UNIVERSITÀ DEGLI STUDI DI PADOVA
Department of Land, Environment Agriculture and Forestry

Second Cycle Degree (MSc)
in Food and Health

Edible insects: a nutritious and sustainable food source

Supervisor
Prof. Francesco Marinello
Co-supervisor
Dott. Lorenzo Guerrini

Submitted by
Francesca Roverato
Student n. 2057460

ACADEMIC YEAR 2023/2024

Contents

Abstract

The growing global population, estimated by the United Nations Food and Agriculture Organization (FAO) to exceed 9 billion people by 2050, poses significant challenges to global food security. In the face of increasing food demand, it is imperative to develop sustainable solutions that reduce waste and optimize the use of natural resources. In this context, entomophagy, or the consumption of insects, emerges as a promising strategy to address these challenges, offering a sustainable and nutritious source of protein. This thesis explores the potential role of edible insects in the global food system, examining the nutritional, environmental, and economic benefits of this ancient yet rapidly evolving practice.

The primary objective of this thesis is to analyze the use of edible insects as an alternative protein source to address food security and environmental sustainability challenges. The research focuses on various aspects, including the nutritional composition of insects, the environmental benefits compared to traditional livestock farming, current regulations in Europe, and cultural and market perceptions of entomophagy. Through a comprehensive literature review and case study analysis, this thesis aims to provide an in-depth overview of the potential and challenges associated with integrating insects into the human diet.

Chapter 1

1. Global food demand and growing population

1.1 Sustainable food and population

Reducing waste is a priority in order to feed a population which, according to estimates by the Food and Agriculture Organization of the United Nations (FAO), will reach over 9 billion from the current 8 billion by 2050. In the coming years, the need for arable land, water, some elements such as phosphorus will increase, not to mention the need for non-renewable resources such as fossil fuels. To feed an increasingly large, urban and wealthy world population, it will be necessary to increase food production by 70%. Annual cereal production will need to rise to about 3 billion tonnes from 2.1 billion today and annual meat production will need to rise by over 200 million tonnes to reach 470 million tonnes. This impressive increase will only be possible thanks to targeted investments and adequate agricultural policies. In developing countries, 80% of the necessary surplus can be obtained by increasing the intensity and yield of crops and only 20% by extending the arable land. However, intensive crops can represent a risk: they deplete the soil and they also require a lot of water (Sadigov R., 2022).

The increasing needs of the growing population must face climate change issues too. Last COP, COP 28, marked the conclusion of the first 'global stocktake' of the world's efforts to address climate change under the Paris Agreement. Having shown that progress was too slow across all areas of climate action – from reducing greenhouse gas emissions, to strengthening resilience to a changing climate, to getting the financial and technological support to vulnerable nations – countries responded with a decision to accelerate action across all areas by 2030. This includes a call on governments to speed up the transition away from fossil fuels to renewables such as wind and solar power in their next round of climate commitments. Global food systems are at an inflection point and there is an increased focus on transforming food systems so that they benefit nature, ensure safe and healthy diets, provide fair wages and livelihoods, and are prosperous. Historically, there have been many calls, summits, and goal-setting exercises to address also hunger and malnutrition through food policy and dialogue. However, malnutrition and hunger remain at unacceptable levels in many parts of the world, and every country is affected by some form of malnutrition (Micha R, *et al.*, 2020).

The Committee on World Food Security's (CFS) Voluntary Guidelines on Food Systems and Nutrition define sustainable food systems as "food systems that enable food security, food security and nutrition for current and future generations in accordance with the three dimensions (economical, social and environmental) of sustainable development. Furthermore, sustainable food systems must be inclusive, equitable and resilient" (CFS, 2021).

The concept of a sustainable diet dates back to the late 1980s with reference to a diet that adheres to nutritional recommendations and, at the same time, low deterioration and consumption of natural resources. Since then, the concept has expanded and in 2010, at the FAO international symposium, all the dimensions involved in the concept of a sustainable diet were explained: "diets with low environmental impact that contribute to food and nutritional security, as well as to a healthy life for present and future generations. Sustainable diets contribute to the protection and respect of biodiversity and ecosystems, are culturally acceptable, economically equal and accessible, adequate, safe and healthy from a nutritional point of view and, at the same time, optimize natural and human resources". In other words, the vision shifts from a unidimensional approach, focusing solely on nutritional adequacy, to a multidimensional approach that connects the three dimensions of food availability, accessibility, and choice with the maintenance of long-term health and environmental sustainability. In the era of combating climate change, the concept of sustainable nutrition inherently satisfies the requirements for possible interventions that aim at the so-called health co-benefits, which allow us to mitigate climate change while simultaneously preventing many chronic diseases. On the other hand, the importance of an approach that promotes the quality of human life and the integrity of natural systems represents today one of the most important challenges of the twenty-first century (Jones AD, *et al*., 2016).

1.2 A general overview of the role of edible insects

Insects have been part of the human diet for thousands of years, with evidence of their consumption found in prehistoric archaeological sites. Throughout history, entomophagy has been a common practice in many cultures, particularly in parts of Africa, Asia, Latin America, and Oceania. In some societies, insects were considered a delicacy and were reserved for special occasions, while, in others, they were a staple food source (Olivadese M. *et al*., 2023).

The roots of entomophagy vary by culture and region, but common reasons include the nutritional benefits of insects, their abundance and accessibility, and the cultural and religious significance of certain species. Although the practice of entomophagy has declined in some parts of the world due to the influence of Western culture and industrialization, it continues to be important in many societies. Despite its long history and potential benefits, entomophagy has faced cultural and social stigmas in many parts of the world. However, recent efforts have been made to promote entomophagy as a sustainable and nutritious food source and to challenge cultural prejudices against insect consumption. The relationship between insects and humans throughout history has always been complex and multifaceted. Insects are a source of both fascination and fear to humans and have played an important role in human culture, economy, and health. Nowadays, there is growing interest in using insects as a sustainable and environmental friendly source of proteins and other nutrients. Entomophagy can be seen as a new opportunity for the food industry and global food security. In fact, insects require far fewer resources than traditional livestock, and there are many references to insect consumption in human history. The ancient Romans are known to eat various insects, including beetles, caterpillars, and locusts. Insects such as crickets, grasshoppers and ants have been eaten for centuries and are still considered a delicacy in many parts of the world, especially in Africa, Asia, Latin America and Oceania (Olivadese M. *et al*., 2023).

The consumption of insects by humans is historically and geographically an ancient and widespread phenomenon. The use of edible insects varies greatly based on local preferences, sociocultural significance, and region. These animals are often considered cultural resources and this place-based knowledge reflects rich biodiversity. Compared to conventionally produced animals, insects are believed to be an attractive source of protein because they have high reproductive capacity, high nutritional quality, very low water and land use, and high feed conversion efficiency, they can use the waste as feed and are suggested to be produced more sustainably. For this reason, FAO has seriously considered entomophagy as part of the solution to future food supply problems (E.M. Costa-Neto. 2016).

Chapter 2

2. Edible insects as emerging food products

2.1 Consumption of insects in different cultures

The world's population is growing rapidly and is expected to approach 10 billion by 2050, creating significant barriers to achieving food security and sustainability. Persistent problems such as fame, malnutrition and excessive greenhouse gas emissions exacerbate these challenges. Furthermore, the combination of population growth and rising incomes has led to a substantial increase in global meat consumption, resulting in significant environmental and climate consequences, as well as negative impacts on public health. To address the issues posed by conventional meat production, there is a growing need for sustainable and nutritious alternative protein sources. Edible insects have emerged as a viable option due to their low environmental impact and high feed content conversion efficiency and excellent nutritional value (María Fernanda Ordonez Lopez *et al*., 2023).

