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Eco-innovation and the Edible Insect Value Chain: A Systematic Review

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ABSTRACT

The growing interest in edible insects as a component in animal feed and human food has caught the attention of researchers from various fields, resulting in a multidisciplinary approach. This emerging value chain positions itself as a sustainable and innovative alternative when compared to traditional protein chains. In this scenario, the objective of this article is to conduct a systematic review to investigate and present research on the consumption of insects by humans and their use as animal feed in an eco-innovation context. Our investigations indicate that research on the value chain of edible insects is present on almost all continents, revealing a growing interest, especially in developing countries. In these regions, insect consumption not only addresses issues of food security but also contributes to income generation. The increase in research on alternative protein sources, such as edible insects, seems to align with a broader trend toward sustainability in food production, underscoring the relevance of the topic in the search for environmentally friendly solutions. Noteworthy results include global recognition and collaborative efforts in edible insect research, highlighting a collective approach to addressing challenges and exploring opportunities. This global cooperation underscores the significance of the topic and the necessity for innovative solutions in addressing environmental and food security challenges.

KEY WORDS: eco-innovation, edible insects, sustainability, human food, animal feed.

JEL Classification: Q0.

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1. Introduction

In the past, before the economic and industrial scenario we have now, humanity was forced to feed on various nutritional sources, including insects. However, the development of civilization led to the decline of the practice of entomophagy (Patel et al., 2019). This scenario, which is currently distant from society, may be just a few steps away from a major cultural, economic, and social change.

Research shows that entomophagy is practiced in one hundred and thirteen countries and that

around two thousand, one hundred and eleven species of insects are consumed by two billion people, with the practice being most prevalent in tropical countries (FAO, 2013). According to Costa-Neto (2016) in Brazil, entomophagy is present in fourteen states, being practiced mainly by thirty-nine indigenous tribes. The creation of insects as a viable protein source represents a new concept for animal nutrition (Gomes et al., 2023).

The increasing population growth rate, food insecurity in some parts of the world, as well as the increasing demand for and increasing cost of ani-

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mal protein, will necessitate a significant increase in production and will place a significant burden on natural resources already limited by the population's growth (Lange & Nakamura, 2023).

There is a global food security alert, with the imminence of global food shortages if appropriate measures are not put into practice (Ayieko et al., 2021). This alert is supported by notes from the Food and Agriculture Organization of the United Nations (FAO) on the need for sustainable protein sources to feed a population estimated to reach nine billion by 2050 (United Nations [UN], 2015).

This need for sustainable protein sources has increased because current livestock production has contributed to several environmental problems such as deforestation, soil erosion, desertification, loss of plant biodiversity, and water pollution (Van Huis, 2015). In this way, the challenge of achieving food security has increased, as there are two challenges to be solved simultaneously: maintaining the quality of the food produced and the equitable distribution of this food (Wardhani and Haryanto, 2020).

Products from edible insects can contribute to the transition to markets for sustainable protein sources, as well as to food security (Veldkamp et al., 2022). In 2012, at FAO headquarters, a specialized consultancy jointly with the University of Wageningen and financial support from the Dutch government evaluated the potential of insects as human food and animal feed, allowing the exchange of information and knowledge to guarantee food security (Vantomme, 2015).

Insects have additional nutritional components and beneficial compounds, including lipids, vitamins and minerals, chitin, Phenolic compounds antimicrobial peptides, all of which contribute to a healthy state (Li et al., 2023). In addition to offering nutritional benefits and helping to combat hunger, edible insects can provide ecological and economic advantages, as they are a cheaper substitute for animal proteins (Patel et al., 2019).

In this way, the edible insect value chain can become a sustainable food system as it can guarantee food security through nutrients, in addition to guaranteeing the financial, social, and ecological pillars of sustainability in the long term (Kawabata et al., 2020).

There is already evidence of an understanding of wild insect populations due to climate change and the increase in the world population (Musundire et al., 2021). Therefore, the need to improve the commercialization of edible insects has become imperative, since a large part of the population, especially in developing countries, cannot access essential animal proteins (Agea et al., 2008; Von Braun, 2010).

The animal feed part of the value chain is also impacted by the growth of the world population, as the need for ingredients for feed for both livestock and pets also grows.

Regardless of the value chain, companies aiming to remain globally competitive need alignment in their activities. However, in practice, the strategy of international engagement and its success still lacks clarity for most business leaders, especially those operating in emerging economies and less developed countries (Vallina-Hernández et al., 2022). Other essential skills, such as agility and innovation, are also crucial for operating in complex environments that demand quick response capabilities and creative solutions to address emerging issues (Troilo, 2023).

Through the environmental problems arising from current livestock production (Van Huis, 2015), the challenges of feeding the world's population by 2050 (UN, 2015), and the global alert on food security (Ayieko et al., 2021), the research question that this work intends to answer is: can the value chain referring to the consumption of insects for human food and animal feed be considered an eco-innovation?

The purpose of this article is to investigate and present research on the consumption of insects by humans and as animal feed in an eco-innovation scenario. To achieve this objective, the research uses a systematic review.

Investigations indicate that research on the edible insect value chain is present on almost all continents. However, there is more emphasis on underdeveloped countries, which seek to combat hunger and improve income generation for their citizens through the consumption of insects.

It is important to highlight that the consumption of edible insects follows different paths depending on the country being analyzed. While in developed

countries the consumption of insects, like any other type of consumption, is an individual choice that reflects eating habits, in poor countries, this consumption can contribute to combating hunger and generating income.

After this introduction, Section 2 discusses the literature review regarding the terms “value chain” and “edible insects”. Section 3 describes the method for designing the survey. Section 4 analyzes and discusses the results of the systematic review, and Section 5 presents the conclusions.

2. Theoretical Framework

2.1. Eco-innovation and Edible Insects

Eco-innovation is the abbreviation of the term environmental innovation, whose objective is to reduce the negative influences of innovations on the natural environment (Reid & Miedzinski, 2008). The advantages of eco-innovation include a decreased environmental impact, increased efficiency, and enhanced competitiveness (Mady et al., 2023).

According to Kemp & Pearson (2007), the concept of eco-innovation is broad, including everything from pollution control to waste reduction. However, the relevant criterion for determining the term is whether the use is less harmful to the environment than the alternatives.

Eco-innovation can originate from new or improved solutions introduced throughout the lifecycle phase of the product or service, that is,

from beginning to end. However, according to evidence, the greatest gains in resource efficiency are found in base production or in the intermediate part, while resource efficiency decreases along the supply chain (Reid & Miedzinski, 2008).

Because of the increasing significance of environmental concerns, depleting ecological resources, and increased environmental impacts, the study of eco-innovation is increasing in importance every day (Riaz et al., 2023).

The definitions of the term can have a motivational or result focus, according to the authors presented in Table 1.

According to Table 1, the definition of eco-innovation is divided into two bases: environmental motivation (innovator's intention) and environmental results (effect on the environment), with environmental motivation being more difficult to verify than a focus on results (Carrillo-Hermosilla et al., 2010).

