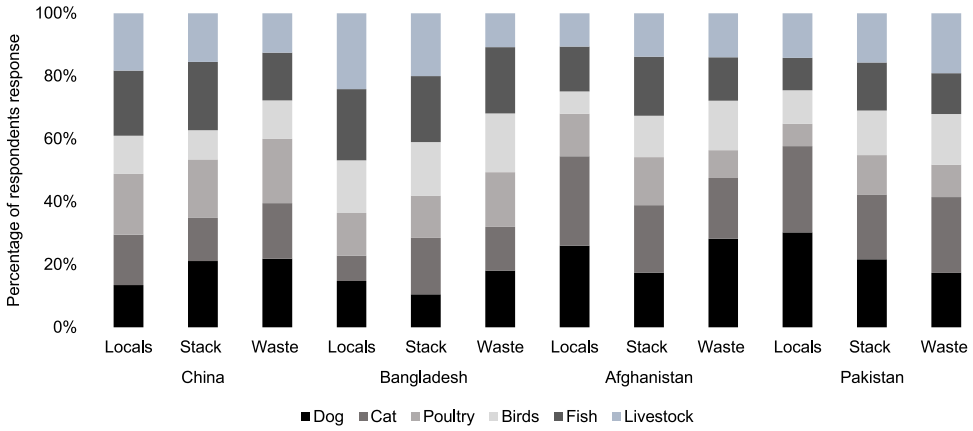

Fig. 3. Social acceptance towards BSFL as feed for livestock.

preferred to feed their dog, fish, birds, and cats as shown in Fig. 3. The stack group and locals of Bangladesh, China, and Pakistan responded the same as of their waste group and disagreed with the Statement however only stack group in Afghanistan agreed with a mean value (3.22 ± 1.04). In contrast, locals disagree, as shown in Table 1(SI). The low generated value for this question shows that social acceptability is poor for animals other than cats and dogs since they prefer direct plant-based feed. However, the difference is that the former's ambition is highly agreed upon while the latter is Not sure, which may be due to the significant difference within the group. At the same time, all groups agreed that 'Pilot study results revealed the animals' health improvement, better protein content and fast growth rate with BSFL feed", motivating them to opt for BSFL food selection'. The respondents' attitudes were generally positive regarding the advantages of BSFL.

3.3. Participants' perception of the application of BSFL technology

Waste, stack holders, and local groups in Afghanistan, Bangladesh, and Pakistan are gradually learning about the advantages of BSFL technology; as they are surveyed, their attitudes were not consistent on the issue of "My acceptance level for secondary consumers will increase, if BSFL is used to rear primary consumers (Rat/grasshopper/crabs) and then primary consumers are used to feeding secondary consumers (Cat/birds, etc.)" as presented in table 3 (SI). In the three groups in Afghanistan, this question was rated local (3.88 ± 0.94) acceptable, stack (4.28 ± 0.68) highly satisfactory, and waste group (3.88 ± 0.94) acceptable. While results in the Waste in Bangladesh, China, and Pakistan groups responded as (3.71 ± 1, 4.22 ± 0.79) and (3.88 ± 1.11) generated an agreed response. This indicates that respondents are highly aware of the safety of the food sources of the animals they raise, and it also reflects some of the public's concerns. The stack group of all three countries also favors the acceptance level for secondary consumers' feed if BSFL is used to rear primary consumers. Only locals in China and Bangladesh disagree with having a mean of (2.93 ± 0.92) however, locals of Pakistan agreed, unlike locals of China and Bangladesh.

Our survey showed different results, with Highly agreeing and Agree responses to the question "I like some BSFL-mediated food product after growing on waste" in nine groups in three countries. The respondents were not resistant to the idea of a high-protein food made from BSFL All eight groups agreed or highly agreed, except for the Local group in Bangladesh, which was unsure of its opinion. On the question, "My cultural values would be flexible enough to allow mixed waste, waste has grown BSFL usage for animal feed production", the respondents' opinions diverged significantly.