The countries with the highest consumption of insects are Mexico (450 species), Thailand (272 species), India (262 species), DRC (255 species), China (235 species), Brazil (140 species), Japan (123 species), and Cameroon (100 species). Mexico is also home to many indigenous cultures and communities that have used insects in their cuisine for thousands of years. Chapulines or grasshoppers are one of the most consumed insects in the country. Dried or fried, they are the most delicious bar or travel snack and can be found with various toppings. However, you can find bugs in some of the best restaurants in Mexico City, including Pujol, so it's not just reserved for street food or snacks (Adrienne Katz Kennedy *et al*., 2023).

In 2015, with the help of Aspire Food Group, an organization dedicated to supporting technology and innovation in insect farming, Ghana became the first of two countries to undertake commercial palm weevil breeding processes. They are iron-rich insects and the project was launched by local farmers as an additional source of income in addition to growing a sustainable protein source. The consumption of insects in various forms and traditions is central among various indigenous groups across the African continent as a whole. The practice of eating insects, however, is reported to be declining in areas that have adopted more Western food sources, among younger generations. The fear is that as the practice of eating insects declines, not only will the cultural practice be lost to future generations, but also the indigenous knowledge that accompanied the tradition. Wasps and many other species are consumed in Japan, including giant hornets (used to make shochu) and their larvae, whose texture, Ho notes, is comparable to that of shrimp. In fact, this practice is so deeply rooted that it is celebrated annually with the Kushihara Hebe Festival, dedicated to celebrating all things wasp. Dozens of varieties of insects were regularly eaten and used medicinally among Native American tribes throughout North America. Indigenous communities used various species as food but also for their medicinal properties, devising specific harvesting systems just like for other wild foods. In 2012 the European Union committed up to $4 million to insect-based protein sources, with the Netherlands investing deeply. In a 2022 survey, one in five Dutch respondents had already tried insects on their own, with almost 80% agreeing that food manufacturers should include more insect-based proteins in theirs products (Adrienne Katz Kennedy *et al.*, 2023.) The United Nations Food and Agriculture Organization (FAO) released a report in 2013 titled "Edible Insects: Future Prospects for Food and Feed Security," which promoted the nutritional and environmental benefits of edible insects. This report has contributed to the increased interest and production of insect-based products in regions where entomophagy is not traditionally practiced. Following the FAO report, the production of insect products has indeed increased in countries where eating insects was not previously common. This growth is driven by the recognition of insects as a sustainable and nutritious food source. The sale and use of edible insects within food products achieved legal status in the Nordic countries of Norway, Denmark, and Finland around 2017. These countries have developed specific regulations to allow the marketing and consumption of insects, aligning with the EU Novel Food Regulation that took effect in January 2018. In many non-Western countries, the practice of eating insects is part of the indigenous diet and has been for hundreds of years. The legal acceptance in Western countries is a more recent development aimed at diversifying diets and promoting sustainable food sources (Adrienne Katz Kennedy *et al*., 2023.)

2.2 Insects as a sustainable food source

Insects are classified as "Novel Food" under the updated Regulation (EU) 2015/2283, which replaced the older Regulation (EC) 258/97. This newer regulation, effective since January 2018, mandates that any novel food, including insects, must undergo a rigorous safety assessment by the European Food Safety Authority (EFSA) before being marketed in the EU. The European Commission has approved several insect species as novel foods. For example, the mealworm was the first insect authorized in 2021, followed by the migratory locust and the house cricket. Recently, the lesser mealworm and partially defatted powder from the house cricket have also been approved. Prior to full EU-wide approval, some member states, like the Netherlands and Belgium, allowed the sale of insect-based products based on their own risk assessments. The transitional measures allowed products that were lawfully marketed in member states before January 2018 to remain on the market temporarily while awaiting EU approval. The updated regulation introduces a simplified authorization procedure for foods considered traditional in third countries, including insects. This aims to facilitate their entry into the EU market, provided there is documented evidence of safe consumption history. While the regulations have streamlined the process, there are still challenges related to proving the "traditionality" of insect consumption and ensuring consistent application across different member states. The exact timeline for new approvals depends on the completion of EFSA's safety evaluations and subsequent regulatory steps by the European Commission. Edible insects exhibit diverse characteristics and are used extensively in the food industry. They undergo various processing steps such as pre-treatment, drying, and extraction of edible compounds. The common method for protein extraction from insects is alkaline solubilization coupled with isoelectric precipitation, while other methods include acid solubilization, dry fractionation, and ultrasound-assisted extraction. These processes aim to maximize protein yield while maintaining functional properties like solubility, foaming capacity, emulsifying, gelation, water holding capacity, and oil holding capacity (Gnana Moorthy Eswaran U. *et al.*, 2023). Edible insects provide a wide range of nutrients, including proteins, mono and polyunsaturated fatty acids, amino acids, vitamins, fibers, and minerals. They are recognized as a sustainable and nutritious protein source, containing all essential amino acids (EAAs) necessary for human health. Insects such as Hermetia illucens (black soldier fly), Tenebrio molitor (mealworm), Acheta domesticus (house cricket), and Apis mellifera (honeybee) have particularly high EAA content. The digestibility of insect proteins is high, ranging from 76% to 98%, comparable to animal proteins. Due to these nutritional benefits, edible insects are used in various food products, including whole insects, powders, protein isolates, canned products, extruded products, hard candies, spreads, liqueur infusions, biscuits, and other food items (Gnana Moorthy Eswaran U *et al.*, 2023).

2.3 Current Status of Insect Utilization: EU Regulations on Consumption, Use, and Sale, and Future Projections for Insect-Based Food Products

Insects represent an emerging food sector in the European Union, with several Member States reporting occasional human consumption. Species such as flies, mealworms, crickets, and silkworms have significant potential for use as food or feed. Insects are promising sources of protein, and numerous studies highlight their potential as novel food and feed protein sources. The possibility of using insects for food and feed has been investigated by food authorities, including the FAO and EFSA.

Currently, eight novel food applications for insects are undergoing safety evaluations by EFSA. The European Commission has authorized the market placement of four insect species as novel foods: *Tenebrio molitor* (mealworm), *Locusta migratoria* (migratory locust), *Acheta domesticus* (house cricket), and *Alphitobius diaperinus* (lesser mealworm). European food legislation on novel foods (EU Regulation 2015/2283) requires comprehensive assessments of nutritional, microbial, and toxicological risks, along with evidence that the novel food is unlikely to cause allergic reactions before it can be authorized for the EU market.

Regulation (EU) 2017/893 specifies safety conditions for producing insect-based feed, listing species such as *Hermetia illucens, Musca domestica, Tenebrio molitor, Alphitobius diaperinus, Gryllodes sigillatus, Acheta domesticus, and Gryllus assimilis* as fulfilling these criteria based on national risk assessments and EFSA's advice. The regulatory framework covers the entire production chain, from wild harvesting to farmed insects, emphasizing the need for food and feed safety monitoring similar to conventional livestock.

Many European countries comply with EU laws on edible insects, and regulatory differences influence the global availability of insect products. Hygiene standards in feed and food production are regulated by various EU regulations, ensuring safety standards in food processing and expanding the range of insect products. Competent authorities, such as the Veterinary Inspectorate or Health Inspectorate, assess product safety, with quality control based on guidelines like Codex Alimentarius.

Animal-based foods have traditionally been dietary staples because they provide essential nutrients. However, edible insects have the potential to serve as healthy, sustainable alternatives due to their high levels of vitamin B12, iron, zinc, fiber, essential amino acids, omega-3 and omega-6 fatty acids, and antioxidants. Adding edible insects like crickets to the human diet could provide numerous environmental and nutritional benefits, including reduced greenhouse gas emissions, decreased agricultural use of land and water, improved management of chronic diseases like diabetes, cancer, and cardiovascular disease, and enhanced immune function.