The value chain referring to the consumption of insects by humans and as animal feed is based on environmental results, considering the concept of Kemp and Pearson (2007):

Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is new to the organization (developing or adopting it) and which results, throughout its life cycle, in reducing environmental risk, pollution and other negative impacts of resource use (including energy use) compared to alternatives.

Table 1

Focus of the Definitions of the Term Eco-innovation, According to the Authors

Authors	Focus	Scope
Rennings (2000)	motivation	sustainable development
European Commission (2008)	result	sustainable development
Andersen (2006)	result	reduction/prevention of environmental impact
Carrillo-Hermosilla, Río and Könnölä (2010)	result	reduction/prevention of environmental impact
Kemp and Pearson (2007)	result	reduction/prevention of environmental impact
	N	22

Source: Adapted from Koeller et al. (2019)

Table 2*Classification of the Term Eco-innovation*

Classification	Description	Types
environmental technologies	pollution control technologies, including wastewater treatment technologies	waste management equipment; environmental monitoring and instrumentation; green energy technologies; water supply; noise and vibration control.
organizational innovation for the environment	introduction of organizational methods and management systems	pollution prevention schemes; environmental management and auditing systems; cooperation between companies to close material loops and avoid environmental damage throughout the value chain.
product and service innovation offering environmental benefits	new or environmentally improved products and environmentally beneficial services	new or environmentally improved material products (goods); green finance products: green leases or climate mortgages; environmental services: solid and hazardous waste management, water management; less polluting and resource-intensive services.
green system innovations	alternative production and consumption systems that are more environmentally benign than existing systems	organic farming; energy system based on renewable energies.

Source: Adapted from Kemp and Pearson (2007)

Furthermore, a new process that is more resource efficient or anything that is more benign to the environment than the previous alternative is considered an eco-innovation (Kemp & Pearson 2007).

Following this vision, Kemp and Pearson (2007) developed a classification for the term, according to Table 2.

According to the classification in Table 2, the value chain referring to the consumption of insects by humans and as animal feed fits into the typology of the classification of green system innovations. This environmental innovation suggests that there are higher chances of reaping positive social benefits resulting from this deeper commitment to long-term sustainable practices (Berrone et al., 2013).

Considering those viable insects for human consumption, such as mealworms, crickets, and grasshoppers emit fewer Greenhouse Gases (GHG)

per kilogram of mass gain, when compared to pork and beef cattle (FAO, 2013), Reduced GHG (carbon dioxide and other gases) can contribute to the enactment of legislation aimed at decreasing the amount of these emissions, thereby lowering carbon footprint and alleviating concerns for consumers and shareholders.

The production efficiency of crickets is better than that of chicken and pork and beef cattle, as shown in Table 3.

According to Table 3, the Feed Conversion Ratios (FCRs)—a measure of an animal's efficiency to convert feed mass into increased body mass—of crickets are two times more efficient than those of chickens, four times more efficient than those of pork, and twelve times more than those of cattle. In addition, the protein efficiency of adult crickets is also higher compared to that of conventional meat, as shown in Table 4.

Table 3
Edible Insect Industry Segmentation

Segmentation	Analysis
products	beetles caterpillars grasshoppers, locusts, and crickets bees, wasps, and ants scale insects and true bugs other edible insects
application	flour bars snacks
regional	North America: U. S Europe: Belgium, France, UK, Netherlands Asia Pacific: China, Thailand, Vietnam Latin America: Brazil, Mexico Middle East and Africa

Source: GMI (2016)

According to Table 4, the protein efficiency of adult crickets is 205g of protein per kg of edible weight, while poultry, pork, and cattle present values of 200, 150, and 190 g of protein per kg of weight, respectively (Van Huis, 2013).

A probable explanation for the FCR of crickets being more efficient than that of meat from conventional animals is the fact that insects are poikilothermic, and in their growth stages there is no investment in metabolic energy to maintain a constant body temperature above environmental

temperatures (Van Huis, 2013).

According to the mentioned data, edible insects can be sustainable protein sources, compared to other alternative sources (chicken, pork, and beef cattle), since they present greater production efficiencies and protein efficiency in terms of resources. Another factor contributing to the consumption of edible insects is studies that indicate that insect-based protein powder is less harmful to the environment than conventional proteins (Smetana et al., 2016).

Table 4
Production Efficiencies of Conventional Meat and Crickets

	cricket	poultry	pork	beef
feed conversion ratio (kilogram feed: kilogram liveweight)	1.7	2.5	5	10
edible portion (%)	80	55	55	40
feed (kilogram: kilogram edible weight) efficiencies (kilogram edible weight) meat	2.1	4.5	9.1	25
efficiencies (kilogram edible weight) cricket		2	4	12

Source: Adapted from Van Huis (2013)

Furthermore, the need for sustainable protein sources has increased, as current livestock production has contributed to several environmental problems, such as deforestation, soil erosion, desertification, loss of plant biodiversity, and water pollution (Van Huis, 2015). Another positive comparative issue regarding livestock production and the production of edible insects is that insects can be cultivated using low-value organic products and byproducts. In this way, at the end of processing, it is possible to have high-value protein from agricultural products wasted daily (Van Huis and Dunkel, 2017).

2.2. Value Chain of Edible Insects for Human Consumption

Research shows that entomophagy is practiced in 113 countries and that about 2,111 species of insects are consumed by 2 billion people, with the practice being more prevalent in tropical countries (FAO, 2013). According to Costa Neto (2016) in Brazil, entomophagy is present in 14 states, being practiced mainly by 39 indigenous tribes.

Edible insects are a new form of food that has several benefits that will address the issue of protein and energy deficiency caused by the rapid growth of the world's population. Using insects as food can increase the economy and have a positive impact on the environment and human survival (Papastavropoulou et al., 2023).

According to Vantomme (2015), the consumption of insects can evolve in different ways in different countries, as it depends on the food culture, social values, local conditions, and livestock development needs. Another point that can drive this evolution is comparative studies of the nutritional value of edible insects with other conventional proteins (Patel et al., 2019).

The food security of villages and families in developing countries can be improved the more the preservation techniques are improved, reducing waste as well as the spoilage of harvested insects, allowing expansion for use in local diets, for example, the mixture of cassava flour with insect powder (Vantomme, 2015).

In Africa, researchers have been dedicated to understanding the value chain of edible insects. According to Niassy et al. (2018), research studies still

lack the necessary details to allow strong industrial production on a commercial scale, an essential requirement for the advancement of marketing opportunities related to the production and consumption of insects.

The difference in this evolution can be seen in most sub-Saharan African countries, whose governments still do not recognize the contribution that entomophagy can offer as a guarantee of food security and informal income, mainly for women, children, and marginalized communities, whose income comes significantly from the insect value chain. Thus, strategies are needed to promote awareness of the value of insects, whether as human food, feed, or pharmaceutical options (Musundire et al., 2021).