Respondents from all three groups in Afghanistan opposed the use of waste-grown (human or animal) BSFL for animal feed production, with different voices appearing in the internal subgroups in Bangladesh, Pakistan, and China, with some agreeing and others disagreeing. The waste group from Afghanistan, Bangladesh, China, and Pakistan responded as (2.29 ± 1.07), (3.68 ± 0.85) (4.27 ± 0.77), and (3.03 ± 1.30).

Locals of Bangladesh, China, and Pakistan agreed with flexible cultural values, but the local Afghani group disagreed with the (2.31 ± 1) mean value. On the other hand, the stack group of Afghanistan and Pakistan disagree with the mean (2.98 ± 1.37) and (2.43 ± 1.18), but China and Bangladesh both agreed to it as per Table 3 (SI). One of the biggest threats to the sale of BSF as chicken feed could be the negative perception of the use of insects grown on (human) waste'.

3.4. Types of BSFL-based feed products

Respondents from all groups were asked to indicate the form of BSFL feed offered to the animal. The stack group from Afghanistan and Bangladesh agreed to use the slightly edible and completely modified edible product with the acceptance

Table 1
Statistical analysis of the overall response of all groups related to an ingredient, utilization, and protein value of organic waste-farmed BSFL.

Response Question	Targeted Groups	Afghanistan	Bangladesh	China	Pakistan
		Mean±SD	Mean±SD	Mean±SD	Mean±SD
I will go for BSFL fat or proteins if extracted and used as manufacturing ingredients for cattle/poultry feed.	Locals	2.75±1.25	3.74±0.78	3.39±1.14	3.62±1.41
	Stack	3.46±1.19	3.62±1.14	3.66±1.36	3.93±0.98
	Waste	3.18±1.36	3.74±0.78	2.97±1.47	3.72±1.24
BSFL-based proteinaceous-feed utilization for growing cattle, poultry, and other farm breeds is appealing	Locals	1.73±1.25	2.53±1.41	3.29±1.19	2.94±1.72
	Stack	3.07±1.5	2.94±1.72	3.22±1.43	3.32±1.65
	Waste	1.73±1.25	2.53±1.41	4.38±0.88	2.13±1.61
I would mainly select to feed, with the acknowledgment of the highly nutritious and protein value of BSFL-based food (no harmful impacts)	Locals	2.97±1.00	2.82±1.45	4.03±1.15	2.86±1.53
	Stack	3.18±1.01	2.86±1.53	3.04±1.25	2.75±1.29
	Waste	2.97±1.06	2.82±1.45	3.05±1.14	2.81±1.39

Table 2
Statistical analysis of the overall response of all groups related to familiarity, acceptability, and perception of organic waste-farmed BSFL.

Response Question	Targeted Groups	Afghanistan	Bangladesh	China	Pakistan
		Mean±SD	Mean±SD	Mean±SD	Mean±SD
Familiarity response with BSFL-based ingredients used for rearing animals	Stack	1.82±1.34	3.22±1.30	3.55±1.42	3.28±1.6
	Waste	3.55±1.22	1.58±1.08	2.06±1.32	3.96±0.81
	Locals	2.79±1.36	1.58±1.08	2.06±1.32	3.10±1.04
Priority to choose BSFL-grown food at relatively Same price as conventional food	Stack	3.13±0.99	2.90±1.16	3.15±1.27	3.31±0.92
	Waste	3.26±0.96	2.83±1.06	3.82±0.57	3.22±1.06
	Locals	3.34±1.12	2.83±1.06	3.82±0.57	3.63±0.75
The acceptable form is if BSFL reared on different waste.	Stack	3.85±1.31	3.84±1.34	3.50±1.42	3.78±1.13
	Waste	3.88±1.30	4.29±0.57	4.38±0.66	3.36±1.51
	Locals	3.50±1.42	4.29±0.57	4.38±0.66	4.21±0.84

level of (3.39 ± 0.71) and (3.13 ± 0.72). The survey findings from China (3.5 ± 0.5) and Pakistan (3.65 ± 1.31) stack groups agreed on using dried, crushed, and mixed forms of BSFL as a feed source.