Future research should aim to understand the beneficial effects of whole insects or insect isolates compared to traditional animal- and plant-based foodstuffs. Ultimately, insects have the potential to be used as meat substitutes or dietary supplements. Edible insects could also play a crucial role in the bioconversion of agri-food wastes, estimated at 1.3 billion tons per year globally. Financial and logistical considerations are crucial in selecting insect feed.

Several EU regulations guarantee the safety of animal feeds, including:

- Commission Regulation (EC) No. 1069/2009
- Commission Regulation (EU) No. 142/2011
- Commission Regulation (EC) No. 999/2001
- Commission Regulation (EC) No. 1137/2014 amending Annex III of Regulation (EC) No. 853/2004
- Regulation (EC) No. 767/2009
- Commission Notice (EU) 2018/C 133/02

These legal acts introduce feed safety standards in the production of edible insects for human and animal consumption. Implemented standards significantly limit the use of many conventional food products as insect feed. Products like wheat flour, soymeal, and skimmed milk cannot be regarded as sustainable feeds in insect farming because they are part of the human diet. Insects effectively convert various types of waste biomass into nutritious products, potentially closing nutrient cycles, minimizing the environmental impacts of food production, and reducing production costs (Table 1).

Species	Utilization in the Agri-Food Sector	
	Food	Feed
Acheta domesticus	✓	✓
Alphitobius diaperinus	✓	✓
Cockroaches	✓	✕
Hermetia illucens	✕	✓
Musca domestica	✕	✓
Tenebrio molitor	✓	✓

Table 1: Insects capable of converting different waste feedstocks.

(Żuk-Gołaszewska K. et al., 2022)

The European regulatory framework for insect-based foods and feeds includes several key regulations:

- **1981:** Introduction of the Hazard Analysis and Critical Control Points (HACCP) system and guidelines for animal nutrition practices (*Codex Alimentarius)*.
- **2001:** Regulation (EC) No. 999/2001 on transmissible spongiform encephalopathies prevention and control.
- **2002:** Regulation (EC) No. 178/2002 establishing the European Food Safety Authority and food safety procedures.
- **2003:** Regulation (EC) No. 1831/2003 on animal nutrition additives.
- **2004:** Regulation (EC) No. 853/2004 on hygiene rules for animal-origin foods and Regulation (EC) No. 854/2004 on official controls for animal-origin products.
- **2005:** Commission Regulation (EC) No. 2073/2005 on microbiological criteria for foodstuffs.

- **2009:** Regulation (EC) No. 767/2009 on the market placement and use of feed.
- **2011:** Regulation (EU) 2015/2283 on novel foods.
- **2015:** EFSA Scientific Opinion on the risk profile of insects as food and feed.
- **2018:** 'Novel Food' Report on the Risk Profile for House Cricket.
- **2021:** Commission Regulation (EU) 2021/1372 on feeding non-ruminant farmed animals with insect-derived protein.

Edible insects represent a sustainable and nutritious alternative to traditional animal-based foods. They offer significant nutritional benefits and environmental advantages, with a robust regulatory framework in place to ensure their safety and marketability in the EU. The continued development and acceptance of insect-based foods could play a crucial role in future food security and sustainability efforts.

Chapter 3

3: Insect Marketing and Nutritional Potential

3.1 Market Classification and Projections

The market for edible insects is expected to reach over 390 million consumers in Europe, driven by new operators and the opening of the market under the Novel Food regulation. According to recent reports, the global market for edible insects is projected to grow to $9.6 billion by 2030, with a CAGR of 28.3% from 2022 to 2030 (IMARC). This market includes products such as whole insects, insect powder, insect meal, and insect oil. Various insect types, including crickets, black soldier flies, and mealworms, are utilized in applications like animal feed, protein bars and shakes, baked goods, confectionery, and drinks.

In Europe, sales authorizations for insect-based products are expanding. For example, the online shop "Essento" in Switzerland markets snacks made from dehydrated crickets and mealworms. Despite the nutritional benefits of insects, including proteins, vitamins, amino acids, and iron, these products are still rare in traditional stores. Consumers often turn to specialized online shops or choose to raise their own insect colonies. However, purchasing from specialized retailers is recommended for safety reasons. E-commerce platforms like 21bites® offer a range of insect-based products, including various flours and seasoned insects. Products made from insect flours, such as pasta, biscuits, bars, and crackers, are available, along with exotic dishes that recreate culinary experiences from regions where insect consumption is common (IMARC) .

3.2 Whole Insects and Regulatory Framework

Regulations 2023/5 and 2023/58 of the European Commission stipulate that, from 2023, foods containing partially defatted powder of house cricket (Acheta domesticus) and larvae of the lesser mealworm (Alphitobus diaperinus) in powdered, dried, paste, or frozen form can be sold in the EU. This authorization includes four edible insects: dried mealworms (Tenebrio molitor), migratory locusts (Locusta migratoria), house crickets, and lesser mealworms.

Cricket powder and mealworm larvae can be used in a variety of products, including bread, cereal products, powdered soups, meat substitutes, beer, snacks, and chocolate. However, consuming whole insects poses risks related to their origin, raising, storage, and processing, making decontamination challenging. It is crucial to raise and consume insects safely and to eat them cooked (Nakimbugwe D, *et al.*, 2020).

The use of cricket flour in the EU is authorized by Implementing Regulation No. 2023/5 as a "novel food" for a trial period of five years. This regulation allows the use of partially defatted powder from Acheta domesticus in various products for the general population. Whole insects are not covered by this regulation and cannot be marketed without authorization, but processed parts of approved insects can be sold. Clear labeling is essential to avoid misunderstandings and allow consumers to make informed choices, especially when there is a risk of allergic reactions.

3.3 Nutritional and Environmental Potential of Insect-Based Foods

Insect flour contains up to 75% high biological value proteins, including all essential amino acids. It also offers unsaturated fatty acids, omega-3 and omega-6, and is rich in B vitamins (including B12), iron, calcium, and magnesium. Despite these benefits, consumer acceptance remains a challenge. Many people find the idea of consuming insects unappealing and may have concerns about safety and quality. Responsible production of insect flours is crucial to ensure safety and sustainability. Additionally, insect proteins can trigger allergic reactions, particularly in individuals allergic to crustaceans, dust mites, and mollusks (Vasilica BTB, *et al.*, 2022).

Cricket flour, for instance, is an excellent protein source, containing over 65% high biological value proteins, fiber, calcium, vitamin B12, iron, phosphorus, and sodium.

However, it remains a niche product with high costs compared to conventional protein sources. Insect-based products have the potential to replace some animal-based foods, contributing to sustainability. Controlled insect farming could also reduce the consumption of wild animals in Asian countries, decreasing contamination and health risks.

Edible insects have a small ecological footprint, requiring less land and water to thrive, and their rapid growth cycles minimize the depletion of arable land. Insects convert low-protein feed into edible protein efficiently, resulting in low emissions of greenhouse gases and ammonia. For example, obtaining one gram of edible protein from mealworms requires eight times less land than from beef. Mealworms also have a smaller environmental impact in terms of greenhouse gas emissions compared to conventional animal agriculture.

According to the FAO, over 2 billion people worldwide already consume edible insects regularly, embedded in the culture and culinary traditions of regions like South America, Africa, and Asia. The consumption of edible insects is spreading to many other countries, with an increasing availability of insect-based foods like pasta, snacks, and energy bars in countries such as Canada, Northern Europe, the United States, Australia, and Japan. The market for edible insects is expected to grow significantly worldwide, with double-digit growth forecasts (Ros-Baró, M. *et al*., 2022).

Interest in insect-based products is also growing in America. In Canada, Aspire Foods produces cricket-based bars popular among athletes. In the United States, restaurants like Oyamel Cocina Mexicana in Washington and Black Ant in New York serve dishes containing insects (Ribeiro JC, *et al*., 2024). As regulatory landscapes evolve, insect-based products could play a significant role in future food security and sustainability efforts.