However, the food safety achievable through entomophagy requires studies, as conducted by Mumbula et al. (2022). In their research on edible termites in Zambia, the collected samples showed microbial loads of Enterobacteriaceae, *E. coli*, *S. aureus*, yeasts, and molds. The analyzed termites might have been exposed to contamination during collection, transportation, or sale. Therefore, technological advancements are necessary to ensure the safety of edible insect consumption.

Although insects for human consumption are widely found in Africa, the formal industry in Europe and the USA is growing rapidly (Ayieko et al., 2021). In the East, the Korean market has been growing since 2012, through government support and successful research results (Kim, T-K et al., 2019).

In Europe, some companies already specialize in the production of insects for human consumption. In this way, these companies already follow protocols, such as hygiene, identification of product batches, and tracking. However, due to the low production volume, the costs are still high (Van Huis and Dunkel, 2017).

Despite the specialization in insect production, further research is still needed to provide insights into dietary changes based on edible insects, such as *Tenebrio Molitor* (TM), as emphasized by Errico et al. (2022) in their study. The research analyzed all high-value products obtained through TM, along with safety aspects. The authors emphasize that despite the approval of TM usage by the European Commission in 2021, certain aspects directly impacting the production process, such as health effects, optimal

production conditions, and by-product conversion capabilities, need to be thoroughly discussed and analyzed.

Aiming to improve the acceptance of insects, research has addressed the functional properties of their proteins to be consumed as food ingredients, their gelatinization, foaming, and emulsification capabilities, as well as their solubility in oil and water. The diversity of ways of using insects can improve the attractiveness of their consumption (Ayieko et al., 2021).

To improve the issue of palatability and reduce possible aversions to whole consumption, insects

can be transformed into powder or flour, in addition to being mixed with other ingredients, enabling increased sales, and generating more profit for the value chain into which it is inserted, such as the food tourism chain (Ayieko et al., 2021).

There is a wide variety of groups of edible insects in the world, which fall into different groups, as shown in Figure 1.

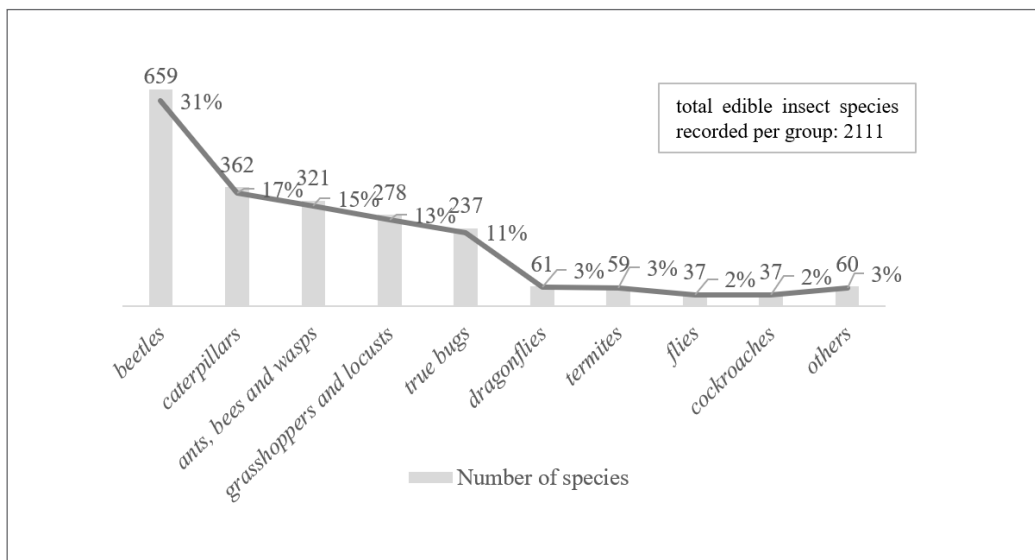
To be worth the effort of catching, insects need to be easy to locate and should preferably be collected in predictable and large numbers. They can be consumed at different stages of life and through different preparation methods: raw, fried, boiled,

Table 5
Protein Efficiencies of Conventional Meat and Crickets

	cricket	poultry	pork	beef
protein efficiency (kilogram protein: kilogram edible weight)	205	200	150	190

Source: Adapted from Van Huis (2013)

Figure 1
Number of Edible Insect Species Recorded per Group Worldwide



Source: Adapted from Jongema (2017)

roasted, and ground (Dobermann et al., 2017).

According to Kamau et al. (2021), crickets have a high potential in fulfilling the daily intake of several micronutrients. Research data carried out in Kenya demonstrate a collection of 0.5 to 3.0 kilograms of fresh weight in each harvest cycle (period of 45 to 60 days), corresponding to a daily intake of 100 grams of fresh crickets for a period from 5 to 30 days (consumed by at least one person per family). For this average daily intake, the protein contribution of crickets is in the order of 25% to 39% of the recommended daily protein for women, and 70% of the recommended daily protein for children.

Despite the continuing need for research to identify ideal foods, estimates for the world market for edible insects by 2023 are in the order of USD 522 million, with more than 40% CAGR (Compound Annual Growth Rate) from 2016 to 2023 (Kim, K-T et al., 2019; GMI, 2016).

GMI also analysed the edible insect industry and segmented it as per Table 3.

According to the analysis by GMI (2016), for Europe (specifically France, the United Kingdom, and the Netherlands) forecasts are that the edible insect market will show a high rate of expansion in the period from 2016 to 2023. For Latin America (mainly Brazil), projections are for a 42.4% CAGR and more than USD 55 million by 2023.

In this way, forecasts of growth of edible insects for human consumption present a great opportunity for new businesses, especially for developing countries (Dobermann et al., 2017). However, there is a challenge to be overcome. Scalability will only be viable once large volume production is possible (Van Huis and Dunkel, 2017).

Another important factor for the growth of the chain is the development of research such as that carried out by Odongo et al. (2018) on the commercialization of edible insects in Uganda and Burundi. They detailed the value chain and market opportunities, highlighting that the edible insect trade represents an alternative source of livelihood, ranging from collectors to street vendors and traders, in both rural and urban areas. The survey results revealed that the price of a kilogram of a specific edible insect was USD 3 compared to USD

3.5 for beef and USD 1.95 for fish.

Research such as that conducted by Donkor et al. (2022) supports the findings of Odongo et al. (2018) by confirming that the grasshopper value chain in Uganda is an excellent source of income for retailers. Among the research results, a notable aspect is the difference in average annual income between individuals working in the high season (around 8 weeks) within the grasshopper chain and those engaged in other sectors. The disparity in average annual incomes varies, with a 392% increase for women and a 451% increase for men involved in the grasshopper chain.

Furthermore, the retail sector in various countries is a crucial pillar for economies. For instance, in Puerto Rico, the sector employs over 20% of workers with an average wage of USD 8.69 per hour (Rios-Pérez et al., 2022). According to this data, the development of the edible insect value chain could strongly impact this sector.

2.3. Value Chain of Edible Insects for Animal Feed

The feed market is also impacted by the growth of the world's population, as the need for feed ingredients for both livestock and pets grow. Edible insects have garnered more scientific interest as a low-cost alternative to replace the need for soya bean and fish meal in animal feeds due to their nutritional value (Kolobe et al., 2023).