The Statement regarding the selection of BSFL if get offered among conventional cattle feed or protein-rich BSFL grown over organic waste, both having the exact cost was more appealing to a local group in Pakistan. On the contrary, Afghanistan prefers mixed feed as a conventional source for livestock, with a mean value of (3.34 ± 1.12) and (2.83 ± 1.06) respectively. The local respondents who prefer traditional feed due to trust level were from Bangladesh (3.82 ± 0.57) and China (3.63 ± 0.75).

It was possible to overcome initial reluctance to a utilizing BSFL as an animal feed with a better general idea of BSFL and a more positive attitude towards some entities at stake as soon as respondents were informed of the many applications for BSFL, their attitudes about using BSFL as animal feed changed dramatically for the better. According to the findings of our study, BSFL-based feed products have yet to be discovered by local inhabitants, companies, and organizations in the area under investigation. Because of this, it is essential to teach people about the BSFL by-products that can be used in some way to make animal feed.

3.5. Economic benefits of BSFL technology

All groups in selected countries agreed to the question, "The BSFL business would be an opportunity to create local jobs and an effort against poverty alleviation". Locals of all countries responded as highly agreed with the Statement and consider BSFL as a source of revenue or investment for waste management operations and outflow of capital expenditures hence, producing mean ratings of (3.9 ± 0.9, 4.16 ± 0.91) (3.55 ± 0.89 and 3.89 ± 0.95) respectively to the question. The waste group in Bangladesh gave an average high score of (4.38) while those in the Local and Stack groups scored (4.16) and (4.15) respectively. The stack of Afghanistan and Bangladesh rated the question against the highest score of (4.48 ± 0.57). Stack groups of China and Pakistan also responded as highly agreed.

The waste group in all countries generated the same mean values near (4.4) except in Afghanistan, as the waste response of (3.89 ± 1.03) was evaluated. Financial considerations also remain a significant concern for waste management groups in all countries. Building on the experiences of a facility and operational setup crisis in the developing world to notice BSFL as an emerging business opportunity for local jobs creations with the accomplishment of SDGs.