Chapter 4

4. Nutritional aspects of insects

4.1 Nutritional composition of insects

Insects have significant potential as ingredients for industrial applications, offering excellent technological properties. They are rich in minerals, carotenoids, vitamins C and E, riboflavin, niacin, and possess a broad amino acid profile. Insects are excellent sources of protein, phosphorus, copper, iron, zinc, and manganese, as well as good sources of magnesium, potassium, and niacin. They exhibit a relevant nutritional composition in terms of both macro and micronutrients.

Insects can contain up to 75% protein, 20-40% fat, and 5-15% chitin in their dry matter. Chitin, found in insects, forms a complex with proteins and lipids, which affects its digestibility. However, chitin is considered an insoluble dietary fiber with protective health effects (Lívya Alves *et al*., 2024). This complex contributes to the overall nutritional and functional properties of insect-based foods.

Edible insects have garnered attention due to their rich nutritional and health components. Studies have demonstrated that the bioactive compounds in edible insects can potentially aid in weight control (Seo, M *et al*., 2017). With the global obesity rate on the rise, leading to diseases such as diabetes, cardiovascular disease, and cancer, finding ways to alleviate obesity is a pressing issue. Insects like *Tenebrio molitor* (mealworm), *Hermetia illucens* (black soldier fly), and *Musca domestic*a (housefly) have shown potential hypolipidemic and anti-obesity effects (Lange, K.W. *et al*., 2023).

Chitosan, isolated from *Acheta domesticus* (house cricket), can bind lipids and has been shown to control body weight in pigs, exerting anti-obesity effects. Additionally, the consumption of insects can enhance human health by replenishing micronutrients or increasing intestinal probiotic content, thus promoting intestinal health.

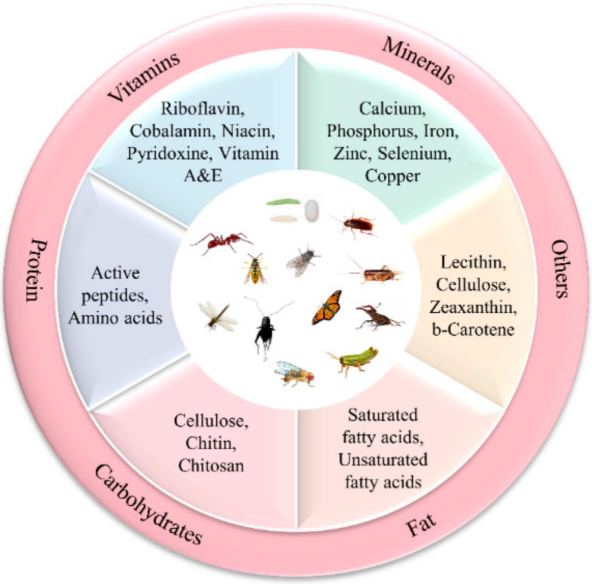

Figure 2: Nutritional composition of edible insects.

(Zhou Y et al. 2022)

4.1.1 Proteins and Amino Acids

Proteins are essential for life, playing critical roles in immune response as antibodies, and in biochemical reactions as enzymes. They also provide energy when needed. Insects are rich in protein, making them a valuable food source. Proteins are composed of over 20 amino acids, nine of which are essential and must be obtained from the diet. Studies have shown that insect proteins indeed contain all essential amino acids required by humans, including Leucine (Leu), Isoleucine (Ile), Lysine (Lys), Methionine (Met), Threonine (Thr), Tryptophan (Trp), Phenylalanine (Phe), and Valine (Val). Insects like *Hermetia illucens* (black soldier fly), *Tenebrio molitor* (mealworm), and *Acheta domesticus* (house cricket) are noted for their high levels of these essential amino acids. The amino acid profiles of these insects often exceed the daily requirements set by the Food and Agriculture Organization (FAO) for adult humans, making them a highly nutritious protein source (A. Van Huis. *et al*., 2017). Studies have shown that insects like grasshoppers, crickets, moths, and termites have higher biological values (85% to 93%) compared to traditional protein sources such as milk casein (77% to 84%) (Ojha, S *et al*., 2021). A comparison of EAA contents of diverse insect sources and well-known protein sources is displayed in Table 2. Insects such as *Hermetia illucens* (black soldier fly), *Tenebrio molitor* (mealworm), and *Acheta domesticus* (house cricket) are particularly notable for their high essential amino acid (EAA) content (Table 3). For instance, *Hermetia illucens* contains 45g of EAAs per 100g of protein, comparable to beef which contains 41.9g. Similarly, *Tenebrio molitor*, *Acheta domesticus*, and *Apis mellifera* (honeybee) have significant EAA levels, making them excellent protein sources.

The protein content of common edible insects like *Acheta domesticus* (72.45%), *Tenebrio molitor* (45%), and *Antheraea assamensis* pupae (38.05%) surpasses that of legumes such as lentils (26.7%), beans (23.5%), and soybeans (41.1%). Additionally, insect proteins exhibit high digestibility, comparable to conventional proteins like beef (89%), pork (90%), turkey (78%), and salmon (85%).

In general, insect protein content ranges from 35% to 60% of dry weight, or 10% to 25% of fresh weight, which is higher than that of cereals and legumes (Zhou Y *et al*. 2022). Orthoptera species, including crickets, locusts, and grasshoppers, tend to have higher protein content (Zhou Y *et al*., 2022). Insects not only provide a wide range of amino acids but also an abundance of essential amino acids, making them an excellent dietary protein source (Figure 3).

In summary, insects are a rich source of high-quality proteins and essential amino acids. Their high biological value, digestibility, and nutritional profile make them a promising alternative to traditional protein sources. Integrating insect proteins into human diets can contribute to better nutrition and health, addressing dietary needs and promoting sustainable food practices.

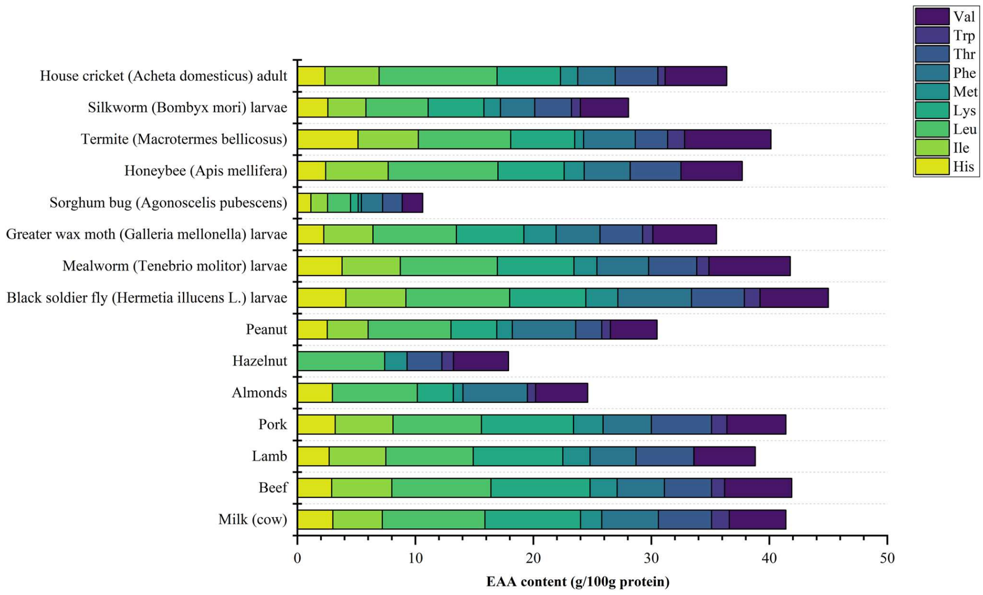

Table 2: Comparison of essential amino acid contents of insect sources and common food sources (A. J. Hernández-Álvarez *et al*., 2022)