Since 2021, in Europe and Member States, processed animal proteins (PAPs) have been authorized for poultry and pork feed. This approval is one of the main stages of the authorization process and significantly marks the guarantee for the sustainable use of resources, both for the production and for the animal protein process, thus mitigating environmental concerns (Ankamah-Yeboah et al., 2018; Veldkamp et al., 2022).

In the West, there are several companies that breed insects for animal feed, such as fish, birds, and reptiles. However, the need for high-scale production and standard quality has been a bottleneck for these companies to achieve competitive production costs (Van Huis & Dunkel, 2017).

Currently in Europe, the aquatic feed market accounts for approximately half of all insect-based animal feed. Projections are for a 75% growth by 2030,

as European insect breeders currently trade around 1000 tons of insect proteins (Veldkamp et al., 2022).

In addition to the potential commercial growth, research to evaluate different processing methods related to the digestibility of nutrients from this feed has also been growing. Processing methods impact the protein digestibility; so, finding the correct nutritional digestibility values has become a critical factor for formulating feeds, considering that there are variations in insect protein digestibility, according to each animal species fed (Veldkamp et al., 2022).

As a novel protein source, insects require the well-designed manufacturing process to produce high quality insect powder, while guaranteeing food safety of the final product (Yan et al., 2023).

According to Ankamah-Yeboah et al. (2018), there is a need for research to measure the impact of insect feed on the value of animal products, when used as a total or partial substitute for standard feeds, such as fish and soy meal. Currently, research is being carried out to analyze the effects of bioactive substances (component of a nutrient or non-nutrient food, which has a specific metabolic or physiological action in the human body) provided by insect meal as animal feed (Veldkamp et al., 2022).

However, various research studies addressing the process within the edible insect value chain encounter obstacles regarding knowledge sharing. As highlighted by Chiu et al. (2022), organizational knowledge is often accumulated over time, leading companies to be reluctant to share it without financial returns.

Considering the insect-based feed as a cheaper alternative to the standard feed and large-scale production, the manufacturers' profits can potentially increase if the cost reduction in feed inputs is considered. However, it is essential to understand consumers' reaction to this new production method, as well as their purchasing behavior (Ankamah-Yeboah et al., 2018).

Insects as a source of animal protein, especially in aquaculture, can influence the purchasing decisions of final consumers. Research carried out with 610 German consumers pointed out that only 23% of respondents care about the type of feed that the fish is fed. On the other hand, 77% of respondents are indifferent to the use of insect-based feed. These data bring promising perspectives for the market, since for the 23% who

care about the feed, public and marketing campaigns can bring about changes in their preferences, inclining them towards a more positive attitude towards insect feed (Ankamah-Yeboah et al., 2018).

In addition to understanding the acceptability by final consumers, it is necessary to analyze other actors in the production chain, such as farmers who may use edible insects as feed. Studies conducted in Kenya on smallholder farmers' willingness to pay for insect-based feeds assessed farmers' knowledge of edible insect feeds and willingness to pay for the product.

According to Chia et al. (2020), the research results reveal that livestock producers are aware of the potential of insects as feed, allowing a positive attitude to the product and consequently encouraging producers to take risks in relation to the acquisition of the new product. Another important result concerns the willingness to pay for the new feed. Farmers are willing to pay more for insect feed for poultry, fish, and pork than for standard commercial feeds. This willingness increases, as knowledge about the new feed increases.

Data referring to the knowledge, attitudes, and practices of farmers in relation to insects as feed are shown in Table 6.

According to Chia et al. (2020), the production of insect-based feed opens new socioeconomic perspectives, especially for increasing job opportunities for young people and women along the entire value chain. The results demonstrate an opportunity for innovative and sustainable use of resources, as insect rearing minimizes the pressure on agricultural land use and marine resources. However, it is crucial to address findings such as those highlighted by Karmaker et al. (2023) in their research, indicating that sustainable practices are not prioritized by top management in small and medium-sized enterprises in volatile environments.

Beyond these points, the production of insects as animal feed requires strict monitoring regarding the concentration of heavy metals (cadmium and lead) in the substrates, aiming to guarantee the safety of the product, making it economically reasonable (Purschke et al., 2017). Most of the risks involved in processing insects for animal feed can be combated using technologies, especially in the processing part, through heat treatment, as heat destroys some of the harmful

Table 6
Farmers' Knowledge, Attitudes, and Practices Regarding Insects as Feed

Parameter	Description	poultry	fish	pork
		farmers (n = 409)	farmers (n = 241)	farmers (n = 307)
knowledge	aware that insects can be used as feed (%)	70	80	0
attitudes	insects are a good source of feed (%)	60	78	0
	make their own feed (%)	9	19	15
practices	ever used insects as feed (%)	31	34	0
	used commercial feeds (%)	80	72	68
	used conventional feeds (%)	78	68	84

Source: Adapted from Chia et al, (2020)

microorganisms (Guiné et al., 2020).

In addition to the market for human food and animal feed, insect production is already seen in other markets, such as cosmetics and traditional medicines. Businessmen in China have grown rich by breeding cockroaches for these markets specifically (Guiné et al., 2020).

Therefore, investments in technology that integrate the links and business processes involved in this value chain can contribute to companies reducing operational costs and improving operational efficiencies, with artificial intelligence algorithms as valuable allies (Haifeng et al., 2022).

3. Method

This article was developed through inductive reasoning using the systematic review method, that according to Sampaio and Mancini (2007) uses the literature on a given topic as a data source.

According to Kitchenham et al. (2008), the systematic review is characterized by the adoption of a methodology for identifying, analyzing, and interpreting all the evidence available during the research, so that it is free of bias and can be repeated if necessary. To allow readers to make their own analyses regarding the quality of the review methodology itself (Bearman et al., 2012).

The advantages of a systematic review include enabling a summary of studies on a given topic, allowing greater research results as their execution comes from primary sources (Sampaio and Man-

cini, 2007). The main objective is to summarize the evidence from primary sources, offering a comprehensive understanding of the researched topic, in addition to allowing a formal synthesis of the most relevant research results, since it is difficult to read all the articles (Bearman et al., 2012; Bie, 1996).

To address the research question on edible insects and value chain, the logical operator 'AND' was applied to combine the search terms 'edible insects' and 'value chain.' The chosen databases were Web of Science (WoS) and Scopus due to the quality and relevance of their publications. In the WoS database, the search was conducted in the 'theme' field, while in the Scopus database, it encompassed the 'title,' 'abstract,' and 'keywords' fields.

The database search adhered to specific criteria, including language, publication date, and the exclusion of duplicate studies. According to Crowther et al., (2010), it is important that at the beginning of the research, inclusion and exclusion criteria are established to obtain records with less bias and the possibility of quick reevaluation in case of questions about the criteria used. These criteria include language, publication date, and duplicate data, also limiting studies by language may be acceptable, but in some areas, it may result in the loss of important data.