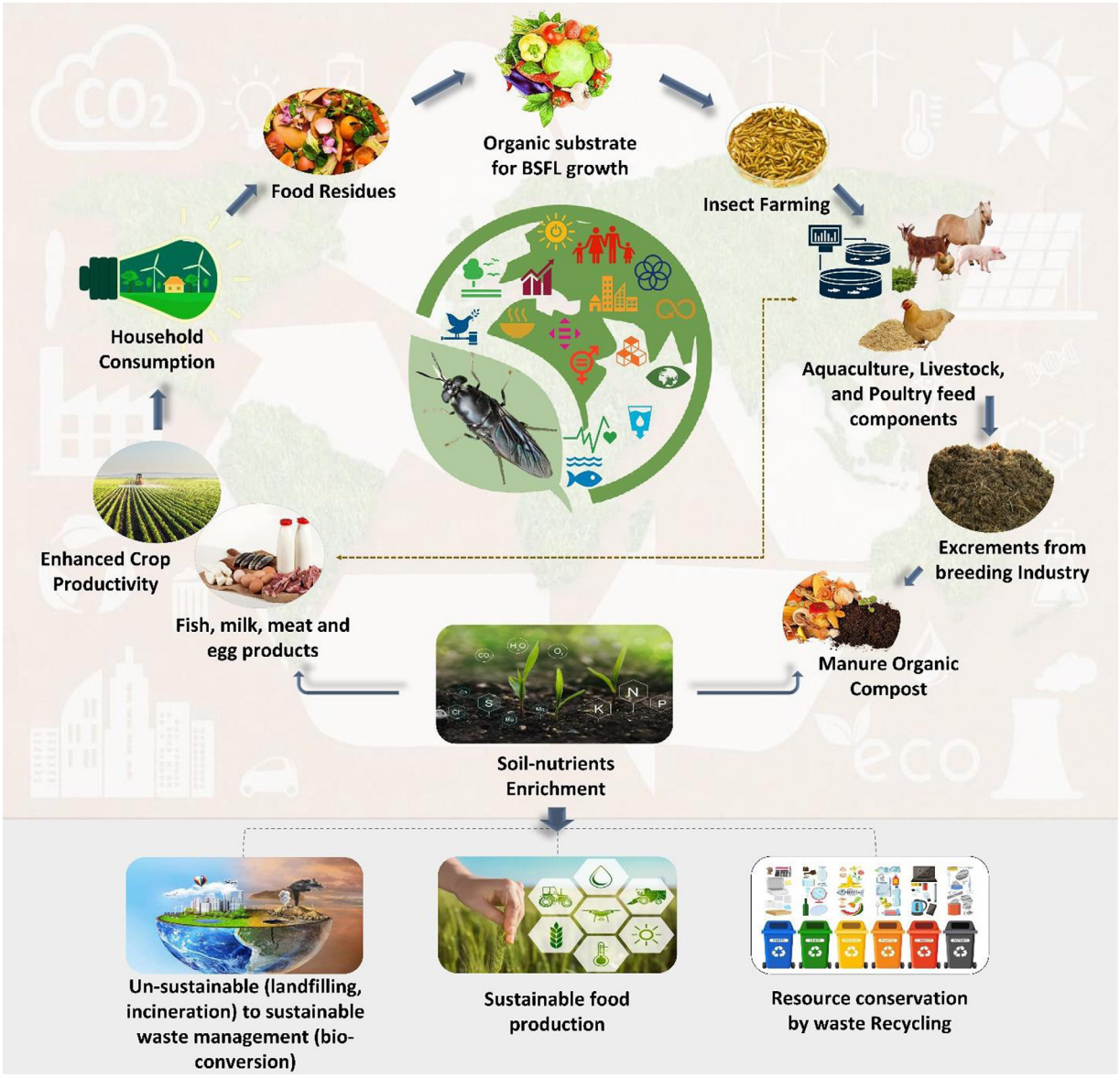

Fig. 4. Model to represent the contribution of BSFL to the Circular Economy and Sustainable development.

3.6. For the BSFL process, the preferred form of waste

This questionnaire component requires the group's response to the Statement: "The repelling elements influence my selection of BSFL-based feeding for my animal when BSFL is produced on municipal and organic solid waste". The response rate from the waste group for the above factors was Afghanistan (3.35 ± 0.93), Bangladesh (2.84 ± 0.99), China (3.1 ± 0.99), and Pakistan (3.14 ± 0.94). The stack group presented their mean scores while agreeing to the Statement, similar to the waste group. At the same time, locals of all countries except Afghanistan (3.35 ± 0.93) disagreed on the influence of repelling elements upon the selection of BSFL-based feeding.

The results demonstrate that the locals of Afghanistan and Pakistan were unsure about responding to the question Statement regarding their support for using BSFL if it grows under flexible environmental conditions and will not act as human pathogens or disease vectors due to having little knowledge of BSFL feed-based technology but the waste group in Bangladesh (3.49 ± 1.11), China (3.93 ± 1.21) showed their response to acceptable. Suppose BSFL is cultured under standard environmental conditions if it carries no vector disease because people are more curious about their health and safety. The waste group in Afghanistan and Pakistan believe feeding animals with alternative BSFL ingredients can cause

illness but intend their support if BSFL-based feed does not act as human pathogens or disease vectors with scores of (4.38 ± 1.14) and (4.21 ± 1.12), respectively.

3.7. The BSFL as a cost-effective technology

Table 3 (SI) The waste group response to the question "The price of BSFL-based feed that it would be cheaper and easily available, as well as appealing to buy it rather than conventional feed" was acceptable in Afghanistan with a mean value (of 3.88 ± 0.94) and in Bangladesh (3.41 ± 0.96). In contrast, it was highly satisfactory in China and Pakistan as per the mean value of (4.38 ± 0.53) and (4.41 ± 0.62). It has been shown that the way of life in BSFL has a healthy return on investment and has the potential to serve as an incentive for the building of industrial facilities as well as opportunities for individuals to find work. When people support BSFL technology, the impact on the ecological footprint should be considered. The response of locals to the same question for Afghanistan, Bangladesh, China, and Pakistan was recorded as (2.83 ± 1.06) (3.82 ± 0.57) (3.63 ± 0.75) and (3.34 ± 1.12), respectively, which shows the respondent of Afghanistan locals not in favor for BSFL products even if available at the same price without compromising to its pretentious nature. While stakeholders of Bangladesh, China, and Pakistan consider and firmly accept BSFL as an alternative to conventional food, with a mean rating of (3.15 ± 1.27) (3.31 ± 0.92), and (3.13 ± 0.99). In contrast, Afghani stakeholders disagree with their locals (2.9 ± 1.16).