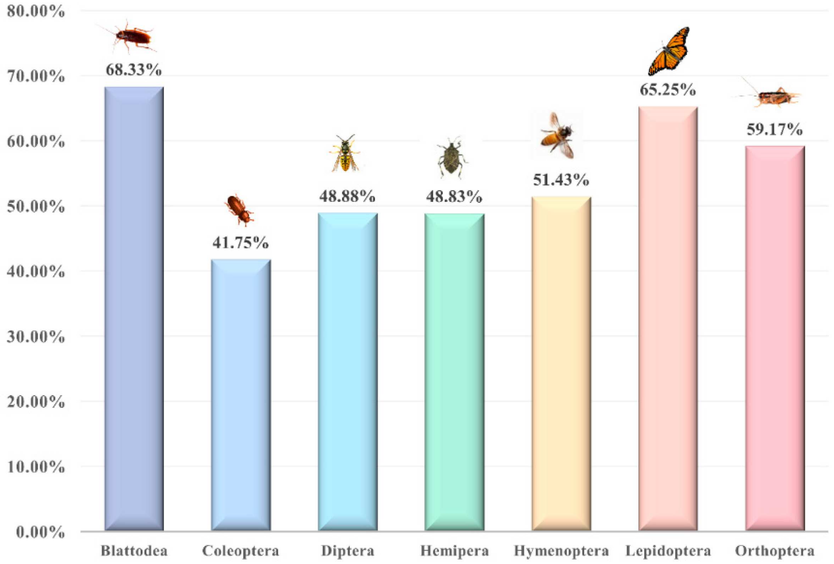

Figure 3: Protein content of edible insects of several common orders.

(Zhou Y et al. 2022)

Scientific Name	Ile	Leu	Lys	Met	Cys	Phe	Tyr	Thr	Trp	Val	Arg	His	Ala	Asp	Glu	Gly	Pro	Ser
Antheraea pernyi	79.5[a]	32.4[a]	45.4[a]	14.7[a]	1.5[a]	81[a]	20.6[a]	46.4[a]	40.5[a]	66.3[a]	41.2[a]	29.4[a]	62.6[a]	64.1[a]	127.4[a]	44.2[a]	122.2[a]	46.4[a]
Bombyx mori	57[a]	83[a]	75[a]	46[a]	14[a]	51[a]	54[a]	54[a]	6[a]	56[a]	68[a]	25[a]	55[a]	109[a]	149[a]	46[a]	40[a]	47[a]
Gryllodes sigillatus	25.6	57.8	38.4	15.9	11.1	22.0	31.8	36.8	NA	47.0	46.6	17.2	58.0	72.8	106.6	40.7	54.2	40.4
Schistocerca gregaria	28.2	77.7	35.1	8.2	3.6	18.7	33.1	35.5	NA	56.6	39.8	20.6	88.8	66.1	107.5	49.4	67.1	33.7
Hermetia illucens	7.62[b]	12.1[b]	11.9[b]	3.37[b]	1.02[b]	7.56[b]	12.1[b]	6.82[b]	3.00[b]	12.9[b]	12.3[b]	5.94[b]	12.2[b]	16.5[b]	19.7[b]	9.14[b]	10.2[b]	7.02[b]
Chilecomadia moorei	6.51[b]	10.1[b]	8.72[b]	2.49[b]	0.87[b]	5.47[b]	7.95[b]	5.74[b]	1.56[b]	9.71[b]	11.7[b]	4.08[b]	8.67[b]	12.9[b]	16.4[b]	6.53[b]	9.52[b]	7.88[b]
Blatta lateralis	7.73[b]	12[b]	12.8[b]	3.35[b]	1.44[b]	7.67[b]	14.3[b]	7.89[b]	1.66[b]	12.3[b]	14[b]	5.49[b]	16.7[b]	15.1[b]	22.6[b]	12.4[b]	10.6[b]	8.38[b]
Musca domestica	8.1[b]	12.4[b]	12.6[b]	5.84[b]	1.4[b]	7.91[b]	9.26[b]	7.54[b]	2.4[b]	11[b]	12.1[b]	5.71[b]	11.7[b]	16.3[b]	21.1[b]	8.43[b]	8.36[b]	6.97[b]
Zophobas morio	9.3[b]	19.1[b]	10.3[b]	2.1[b]	1.5[b]	6.8[b]	13.7[b]	7.8[b]	1.8[b]	10.3[b]	9.6[b]	6.0[b]	14.3[b]	15.8[b]	24.2[b]	9.5[b]	10.8[b]	9.2[b]
Tenebrio molitor	8.6[b]	14.3[b]	11.2[b]	2.6[b]	1.5[b]	7.5[b]	14.3[b]	6.4[b]	1.7[b]	12.2[b]	10.3[b]	6.5[b]	13.7[b]	16.2[b]	22.8[b]	9.9[b]	12.1[b]	9.1[b]
Galleria mellonella	6.3[b]	12.4[b]	7.9[b]	2.2[b]	1.1[b]	5.3[b]	8.8[b]	5.9[b]	1.2[b]	6.8[b]	7.1[b]	3.3[b]	9.4[b]	13.4[b]	19.5[b]	7.4[b]	9.5[b]	10.5[b]
Acheta domesticus	9.4[b]	20.5[b]	11.0[b]	3.0[b]	1.7[b]	6.5[b]	10.0[b]	7.4[b]	1.3[b]	10.7[b]	12.5[b]	4.8[b]	18.0[b]	17.2[b]	21.5[b]	10.4[b]	11.5[b]	10.2[b]
Gryllus bimaculatus	9.2[b]	16.5[b]	11.4[b]	3.5[b]	1.6[b]	7.4[b]	11.7[b]	8.1[b]	2.2[b]	13.6[b]	11.4[b]	5.2[b]	19.3[b]	19.7[b]	24.4[b]	12.4[b]	12.5[b]	10.5[b]
Gonimbrasia belina	13.0[c]	18.3[c]	25.6[c]	4.1[c]	1.1[c]	13.5[c]	22.3[c]	18.4[c]	4.8[c]	19.1[c]	45.7[c]	18.4[c]	23.6[c]	31.3[c]	43.5[c]	17.9[c]	18.6[c]	17.5[c]
Gynanisa maja	18.8[c]	27.2[c]	40.2[c]	8.2[c]	2.2[c]	19.8[c]	41.7[c]	22.6[c]	7.5[c]	20.9[c]	31.4[c]	25.3[c]	25.5[c]	39.9[c]	52.4[c]	19.9[c]	25.0[c]	23.1[c]
Ruspolia differens	26.1[c]	26.7[c]	57.4[c]	4.3[c]	0.7[c]	26.1[c]	25.3[c]	28.6[c]	0.3[c]	16.4[c]	49.8[c]	44.1[c]	26.6[c]	49.0[c]	84.3[c]	26.0[c]	19.0[c]	25.9[c]
Macrotermes falciger	18.9[c]	31.6[c]	37.2[c]	8.2[c]	1.3[c]	19.7[c]	34.4[c]	19.5[c]	3.5[c]	21.7[c]	30.1[c]	26.5[c]	27.4[c]	37.3[c]	46.8[c]	18.9[c]	19.3[c]	20.8[c]
Imbrasia belina	22.0[c]	35.0[c]	36.0[c]	9.0[c]	NA	25.0[c]	36.0[c]	27.0[c]	7.0[c]	NA	32.0[c]	17.0[c]	NA	NA	NA	NA	NA	NA
Apis mellifera	16.0[c]	25.0[c]	19.0[c]	NA	3.0[c]	2.0[c]	15.0[c]	16.0[c]	NA	17.0[c]	16.0[c]	7.0[c]	16.0[c]	26.0[c]	50.0[c]	14.0[c]	NA	14.0[c]
Rhynchophorus ferrugineus	8[c]	12[c]	11[c]	2[c]	1[c]	7[c]	21[c]	8[c]	1[c]	10[c]	10[c]	4[c]	11[c]	16[c]	25[c]	9[c]	10[c]	9[c]

Table 3: Amino acid composition of insects.