By filtering with the strings 'edible insects' and 'value chain,' the oldest article identified was dated 2015, and the most recent one was from 2022, marking the start year of this research. The filters

yielded twenty-six non-duplicated articles across different languages and countries, offering a global perspective on the consumption of insects as food.

The data were processed in a spreadsheet, and the analysis began by reviewing the articles in descending order of citations, prioritizing the reading of those that highlighted crucial parts of the value chain in their abstracts, such as feed suppliers, insect producers and processing, manufacturers, retailers, and consumers. The results and discussions were developed based on these analyses, contributing to a comprehensive understanding of the value chain of insects as human food and animal feed.

Figure 2 presents the selection and evaluation process of the studies found.

4. Discussion and Results

Despite the worldwide attention to the need for sustainable protein sources and the multidisciplinary research on the theme “edible insects value chain”, the terms “edible insects” and “value chain” resulted in only 26 articles in the Web of Science and Scopus databases, as shown in Appendix A.

A small number of articles were found, and the concatenated terms of the searches were recent. Thus, all the articles found were analyzed.

Bibliometric indicators from the research were obtained, such as the number of research publications, the number of publications by research areas, the number of citations of articles by research areas, journal productivity, and author productivity by continent and country.

Regarding the number of research publications, these data show the novelty of the subject, mainly considering that no filter of initial and final dates was considered at the time of the research.

In Figure 3, it is possible to analyze the number of research publications on edible insects and value chain during the period from 2015 to 2022.

According to Figure 3, the period from 2015 to 2018 presented an average of 2.5 articles per year. In 2019, there was a decrease in the number of articles, with a slight linear increase observed in the following years at a constant rate of two articles per year. The average annual rate after 2019 is four articles. It is important to note that the research was concluded before the end of 2022. Thus, the number of

articles for the year may be higher.

The data reveals a consistent growth trend in recent years, indicating a steady rise in the production of articles related to the subject. The highest annual average underscores ongoing and potentially increasing interest in the study area, despite the temporary decrease in 2019.

The notable novelty of the topic suggests that research on the value chain of edible insects as an alternative protein source is an emerging area of study, indicating a growing and potential demand for information.

The increase in research may reflect an awareness of the importance of sustainable approaches in food production, as consumers and the industry are increasingly interested in food options that minimize environmental impact. These findings align with Van Huis's (2015) research, indicating that alternative protein sources like edible insects are more sustainable compared to livestock production, which contributes to various environmental issues.

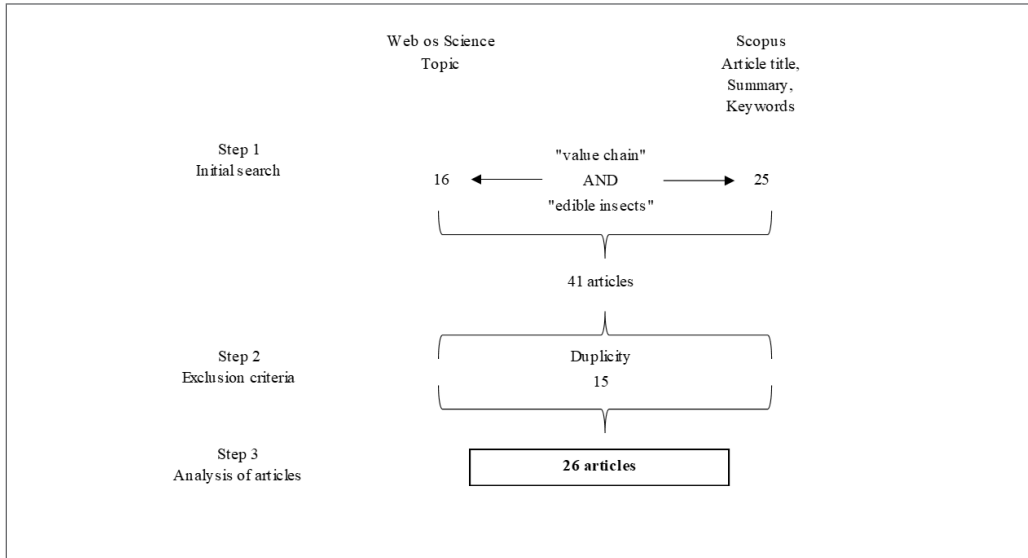
In summary, the growth in research on alternative protein sources, such as edible insects, appears to align with a broader shift toward sustainability in food production, highlighting the significance of the topic in the quest for more environmentally friendly solutions.

Regarding the number of publications by research areas, it was possible to identify the research areas for the terms “edible insects” and “value chain,” allowing for a comprehensive mapping of the production system in which the value chain of edible insects is situated. Figure 4 illustrates the number of publications by area of research on edible insects and value chain.

To determine the research areas of the journals, the Journal Citation Reports (JCR) categorization was utilized. Journals with more than three categorizations were designated as multidisciplinary, while those not listed in the Journal Citation Reports were disregarded. Figure 4 highlights the main areas of interest in research on edible insects and the value chain.

The first category, representing 35% of the articles, was published in journals categorized as entomology and food science and technology. The second category, with 19% of publications, covers food

Figure 2
Selection and Evaluation Process of the Identified Studies



science and technology, followed by the multidisciplinary category, comprising 15% of publications. These data indicate that researchers have a significant focus on the relationship between technology and food science.

Technology plays a crucial role in various productive systems, driving innovations in production to increase efficiency, reduce waste, and optimize resources. In agriculture, intelligent monitoring has enhanced the quality and safety of food. Additionally, the analysis of large volumes of data over time enables the prediction of future scenarios, especially in response to environmental impacts.

According to Kemp and Pearson (2007), technology also has the power to accelerate developing production chains. This is how the use of technology has contributed to the advancement of the edible insect chain, especially in terms of food safety. Research worldwide is conducted to ensure that this new protein source is safe for both animal feed and human consumption.

Another crucial aspect is the application of information technologies in consumer education, especially regarding new foods. Communication and education can be facilitated through social media and digital platforms, providing consumers with