3.8. The acceptance rate of BSFL as an animal feed by residents

Participants were presented with a description of black soldier fly larvae (BSFL) to know their acceptance rate for the food prepared using BSFL mixed with conventional foods for their pets. Residents only consider the results, as most of the local participants in Afghanistan, Pakistan, and Bangladesh keep animals for milk, meat, and fertilizer as a source of income. In China, most participants have dogs, cats, and birds as home pets. In the acquired results, participants rated their willingness to accept 500 grams of BSFL to be mixed with conventional foods. Residents of Chongqing scored the highest, followed by residents of Pakistan and Bangladesh with their willingness to add 132 grams,125 grams 120 grams of BSFL to the meal for their pets, respectively.

In comparison, the residents of Afghanistan responded to the lowest 90 grams out of 500 grams. It is evident from the result that the residents are unaware of BSFL as feed for their livestock and pets and do not have access to the product.

4. Discussion

Only recently, there has been research on the acceptance of BSFL by consumers in various cultural contexts. To better understand the public's attitude, perception, and social acceptance towards BSFL. The questionnaire covered the level of understanding of the use of BSFL for waste management, its product for animal use, its biosafety towards sustainable management, and the evaluation of the repelling factors. Almost all respondents had not been involved in the practice of BSFL technology. Still, most favored the benefits related to waste management that BSFL technology brings. Besides, the acceptance of animal feed made from BSFL varied depending on the country and subgroup, but most respondents answered in the affirmative.

4.1. Social acceptability BSFL in underdeveloped countries before employing livestock

The response among the general population, individuals from waste management departments, demonstrated the strong possibility of mainly adopting BSFL as feed for livestock in Asian culture. The response variation of participants regarding BSFL technology was dependent on numerous repelling factors, including unfamiliarity with the BSFL technique, having no experience, varying the potential of productivity, suitability related to nutritional concerns, contrasting and varying cultural or religious practices/beliefs, local market system, in-adequate governmental policies, cost-benefit mechanism, nature of the substrate and other environmental factors.

Response to explore BSFL grown over organic waste among local residents was much higher in Bengali, Chinese, and Pakistan respondents than Afghani locals for using BSFL as feed for their animals due to a lack of knowledge and practical implementation of BSFL in their surrounding environment. China's food security achievement for its locals in recent decades has negatively affected the environment (Su et al., 2023). The environmental costs of this damage are not only questioned the protentional of agro-ecosystem, long-term foodproduction sustainability, and bio-physical impacts, including human health at all levels from the local to the global, with economic loss estimates ranging from 7 to 10% of (GDP) (Martínez Aldaya et al., 2021). Table 3 (SI) shows the generated mean of 3.63 ± 0.7 for prioritizing BSFL-grown food. Pakistan and Bangladesh are more inclined to fulfill the present needs with innovative food production. The local public has the same challenges as China and produces a mean of (2.79 ± 1.36) and (2.06 ± 1.32) for statement response on familiarity.

Pakistan is among the largest growing nation in South Asia (Qaiser, 2022). More than half of its population lives below the poverty line and encounters hunger and food insecurity (Javed et al., 2022). Local people are more influenced towards new feed resources for humans and feedstock and generate the highest mean value among other groups. It suggests

that the local community in Pakistan is very enthusiastic about the dietary benefits of BSFL-based animal feed. The local Afghani group responded with their least preference to adopt BSFL-oriented feed for livestock (2.83 ± 1.0) despite having experiences with BSFL products while generating a mean of (3.01 ± 0.41) for the question stated as "My experience about BSFL Technology Product". Most of the general public is unaware of new technologies due to a lack of knowledge and resources besides conventional feedstock. This could be the reason for imprinting the most negligible response, as per Table 7 (SI). Moreover, one significant reason contributing to the least acceptance is the reluctance to eat or the avoidance of new foods, as most locals in Asia have food neophobia (Font-i Furnols, 2023)