(Zhou Y et al. 2022)

4.1.2 Fats and Carbohydrates

Insect fat is a significant energy source and provides essential fatty acids, such as linoleic acid (LA, omega-6) and α-linolenic acid (ALA, omega-3), which are crucial for maintaining human health (Waterhouse, D. *et al*., 2016). The fatty acid composition varies among insect species. For example, beetle larvae predominantly contain oleic acid, while linoleic acid is more abundant in cricket larvae. Tenebrio molitor (mealworm) larvae and crickets are particularly high in linoleic acid.

Insect fats are often referred to as insect oils because they remain liquid at room temperature due to their high content of unsaturated fatty acids (57–75%). These fats are valuable for making pasta, sweets, and butter. Lipids are the second most abundant nutrient group in insects, especially in the larval stage, with dried insects containing 10–50% lipids. Insects can have up to 43% of their dry weight as fat, though this varies significantly between species. For instance, beetles have an average fat content of around 33.40%, while orthopterans (e.g., grasshoppers) have about 13.41%. Generally, female insects, larvae, and pupae have higher fat content.

The composition of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) in insect fat directly influences its nutritional quality. Unsaturated fats are crucial for cardiovascular, brain, and metabolic health. Including these fats in the diet can provide significant health benefits and reduce the risk of chronic diseases. Insects have been shown to have a fatty acid composition similar to poultry and fish but often with a higher proportion of PUFAs compared to traditional livestock like beef and pork.

Carbohydrates in insects are primarily found in the exoskeleton, mainly composed of chitin—a long-chain polymer of N-acetyl-D-glucosamine. Chitin provides structural support and protection to insects. The chitin content in the dry matter of Tenebrio molitor can reach 137.2 mg/kg. Large quantities of chitin can be used to produce bioactive chitosan, which has numerous applications in biotechnology and medicine. Although the overall carbohydrate content in insects is low, insect polysaccharides, such as those from silkworm pupae, possess immunomodulatory properties (Zhou Y *et al.* 2022).

Chitin is a natural, non-toxic polysaccharide with antimicrobial and antioxidant properties, commonly sourced from crustaceans, insects, and fungi. Human gastric juice contains chitinase, an enzyme capable of digesting chitin, indicating that humans can utilize chitin. Traditionally, marine crustaceans have been the primary source of chitin, but they are expensive to obtain. Insects offer a more sustainable and reproducible source of chitin. Cricket chitosan has been shown to inhibit or eliminate pathogenic bacteria by promoting probiotic levels (Kipkoech, C. *et al.*, 2021). Unlike crustaceans, chitin from insects is usually extracted under less harsh conditions.

Insects rich in chitin include Coleoptera, Lepidoptera, Hymenoptera, Diptera, Orthoptera, and Hemiptera (Ma, J. *et al*., 2021). Insect residues such as wings, legs, or bodies discarded during processing can also be potential sources of chitin. These residues can be processed to extract chitin, allowing for more complete utilization of insects. Chitin extraction and purification methods may vary depending on the source and intended application, commonly involving deproteinization and demineralization processes to remove proteins and minerals, resulting in purified chitin.

4.1.3 Vitamins and minerals

Vitamins and minerals are essential for maintaining proper body function and overall health. While traditional food sources like vegetables, fruits, meats, and grains are well-known providers of these nutrients, edible insects are increasingly recognized as valuable sources as well. Insects contain various vitamins, including A, D2, D3, C, E, K, thiamine (B1), riboflavin (B2), pantothenic acid (B5), niacin (B3), pyridoxine (B6), folic acid (B9), D-biotin (B7), and B12, alongside minerals such as potassium, calcium, magnesium, zinc, iron, phosphorus, copper, and manganese. These nutrients can be extracted from insects and used as dietary supplements (Nowakowski, A.C *et al*., 2022).

In general, insects typically have higher amounts of calcium, copper, zinc, and manganese than traditional meats like chicken, pork, and beef. This higher bioavailability makes insects a valuable nutritional resource, particularly in regions where iron and zinc deficiencies are prevalent (Meyer-Rochow, V.B. *et al*., 2022). For instance, Oecophylla smaragdina and Odontotermes are rich in iron, zinc, and copper, and their proper consumption can help meet the recommended daily intake. Additionally, minerals in edible insects are easily absorbed and utilized by the body, similar to beef tenderloin. Iron and zinc are crucial in preventing malnutrition and developmental delays. However, despite their potential, insects are not receiving much attention as a source of these minerals in human diets.

Iron and zinc levels in edible insects can vary according to species, development stage, and diet, ranging from 4–62 mg/100 g dry matter for iron and 9–27 mg/100 g dry matter for zinc (Mwangi, M.N *et al*., 2018). Common vitamins found in insects, such as B12, riboflavin, and thiamine, can also vary by species. Vitamin B12, primarily found in animal foods, is vital for those who do not consume meat or fish, as it helps maintain a healthy nervous system and red blood cells. For example, dried cricket powder contains ten times more vitamin B12 compared to beef.

The incorporation of insects into diets can significantly enhance nutrient intake and address deficiencies, particularly in areas with limited access to diverse food sources. Thus, promoting the consumption of edible insects could be a viable strategy to improve global nutrition and health.

4.1.4 Other Compounds

Phenolic compounds have long been recognized for their positive impact on human health, particularly due to their antimicrobial and antioxidant properties. While plants are traditionally known as the primary source of phenols, it is notable that insects also produce these beneficial compounds. Phenolic compounds such as phenolic acids, flavonoids, and tannins are efficiently synthesized by insects, often requiring fewer resources like water, land, and fertilizer compared to plants. This makes insect-sourced polyphenols a more sustainable alternative (Lee, J.H. *et al*., 2021).

Many insects, including bees, houseflies, yellow jackets, and crickets, are known to provide phenolic chemicals. The quantity of polyphenols in insects can vary significantly depending on their diet and life stage. This variability underscores the importance of understanding and optimizing insect diets to maximize the health benefits of these compounds.

In addition to phenolic compounds, insects produce antimicrobial peptides (AMPs), which are short proteins with potent immunological effects against bacterial, viral, fungal, and parasitic organisms. These AMPs are crucial for the insects' innate immune defense and hold significant potential for applications in medicine and agriculture, particularly in addressing antibiotic resistance (Patyra, E. *et al*., 2023). For instance, the silkworm (*Bombyx mori*) produces antimicrobial peptides like moricin, gloverin, and cecropin, which exhibit broad-spectrum activity. Cecropin, first discovered in the pupae of *Hyalophora cecropia*, has been shown to inhibit the growth of viruses and malaria-associated parasites (Orivel, J. *et al*., 2021).

The beneficial functions of active compounds in edible insects are increasingly recognized by the public. However, the presence of anti-nutrients in insects is a topic of some controversy. Anti-nutrients are secondary metabolites synthesized by plants for self-protection, which accumulate in the bodies of insects as they feed on these plants. These substances, including phytates, tannins, oxalates, trypsin inhibitors, lectins, and hydrocyanides, can inhibit the absorption of vital nutrients in insects.

Interestingly, despite their reputation, anti-nutrients have shown beneficial effects in the treatment of various diseases. They are especially noted for their roles in managing obesity, diabetes, antiviral therapy, neuroprotection, lowering blood cholesterol levels, and inhibiting cancer growth. Edible insects containing these anti-nutrients could thus potentially contribute to these health benefits, but more research is needed to fully understand their effects and optimize their use in human nutrition.