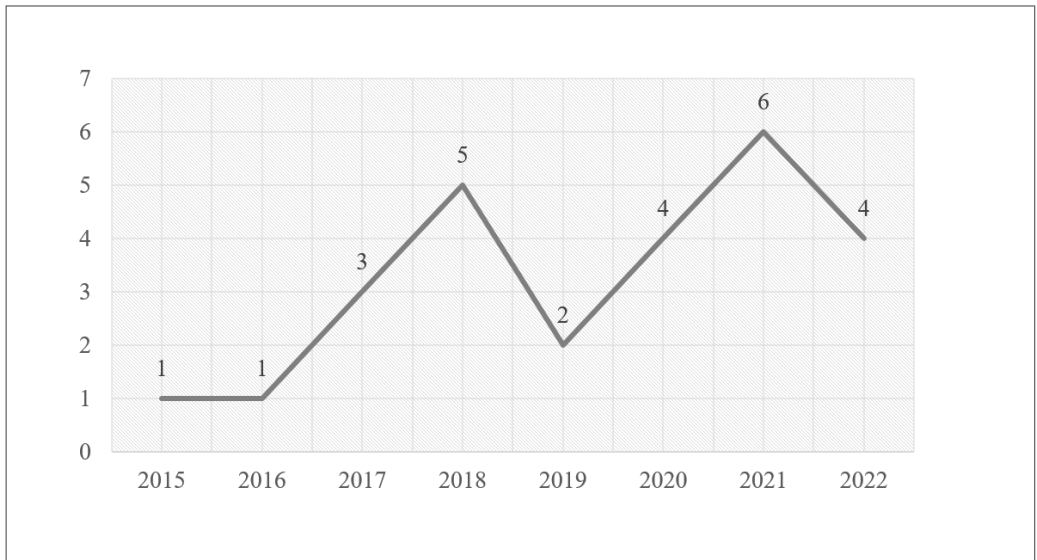
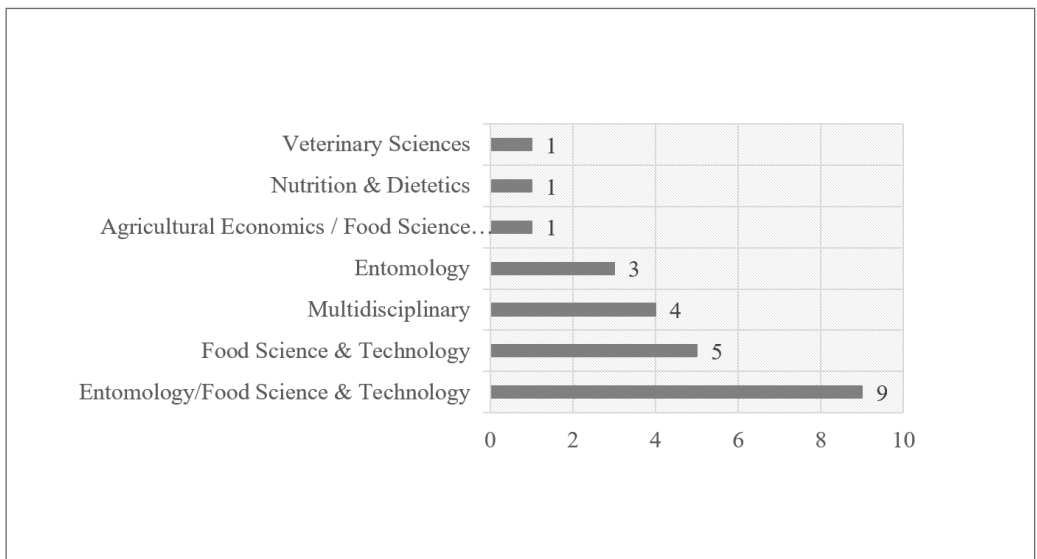
a deeper understanding of the quality, safety, and processing of new products, promoting transparency in this new chain.

The intersection of technology and food science results in significant advances for the edible insect chain, especially concerning environmental issues, bringing benefits to society.

Through the number of citations of articles by research areas, it is possible to identify the most relevant ones for reading and further exploration in future research. Figure 5 presents the number of article citations by research area in the journals.

For duplicate articles, the highest number of citations among the databases was considered. Journals not listed in the Journal Citation Reports were disregarded. Thus, according to Figure 5, the most cited articles were found in three main categories: entomology/food science and technology, with 296 citations; multidisciplinary, with 234 citations; and food science and technology, with 174 citations.

These three main categories represented more than 60% of the total citations, aligning with the analysis of data derived from the number of publications in the research areas on edible insects and the value chain. Notably, there was an alternation between food science and technology and multidis-

Figure 3*Number of Research Publications Between 2015 and 2022***Figure 4***Research Areas on Edible Insects and Value Chain*

ciplinary in the second and third positions.

While entomology provides knowledge about the biology, physiology, and ecology of insects as a potential food source, food science and technology offer analyses of nutritional properties, food safety, and processing of potential edible insects. Both areas converge to drive innovation in the edible insect value chain.

The development of a productive chain requires the involvement of various disciplines. Multidisciplinary collaboration is crucial to mitigate challenges and explore the potential of edible insects. As highlighted by Van Huis and Dunkel (2017), in addressing edible insects for human consumption, indicating the need to expand the chain to achieve substantial volumes, improve palatability to increase acceptance, and analyze the functional properties of insect proteins as food ingredients. This is due to the diversity of ways insects can be used, enhancing their attractiveness for consumption (Ayieko et al., 2021).

In the context of edible insects for animal feed, advances in science and technology enable more efficient pathogen detection, identification of ideal insect types for each species to be fed, and optimal proportions of adding insect protein to feeds.

The productivity of journals also needs to be analyzed. Knowing the journals that publish the most on the researched topic allows a better selection of articles for understanding the terms, as well as facilitating the literature review in a way that familiarizes the research focus of each journal.

Table 7 presents the 16 journals found and their respective productivity.

According to Table 6, the journal with the highest productivity is the Journal of Insects as Food and Feed with nine articles found; followed by Frontiers in Sustainable Food Systems and International Journal of Tropical Insect Science, each with two articles. These three journals together represent 50% of the total productivity, with the remaining productivity spread among the other journals.

Table 7
Productivity of Journals

Journal Information	Publications	Percentage
Journal of Insects as Food and Feed	9	35%
Frontiers in Sustainable Food Systems	2	8%
International Journal of Tropical Insect Science	2	8%
British Food Journal	1	4%
Comprehensive Reviews in Food Science and Food Safety	1	4%
Edible Insects in Sustainable Food Systems	1	4%
Food Additives and Contaminants Part A-Chemistry Analysis Control Exposure & Risk Assessment	1	4%
Food and Energy Security	1	4%
Food Quality and Preference	1	4%
Frontiers in Veterinary Science	1	4%
Insects	1	4%
Journal of Ethnobiology and Ethnomedicine	1	4%
NFS Journal	1	4%
Nutrition Bulletin	1	4%
PlosOne	1	4%
Waste Management	1	4%
Total	26	100%

The analysis of this information highlights the thematic specialization of each journal in approaching research on edible insects. Articles found in the *Journal of Insects as Food and Feed* focus on entomophagy in Africa, especially in informal contexts. This reflects specific attention to the region and local practices, indicating a commitment to understanding the cultural and social nuances associated with insect consumption.

The journal seems to concentrate not only on dietary aspects but also on broader implications such as food and nutritional security. The exploration of parts of the production process, such as fermentation, suggests an interest in understanding not only insect ingestion but also their preparation and processing as food. Furthermore, by addressing market opportunities, the journal recognizes the economic importance of this practice in the food chain, both for human and animal consumption.

The journals *Frontiers in Sustainable Food Systems* and *International Journal of Tropical Insect Science* have articles about insect farming by refugees in Africa. This focus highlights the practical and potentially transformative application of entomophagy in specific contexts where food security may be a central concern. By investigating the nutritional quality and safety of insects, these journals contribute to a more holistic understanding of the benefits and challenges associated with using insects in food.