Solid waste in Pakistan is primarily organic, which is more vulnerable to environmental pollution (Zia et al., 2020). The values of Table 3 (SI) depict a waste group of Pakistan is highly agreed for adaptation to BSFL while preferring the choice to rear BSFL on various waste as they seem BSFL an economic, valuable, and cleanest method to manage waste but repelling factors can also affect their selection of BSFL-based feed. Similarly, while living in the age of information, waste group respondents in China perceived that using BSFL to convert organic waste into valuable products has several benefits (Liu et al., 2022). Moreover, in response to BSFL-based ingredients used for rearing animals in Table 6 (SI). The waste group believes it is more attractive to get rid of solid waste and decided on the use of food waste, preferring animal waste to rare BSFL, the waste group in China only prefers animal waste to rear BSFL. This viewpoint is supported by the findings of our study, which also hints that BSFL, as an alternative method of waste management, results in lower costs for transport and maintenance than composting. BSFL has other benefits (Ipema et al., 2021). And most of the respondents expressed their approval of food waste. In Table 4 (SI)., the Waste group of Bangladesh shows they were not sure regarding familiarity with BSFL. Still, their acceptance of BSFL reared on waste, and their adaptation to BSFL as animal feed is relatively more accessible and cheaper. Organic waste generation in only Kabul City in 2017 was about 2000 tons per day and expected that the city will grow to 3300 tons per day with a per capita generation of 0.6 kg per day by 2025 (Khoshbeen et al., 2019). The waste group in Afghanistan highlights their intentions for the preferred animal to feed with BSFL-based food grown on various wastes. However, waste groups like the stack group of Afghanistan demanded this food at relatively low prices compared to conventional food. Different groups strongly agree with BSFL-based feed products because they know they can manage waste by rearing BSFL and producing highly nutritional feed products. Regarding extraction and manufacturing in Table 3 (SI), Bangladesh, China, and Pakistan locals generated the highest accessibility

The pet sector is growing in China (Xiao et al., 2021). With an annual rate of 30% ~50% of the development of this fast-growing industry, the pet industry has been relatively developed while considering fewer cities, including Beijing, Shanghai, Guangzhou, and others (Sergeevna, 2022). With Beijing as an example, in 2008, the per capita GDP broke through $9000 These facts show that the existing domestic pet feed production and supply could be uneven in the future (Wang, 2022). Highlighting the intentions to trace and efforts to improve resource efficiency while the goal to excel in the global market, making China's Stakeholders for their high acceptability to produce food from wastes showing and intended to access markets with BSFL-based food at the relatively same price. On the other hand, the Stack group of Pakistan (Table 3 SI) agreed with high acceptability and a priority with BSFL growth on various wastes due to varying socio-economic food trends.

Waste management stack holders and locals in Afghanistan and Bangladesh are gradually learning about the advantages of BSFL technology as they are surveyed. Still, their attitudes were not consistent on the issue of the implementation of BSFL technology. Respondents from all three groups in Afghanistan agreed to use waste-grown BSFL technology for animal feed production, with different voices appearing on rearing methods. Stakeholders firmly favor introducing new ways similar to the Bengali stakeholder group.

Pakistani stack groups selected BSFL grown over organic waste with condition cost-effectivity and consistent availability. Still, one of the biggest threats to the sale of BSFL larvae grown on (human) waste as animal feed could be negatively perceived in insects due to some social and religious stigmas reported, according to the finding. Whereas, it was possible to overcome initial reluctance to utilize BSFL as animal feed grown from human waste with the help of a more favorable public image of BSFL and a more positive attitude towards the sort of commodities at stake. As soon as respondents were informed of the many applications for BSFL, their attitudes about the use of BSFL as animal feed would change dramatically for the better.