In summary, the nutritional and medicinal potential of insects is vast, encompassing beneficial phenolic compounds and antimicrobial peptides, as well as potentially advantageous anti-nutrients. This multifaceted nutritional profile highlights the promise of insects as a sustainable and health-promoting food source.

4.2 Comparison of nutritional composition of insects and other common sources of proteins

Edible insects offer impressive nutritional benefits, often surpassing traditional meat sources. For example, 100 grams of African termites provide 610 calories, 38 grams of protein, and approximately 17 grams of fat (0.5997 ounces). In contrast, the same portion of moth larvae contains 375 calories, 46 grams of protein, and 10 grams of fat. A typical 100-gram hamburger provides 245 calories, 21 grams of protein, and 17 grams of fat. These comparisons demonstrate that insects can be nutritionally superior or comparable to red meat and poultry, particularly in protein content, with some species also being lower in fat.

Insects like the American-style silkworm, palm butterflies from French Guiana, and water bugs from Thailand are highly nutritious, rich in fiber, proteins, and vitamins. Fresh edible caterpillars contain 28 grams of protein per 100 grams, compared to 21 grams in chicken for the same weight (Adrien Fernandes, J.F *et al*., 2023). In terms of digestibility, insect protein is on par with milk, soy, and casein.

The FAO (United Nations Food and Agriculture Organization) advocates for the inclusion of insects in the human diet as a sustainable solution to global food security. Nearly 2000 species of insects are considered edible, and they are consumed by at least 2 billion people worldwide. Insects can help alleviate global hunger due to their high-quality protein and vitamin content, which are comparable to those found in meat. Moreover, insects have a significantly lower environmental impact. They require much less land, water, and feed compared to traditional livestock and produce fewer greenhouse gases. For example, crickets need six times less feed than cattle, four times less than sheep, and twice less than poultry to produce the same amount of protein.

Insect farming is not only environmentally friendly but also has the potential to stimulate new economic and industrial markets, creating job opportunities. This makes edible insects a promising option for both sustainable food production and economic growth (Shah AA, *et al*., 2022).

Source	Protein (g/100 g)	Fat (g/100 g)	Saturated Fat (g/100 g)	Sodium (mg/100 g)	Calcium (mg/100 g)	Iron (mg/100 g)	Lodine (mg/100 g)	Vitamin C (mg/100 g)	Vitamin A (mg/100 g)	Riboflavin (mg/100 g)	Niacin (mg/100 g)
Beef	20.6	9.3	3.8	60	5	1.95	10	0	0	0.23	4.7
chicken	19.9	7.2	1.81	80	8	0.88	6	1.1	0	0.16	6.5
pork	20.1	12.4	3.5	62	7	0.8	5	0	0	0.235	5.6
Cricket (adult)	20.1	5.06	2.28	152	104	5.46	0.021	3	6.53	3.41	3.84
Honeybee (brood)	15.2	3.64	2.75	19.4	30	18.5	NA	10.5	25.7	3.24	NA
Silkworm (pupae)	14.8	8.26	3.45	14	42	1.8	NA	NA	NA	1.05	0.9
Mopane caterpillar (final instar)	35.2	15.2	5.74	NA	700	NA	NA	NA	NA	NA	NA
Palm weevil (larvae)	9.96	25.3	9.84	11	39.6	2.58	NA	0.00425	11.3	2.21	NA
Mealworm (larvae)	19.4	12.3	2.93	53.7	42.9	1.87	0.017	1.2	9.59	0.81	4.07

NA = not available.

Table 4: Comparison of nutrient content between common insects and conventional poultry.

(Halloran, A. et al. 2016)

4.3 Insect products available on the market

The focus of my thesis was to create a comprehensive table cataloging most of the edible insect products available on the market. This table includes over 100 products and was compiled through research on various websites, as well as insights from the scientific work titled "Edible Insects as Emerging Food Products – Processing and Product Development Perspective.” (https://doi.org/10.1007/s13197-022-05489-y)

Edible insects are increasingly being incorporated into diets worldwide due to their exceptional nutritional value and numerous health benefits. They are an inexhaustible resource that can be sustainably harvested from nature, boasting high feed conversion efficiency. Recognizing the potential of edible insects in sustainable food production highlights their role in enhancing food security and biodiversity conservation, ensuring a sufficient supply of insect resources for future global food needs. These insects are processed to develop innovative products, improve sensory and nutritional qualities, and extend shelf life.

The remarkable characteristics of edible insects make them highly valuable for the food industry. Edible insects are formulated into a diverse range of food products, ensuring safety regulation compliance. Their broad nutritional profile includes proteins, mono- and polyunsaturated fatty acids, amino acids, vitamins, and minerals, making them suitable ingredients for developing products like whole insect powder, protein isolates, canned goods, extruded products, hard candies, spreads, liqueur infusions, biscuits, and more.

The data for the table were gathered from numerous online sources. The table is structured to provide detailed information on each product, including:

- Commercial name

- Manufacturer
- Link to website
- Type of product
- Size of packaging (in grams)
- Percentage of insect content
- Cost per unit (in Euros)
- Nutritional values
- Claims
- Country of origin and distribution
- Distribution network

This detailed catalog aims to showcase the diversity and potential of edible insect products, providing a valuable resource for consumers, researchers, and industry stakeholders interested in the burgeoning field of insect-based foods. Here, I have provided an excerpt from the table featuring some of the edible insect products available on the market (Table 5).

ACHETA (CRICKET) POWDER EXO	Exo	https://exoprotein.com/	Cricket powder	454	100	35,80		Nutrient-rich, tasty, dairy-free, and environmentally friendly alternative to other animal protein sources. EXO Acheta Protein Powder is non-GMO, and provides 6g of complete protein, a healthy dose of prebiotics, Vitamin B12, Copper, Biotin, Zinc, Iodine, and Manganese per serving.	USA and worldwide	WEB
CHOCOLATE CHIRP COOKIES EXO	Exo	https://exoprotein.com/collections/featured/products/chocolate-chirp-cookies-1	Cookies with cricket powder	196		5,50		Source of probiotic chitin for gut health,Vit B12. 40 % more potassium than whey and all 9 essential aminoacids.	USA and worldwide	WEB
FUDGE BROWNIE MINI BITES EXO	Exo	https://exoprotein.com/products/fudge-brownie-mini-bites	Mini bites	200		6,41	 **Nutrition Facts** 5 servings per container **Serving size 1 Pouch (40g)** **Amount Per Serving** **Calories 180** % Daily Value* **Total Fat** 9g 12% Saturated Fat 5g 25% *Trans* Fat 0g **Cholesterol** 35mg 12% **Sodium** 115mg 5% **Total Carbohydrate** 22g 8% Dietary Fiber 1g 4% Total Sugars 15g Includes 15g Added Sugars 30% **Protein** 4g 8% Vitamin D 2.9mcg 15% Calcium 20.6mg 2% Iron 1.59mg 8% Potassium 64mg 2% Vitamin A 4% Vitamin B12 20% *The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.	With less sugar, more protein, and half the ingredients per serving versus the other guys, these All-Natural, Non-GMO, and Gluten Free bites	USA and worldwide	WEB