Moreover, the exploration of current trends related to insect consumption in human food and gastronomy by these journals indicates a connection to broader debates on food sustainability and contemporary dietary choices. This suggests that these journals are attentive not only to technical and scientific aspects but also to evolving cultural and social dynamics related to insect consumption.

Overall, this diversity of approaches among the journals highlights the complexity and breadth of the emerging field of research on edible insects, encompassing specific regional issues to global considerations of sustainability and food security.

Another important indicator refers to the author productivity by continent and county. Knowing the origin of the publications makes it possible to identify countries interested in the researched theme, as

well as to be aware of the universities in which the research is concentrated.

Figure 6 shows the countries of the authors of each article from the survey.

The analysis of the data reveals that 49% of the authors are from the African continent, with 13 of these authors being of Kenyan nationality. In second place are authors of European nationality, representing 43% of the total, with four of German and Danish origin, and three of Belgian and Dutch origin, as shown in Figure 6. These data provide insights into the countries and territories most engaged in research on edible insects and their value chain.

The presence of authors from different continents and international collaboration in various articles suggests that research on edible insects is a globally recognized area of interest. The diversity of collaborations transcends borders, indicating a collective approach to addressing challenges and exploring opportunities related to edible insects.

This data reflects significant interest in the topic, especially among researchers from developing countries. These researchers aim to tackle challenges such as hunger and improve income generation by promoting the consumption of insects. The connection between research on edible insects and food security in developing countries is evident, suggesting that these countries see insects as a potential solution to food challenges.

As an example, there is insect farming in Cambodia, which is used to mitigate rural poverty, increasing the income of family farming through the production of crickets (Guiné et al., 2020). The results obtained also reflect how this value chain is analyzed with interest by African countries, concerned about the food security of their population (Kawabata et al., 2020).

The diversity of nationalities among the authors may also reflect different cultural perspectives on insect consumption. This cultural diversity can influence research approaches, considering factors such as dietary preferences, social acceptance, and culinary traditions. The results suggest that research in this area may have positive impacts globally, but particularly in vulnerable communities.

An important point to highlight is the divergence

Figure 5
Number of Citations of Articles by Research Areas

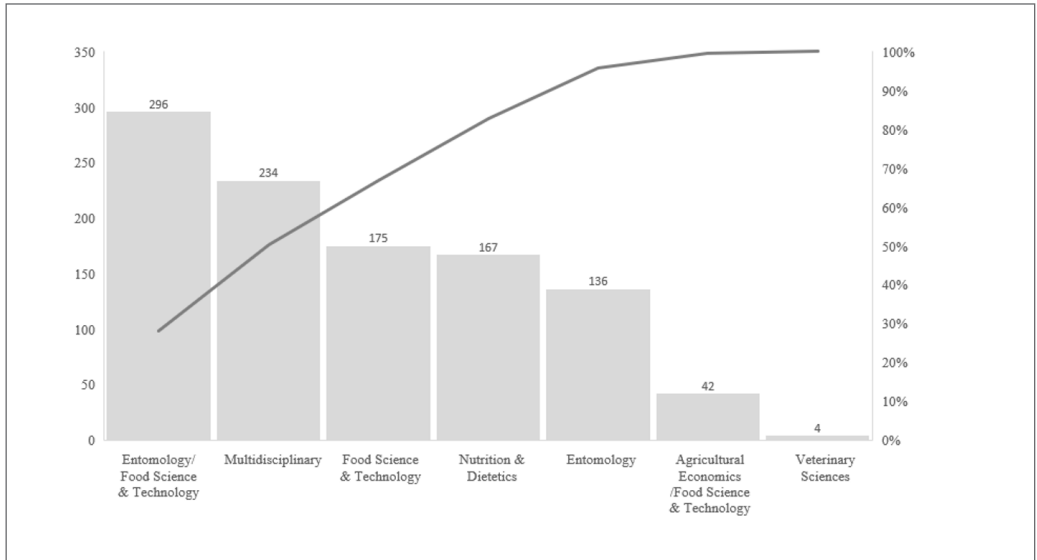


Figure 6
Author Productivity by Continent and Country



in the paths of edible insect consumption, depending on the country under analysis. This divergence between developed and developing countries is a complex phenomenon that reflects both cultural differences and distinct socio-economic contexts.

In developed countries, the consumption of insects is more aligned with an individual choice, often linked to dietary, environmental, or even gastronomic considerations. It is an expression of personal food preferences, and in some cases, it can be seen to explore new protein sources or adopt more sustainable diets. In these contexts, the acceptance or rejection of insect consumption is often associated with individuals' willingness to try new foods and overcome cultural barriers related to food taboos.

In developing countries, on the other hand, the consumption of insects plays a more vital role, contributing to addressing significant challenges such as hunger and income generation. In many communities in these countries, insects represent a valuable source of essential nutrients, offering an affordable and readily available alternative to address nutritional deficiencies. Additionally, the breeding and commercialization of insects can become important economic activities, providing livelihoods for local communities.

This differentiation highlights the importance of understanding the consumption of edible insects not only as a global trend but as a practice deeply rooted in specific contexts. Research and policies related to edible insects should consider these nuances to develop effective approaches that promote food security and sustainability, considering the distinct characteristics of each cultural and economic scenario.

5. Conclusion

The objective of this research to investigate and present research on the production of insects for human consumption and animal feed in an eco-innovation scenario was achieved.

The value chain referring to the consumption of insects for human food and animal feed is an eco-innovation, because the production process proves to be more efficient in terms of resources than the

production process of pork, chicken, and beef cattle, as highlighted in previous studies that analyze the conventional meat production compared to that of crickets, that demonstrated that the feed conversion rate of crickets is twice more efficient than that of chicken, four times more efficient than that of pork, and twelve times more than that of cattle.

In terms of the focus of the definitions of the term eco-innovation, the value chain referring to the consumption of insects for human food and animal feed, focuses on environmental results, whose scope is the reduction/prevention of environmental impact, since its innovative intends to mitigate environmental problems arising from current livestock production, aiming to respond to global alerts on food security regarding the need for sustainable protein sources for the future.

Edible insects are an alternative system of production and consumption that is more environmentally benign than the existing systems related to the production of chicken, pork, and beef cattle, as indicated in previous research, which indicated that insects viable for human consumption, such as mealworms, crickets, and grasshoppers, emit fewer Greenhouse Gases (GHG) per kilogram of mass gain when compared to pork and beef cattle.

Other results obtained also compared four different types of animals, in which the protein efficiency of adult crickets is 205g of protein per kg of edible weight, while poultry, pork, and cattle present values of 200, 150, and 190 g of protein per kg of weight, framing the value chain referring to the consumption of insects by humans and as animal feed in the classification typology of green system innovations.

The notable novelty of the topic suggests that research on the value chain of edible insects as an alternative protein source is an emerging area of study, indicating a growing and potential demand for information. The growth in research on alternative protein sources, such as edible insects, appears to align with a broader shift toward sustainability in food production, highlighting the significance of the topic in the quest for more environmentally friendly solutions.