Another significant response was recorded on the question about using BSFL-based feed for cattle and poultry; only locals of China highly agreed with this Statement, while the remaining countries showed little intention to use BSFL-Based feed for cattle and poultry. As shown in Table 1(SI). The stack group of Pakistan seems more agreed than China, Afghanistan, and Bangladesh. While only the waste group of China highly agreed with this, all other waste respondents disagreed.

While all groups in China are pleased with the benefits of BSFL, in China, the cultivated land per capita is only 0.08 ha, less than 40% of the world average (Zhong et al., 2023). Therefore, China is willing to switch from their traditional feed source provided they get good instruction and information about BSFL. The contribution of BSFL to the management of organic waste for a circular economy is very diverse (Liu et al., 2022). Our data from one company in China shows that the BSFL can reduce mixed waste by 70%, the same finding, and turn it into a quality product. By treating 10 tons of garbage daily, BSFL can produce 35 kilograms of larvae for every 1 ton of waste. Each kg market is valued at 3 RMB, and one ton of waste is about 400 RMB. BSFL is a circular economy that uses waste to become a resource in another process (Jagtap et al., 2021). Our finding revealed that no industries in Pakistan, Afghanistan, or Bangladesh treat waste with BSFL technology; people are willing to make small enterprises manage waste and make it a source of income, but

due to the lack of exposure and market trust, these two is the big obstacle to implementing the BSFL technology; need some basic research, safety measure, and marketing to evaluate the advantages and convince the people to implement the technology. Most Afghans, Pakistani, and Bangladeshi people feed grain, maize, rice, and other human food directly to animals. Maize, rice, and other grains are priced differently in different locations. The average price of one kg is 0.5 dollars. Still, if we feed animals with BSFL, 14 of 17 sustainable development goals can be met. Hence, BSFL is the best technology for treating waste while converting it into biomass and fulfilling sustainable purposes. In this way, we can consider BSFL as a dual function, saving resources and GDP and helping countries' economic development.

In Afghanistan, Bangladesh, and China, all three groups who responded to the survey were enthused about the possibility of employing food and animal waste to grow BSFL to manufacture animal feed. BSFL processing to food form is environment friendly, and during the BSFL growth, 38 to 74% dry mass reduction of the organic waste could be achieved (Rehman et al., 2023). In Afghanistan, Local groups seem to have BSFL as an opportunity to have a new business, generating the highest response corresponding to the question, "The BSFL business would be an opportunity to create local jobs and an effort against poverty alleviation". This indicates that respondents from the local group in Afghanistan were highly optimistic about the idea of BSFL. Respondents in Bangladesh and Pakistan also agreed to a high degree on this perception. China received the highest score on the perception of new business out of all the other groups, indicating widespread agreement.

BSFL efficiency in decomposing organic waste depends on optimal conditions in the targeted regions (Mannaa et al., 2023; Salam et al., 2022). However, the production methodology has some social taboos prohibiting organisms' eating. Significantly, the use of different wastes from different sources will adversely affect operations (e.g., running over or under capacity) of BSFL waste facilities with concurrent impacts on BSFL growth and performance that may influence the sustainability as studied by (Mertenat et al., 2019).

It is economically viable yet needs further determination and enhancement to produce sufficient larvae to replace or supplement animal feed requirements. It can be an excellent cost-effective alternative meal for livestock (Raman et al., 2022). Our findings are likely relevant to this view and indicate that the promotion and practical application of BSFL technology has a long way to go. However, using garbage as a growing condition for BSFL carries many risks (Surendra et al., 2020). The growth of pathogenic microorganisms and other harmful substances will cause direct harm to the development of animals fed on BSFL and indirectly affect human health (Perera et al., 2023). Other than perception and acceptability, the technical feasibility and efficiency of the BSFL system are not extensively studied in each country, which remains unclear for the industrial and commercial application of this technology. The challenges associated with promoting global entomophagy, which requires improved rearing methods, alleviating the risks related to insects' consumption, etc., are also of significant concern in each targeted area.

4.2. Role of BSFL in circular economy and sustainable development

Waste management is deprived in the underdeveloped world because of the smidgen budget to manage it, and considering their food and energy requirements (Koutsos et al., 2023) Suggests that BSFL technology is an emerging solution to these problems. According to (Zhang et al., 2023). every animal that produces meat needs a safe source of nutrition before and after processing. This suggests that much time, money, and effort make conventional poultry and cattle flesh appetizing and suitable.