Another important result is the application of in-

formation technologies in consumer education, especially regarding new foods. Communication and education can be facilitated through social media and digital platforms, providing consumers with a deeper understanding of the quality, safety, and processing of new products, promoting transparency in this new chain.

The presence of authors from different continents and international collaboration in various articles suggests that research on edible insects is a globally recognized area of interest. The diversity of collaborations transcends borders, indicating a collective approach to addressing challenges and exploring opportunities related to edible insects.

In conducting this study, we chose to utilize the Web of Science (WOS) and Scopus databases for analyses. The specific selection of these databases may have led to the exclusion of relevant articles that could have further enriched the scope of the research. We acknowledge that information availability extends beyond these databases, and therefore, the inclusion of other sources is crucial for a comprehensive analysis.

An additional limitation lies in the incomplete exploration of other information sources, such as conference proceedings and books. The exploration of such material is vital, as these formats often capture innovative research and preliminary results that may not have been formally published in journals. This limitation underscores the importance of adopting a more inclusive approach in the pursuit of knowledge.

We also identified a significant opportunity for future research, focusing on the relationship between eco-innovation and specific sustainable development goals. This proposal is based on the growing need to understand how eco-innovation practices can contribute to specific goals, going beyond general analysis. By concentrating on key areas of sustainable development, research can provide more targeted and practical insights to guide policies and business practices.

Another possibility is to explore consumer perception and acceptance of products resulting from eco-innovation in the edible insect value chain. This would involve investigating factors influencing the acceptance or rejection of these products and

examining how the message of sustainability and innovation can be communicated more effectively to consumers.

An additional propose would be test specific strategies to engage value chain stakeholders, including producers, consumers, and government regulatory agency. Involvement of these stakeholders can contribute to creating a more conducive environment for eco-innovation in this emerging chain.

Ultimately, we recognize that this study represents a specific contribution to an evolving field, and we suggest these directions for future research to further enhance understanding of the intersection between eco-innovation and the edible insect value chain.

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Appendix A

Table 1

Results of Systematic Review

Authors	Article Title
Egonyu, J.P; Kinyuru, J. Fombong, F. Ng'ang'a, J. Ahmed, Y.A. and Niassy, S.	Advances in insects for food and feed
Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N.K. and Ekesi, S.	African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security
Münke-Svendsen C., Ao, V., Lach T., Chamnan C., Hjørtso C.N. and Roos N.	An explorative study of the practice of light trapping and the informal market for crickets in Cambodia
Imathiu, S.	Benefits and food safety concerns associated with consumption of edible insects
Alemu, M.H., Olsen, S.B., Vedel, S.E., Pambo, K.O. and Owino, V.O.	Combining product attributes with recommendation and shopping location attributes to assess consumer preferences for insect-based food products
Niassy, S., Musundire, R., Ekesi, S. and Van Huis, A.	Edible insect value chains in Africa
Alemu, M.H., Olsen, S.B., Vedel, S.E., Pambo, K.O. and Owino, V.O.	Edible Insects as New Food Frontier in the Hospitality Industry
Lakemond, C.M.M., Veldkamp, T. and Van Huis, A.	Edible insects: the value chain
Van Campenhout, L.	Fermentation technology applied in the insect value chain: making a win-win between microbes and insects
Ojha, S., Bussler, S. and Schluter, O.K.	Food waste valorisation and circular economy concepts in insect production and processing
Espitia Buitrago, P.A., Hernández L.M., Burkart, S., Palmer, N. and Cardoso Arango, J.A.	Forage-Fed Insects as Food and Feed Source: Opportunities and Constraints of Edible Insects in the Tropics
Donkor, E., Mbeche, R. and Mithofer, D.	Gender differentials in value addition and lean season market participation in the grasshopper value chain in Uganda
Purschke, B., Scheibelberger, R., Axmann, S., Adler, A. and Jager, H.	Impact of substrate contamination with mycotoxins, heavy metals and pesticides on the growth performance and composition of black soldier fly larvae (<i>Hermetia illucens</i>) for use in the feed and food value chain
Ankamah-Yeboah, I., Jacobsen, J.B. and Olsen, S.B.	Innovating out of the fishmeal trap: The role of insect-based fish feed in consumers' preferences for fish attributes
Kamau, E., Kibuku, P. and Kinyuru, J.	Introducing cricket farming as a food security and livelihood strategy in humanitarian settings: experience from Kakuma Refugee camp, Kenya
Niassy S., Ekesi S., Hendriks S.L. and Haller-Barker A.	Legislation for the use of insects as food and feed in the South African context
Odongo, W., Okia, C.A., Nalika, N., Nzabamwita, P.H., Ndimubandi, J. and Nyeko, P.	Marketing of edible insects in Lake Victoria basin: the case of Uganda and Burundi
Mumbula, I., Nyunja, R. and Chungu, D.	Microbial load of edible termites (<i>macroterme</i> spp.) from collection to marketing in Serenje District, Central Zambia

Table 1*Results of Systematic Review (Continued)*

Authors	Article Title
Veldkamp, T., Nathan, M., Frank, A., David D., Van Campenhout, L., Gasco, L., Roos, N., Smetana, S., Fernandes, A. and Van der Fels-Klerx, H. J	Overcoming Technical and Market Barriers to Enable Sustainable Large-Scale Production and Consumption of Insect Proteins in Europe: A SUSIN-CHAIN Perspective
Meutchieye, F. and Niassy, S.	Preliminary observations on the commercialisation of Rynchophorus phoenicis larvae at Mvog-Mbi market in Yaoundé, Cameroon
Kinyuru, J.N and Ndung'u, N.W.	Promoting edible insects in Kenya: historical, present and future perspectives towards establishment of a sustainable value chain
Chia, S.Y., Macharia, J., Diiro, G.M., Kassie, M., Ekesi, S., Van Loon, J.J.A., Dicke, M. and Tanga, M.C.	Smallholder farmers' knowledge and willingness to pay for insect-based feeds in Kenya
Musundire, R., Ngonyama, D., Chemura, A., Ngadze, R.T., Jackson, J., Matanda, M.J., Tarakini, T., Langton, M. and Chiwona-Karlton, L.	Stewardship of Wild and Farmed Edible Insects as Food and Feed in Sub-Saharan Africa: A Perspective
Errico, S., Spagnoletta, A., Verardi, A., Moliterni, S., Dimatteo, S. and Sangior- gio P.	Tenebrio molitor as a source of interesting natural compounds, their recovery processes, biological effects, and safety aspects
Bomolo, O., Niassy, S., Tanga, M.C., Chocha, A., Tartibu, L., Shutcha, M.N., Longanza, B., Ekesi S. and Bugeme, D.M.	The value chain of the edible caterpillar <i>Elaphrodes lactea</i> Gaede (Lepidoptera: Notodontidae) in the Miombo forest of the Democratic Republic of the Congo