The BSFL is an unusual method for raising family income using a readily available resource. Due to their high protein, it can be used as an animal feed protein source (Kim et al., 2021). By establishing BSFL-raising farms, production, and processing facilities, residents can amass money due to the commodity's rising demand Singh and Kumari (2019). The development of BSFL has a favorable effect on the organic compost generated by waste degradation, which may then be employed as a soil fertilizer to increase soil productivity (Arabzadeh et al., 2022).

In return for fish, eggs, meat, and milk, it may be fed to fish, cattle, dogs, birds, and fowl; since recycling trash saves resources, BSFL technology is shifting from an old and unendurable system to a modern and sustainable one (Surendra et al., 2016). It will favor several long-term development objectives, such as greater food security, better health, economic growth, and environmental sustainability. Due to the aforementioned nations' favorable environmental and climatic circumstances, the BSFL invention has great potential to solve the current crisis linked to solid waste disposal. It may also support regional development, employment creation, and the local recycling of biodegradable trash.

5. Future directions and practical implications

The research offers significant insights into the potential of Black Soldier Fly Larvae (BSFL) technology as a sustainable and profitable solution to waste management problems in specific Asian countries, including China, Pakistan, Afghanistan, and Bangladesh. The practical significance of black soldier fly larvae (BSFL) farming in these areas is highlighted, which can lead to policy modifications and contributes to filling gaps in research into public acceptance, social perception, and Attitude towards BSFL-based organic waste management.

The study provides a basis for future research to broaden the project's scope by including a larger geographical area, a wider range of demographics, and improving scientific understanding of residents' insect technology. Implementing this research would increase the applicability of our research outcomes and facilitate the worldwide acceptance of Black

Soldier Fly Larvae (BSFL) technology. Additionally, there is a substantial opportunity to research the socio-economic and cultural variables that impact the adoption of BSFL technology. The aforementioned applications can potentially tailor public involvement tactics and employment initiatives, resulting in improved execution of black soldier fly larvae (BSFL) cultivation methods in various environments and populations.

6. Conclusions

This study highlights Black Soldier Fly Larvae (BSFL) as an economically and ecologically beneficial waste remediation solution that is environmentally friendly. It demonstrates the broad applicability of BSFL technology in manufacturing, satisfying various requirements. Chinese respondents acknowledge the nutritional value of BSFL-based feed significantly (4.08), indicating no adverse effects. Consumer behavior in all nations surveyed favored BSFL-based animal feed, but potential deterrents can influence selection. Substantial feedback supports the use of BSFL for livestock and poultry feed, with Bangladesh (3.74), excluding Afghanistan (2.75), expressing the strongest accord. However, local acceptability cannot be assured due to cultural, religious, and market system variables. BSFL is viewed as an inexpensive, sustainable waste management method and a significant contributor to the animal feed industry, particularly in developing nations. Future research into the impact of BSFL feed on local markets will be informed by findings from multifaceted factors, which will significantly impact business prospects and job creation.

CRediT authorship contribution statement

Muhammad Salam: Designed the study, Collect data, Analyzed the data, Reviewed, Writing – original draft. **Longyu Zheng:** Designed the study, Supervision. **Dezhi Shi:** Designed the study, Collect data. **Zheng Huaili:** Supervision. **Viola Vambol:** Reviewed, Writing – original draft. **Shaphan Yong Chia:** Reviewed, Writing – original draft. **Md. Nuralam Hossain:** Collect data. **Abdelaziz Mansour:** Review. **Moataz Eliw:** Review. **Mengyao Dong:** Collect data. **Amina shazadi:** Collect data. **Ehsan Ullah:** Collect data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgments

This Research work was supported by the National Natural Science Foundation of China (Grant Number : 32172783) and the Special Fund of Basic Scientific Research Fund of Central Universities (2662020SKPY004). We acknowledged the anonymous reviewers for polishing the language of the paper and for in-depth discussion.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eti.2023.103260.

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