Bud's Cricket Power **Bud's cricket powder**	Bud's cricket powder	https://budscricketpower.com/product/buds-cricket-powder-16oz/	Cricket powder	450	100	32		From crickets raised on GMP-certified farms, registered with the United States FDA, meeting both European and American standards for hygiene. Crickets are extremely nutrient rich; on a per serving basis our Cricket Powder has more Protein than Beef, more Calcium than dairy Milk, more Iron than Spinach, more Vitamin B12 than Kale, and more Omega-3 than Salmon. Crickets are one of the most sustainable protein source available on the planet, using 2,000x less water than beef and 216x less water than soy per pound produced.	USA and worldwide	WEB	
Whole Roasted Crickets **Bud's cricket powder**	Bud's cricket powder	https://budscricketpower.com/product/buds-cricket-power-whole-roasted-crickets-1-2-lb-8-oz-227g/	Roasted and toasted flavoured crickets	230	100	20		Crickets and many other insects use considerable less resources, land, water and feed to produce relative to traditional forms of livestock. Crickets also emit a negligible amount of greenhouse gases.	USA and worldwide	WEB	
Whole Roasted Spicy Crickets **Bud's cricket powder**	Bud's cricket powder	https://budscricketpower.com/product/whole-roasted-spicy-crickets-45grams/	Roasted and toasted flavoured crickets	45	100	9		ENERGY WHEREVER YOU GO: Enjoy at home on the couch or on the hiking trail! These dried insects are incredibly protein packed, providing you with a healthy snack that will give you long-lasting energy throughout the day. NUTRIENT DENSE: Cricket protein is nothing to scoff at. Crickets are 65% protein by weight, making them a great choice for a light snack or giving your favorite meal a boost of flavor and protein.	USA and worldwide	WEB	
Premium cricket powder **All things bugs** **Goipro**	Goipro	https://allthingsbugs.com/product/premium-cricket-powder-by-all-things-bugs/	Cricket powder	450	100	32		Farm-raised crickets. With its mild aroma, neutral flavor, and minute particle size, this powder is perfect for anybody who needs an extra protein boost in their diet by adding it to any recipe without compromising the taste or texture. Paleo diet and gluten free	USA and worldwide	WEB	

PROTEIN PASTA FUSILLI BASIL JIMINI'S	Jimini's	https://www.jiminis.com/shop/lang/en/protein-pasta/306-pates-3760274101700.html	**Protein pasta with buffalo worm powder**	250	4	4,99	Values per 100g: Energy 1573 kj / 371 kcal Fats 1,9g of which saturated fat 1,2g Carbohydrates 72g of which sugars 1,8g Fibre 3,7g Protein 15g Salt 0,13g	Source of protein and fibers	France and worldwide	WEB
CRICKETS CAYENNE PEPPER JIMINI'S	Jimini's	https://www.jiminis.com/shop/lang/en/insect-snacks/234-edible-crickets-cayenne-pepper-3770004159246.html	**Roasted and toasted flavored crickets**	15	65	6,95	Values per 100g: Energy 1610kJ / 385 kcal Fats 18g of which saturated fat 6,8g Carbohydrates 9g of which sugars 2,4g Fibre 9,5g Protein 42g Salt 1,8g	High in protein and fibers	France	WEB
PROTEIN BARS FIG & CHOCOLATE JIMINI'S	Jimini's	https://www.jiminis.com/shop/lang/en/protein-bars/279-fig-and-chocolate-protein-bars.html	**Protein bars with whole buffalo worms (Alphitobius diaperinus)**	12X40	5,5	22,80	Values per 100g: Energy 1711kJ / 410kcal Fats 20g of which saturated fat 3.7g Carbohydrates 33g of which sugars 29g Fibre 8.9g Protein 20g Salt 0.28g	High in protein and fibers, no added palm oil. Naturally gluten free, milk free, additive free and palm oil free Made from 94.5% organically grown ingredients	France and worldwide	WEB

Table 5*:Examples of edible insect products available on the market*

4.3.1 Manufacturers

Here are some manufacturers I've discovered, along with their histories and missions:

- **Circle Harvest:** Circle Harvest has been raising 100% Australian-farmed crickets on their farm in western Sydney since 2007. These crickets are fed a nutritious diet of fruit and vegetables that were originally destined for landfill, thereby integrating these resources back into the food system as feed for nutrient-rich crickets. This practice not only supports sustainability but also contributes to food security by utilizing food waste effectively

- **DeliBugs:** DeliBugs, based in the Netherlands, specializes in the sale of edible insects, offering both freeze-dried and powdered varieties. Their product range includes sweets and snacks made from grasshoppers, crickets, and worms. DeliBugs aims to promote the consumption of insects, highlighting their nutritional benefits and sustainability. They provide a variety of products suitable for different dietary needs and preferences, ensuring the origin and food safety of their products are guaranteed

- School friends Shami Radia and Neil Whippey co-founded **Eat Grub** in 2014, initially as a part-time pop-up restaurant concept. By 2016, they transitioned fully into the insect-based food business. Based in London, Eat Grub partners with an external manufacturer to produce a variety of insect products. Their range includes roasted crickets, which were listed in Sainsbury's last year and are now available in 250 of their stores. They also offer protein bars, energy powders, and raw ingredients derived from grasshoppers, mealworms, and buffalo worms. The company started gaining traction when they began testing their products through pop-up restaurants, eventually developing a more extensive product line. Their approach included energy bars and protein powders, which helped them gain entry into larger retailers like Ocado and Planet Organic. Eat Grub's roasted crickets became particularly popular, leading to their listing in Sainsbury's stores. The company has also started exporting to other European countries, including Finland, Germany, and the Netherlands.

- **Exo:** Exo is an American company founded by Gabi Lewis and Greg Sewitz in 2013. The company specializes in producing protein bars using cricket flour made from pulverized house crickets. Their products are marketed as a nutritious source of protein, containing up to 70% protein, which is significantly higher than traditional protein sources like chicken or beef. Exo's products include protein bars, energy powders, and other cricket-based foods, emphasizing sustainability and nutritional benefits. The founders started the company during their time at Brown University and later moved to New York, where they collaborated with an R&D expert from the Fat Duck restaurant to refine their recipes. Exo's cricket-based products have gained popularity and are now recognized for their environmental advantages and high nutritional value

- Since 2012, **JIMINI'S** has established a network of over 300 partner retailers across six European countries. JIMINI'S specializes in creating healthy and delicious insect-based products. Their products are made from insects bred in Europe and are manufactured in their workshop in Vaux-le-Pénil, near Paris. The company offers a variety of products, including whole insects (plain or seasoned), as well as dehydrated and powdered forms.

- **Merci Mercado:** Merci Mercado aims to preserve the authenticity of food products and bring them to chefs and food enthusiasts worldwide. The company is dedicated to maintaining high-quality standards for its products. Specializing in edible insects sourced from Mexico, Merci Mercado emphasizes core values of sustainability, versatility, health, and deliciousness. Their range includes various insect-based products like grasshoppers (chapulines), which are integrated into gourmet recipes reflecting traditional Mexican cuisine. Merci Mercado collaborates closely with local producers, respecting their values, traditions, and environmental practices. This approach ensures that their products not only meet but often exceed quality and sustainability standards, such as those certified by ENTOTRUST, which guarantees the safety, nutritional value, and environmental benefits of their insect-based offerings

- Founded in 2011 by Cédric Auriol, **Micronutris** is a French company dedicated to the breeding, processing, and marketing of edible insects. Auriol's passion for innovation, nutrition, and sustainable development led to the creation of Europe's first insect farm for human consumption. Micronutris has become a benchmark in the sector and was the first company in the world to obtain ISO 22000 certification for food safety. This certification highlights their commitment to high-quality production standards, ensuring that their insects are fed 100% plant-based and organic feed

- **Minus Farm:** Minus Farm is an urban micro-farm in France that promotes the sustainable integration of edible insect proteins into diets. They raise, process, and package their insects locally, ensuring that the insects are fed with foods sourced from 100% French and organic farming. This approach guarantees no use of pesticides, GMOs, artificial colors, or flavors, emphasizing their commitment to sustainability and quality.

- **Nimavert:** Nimavert was founded in late 2016 by Nico and Maarten, with the aim of introducing edible insects into Western diets. The company initially focused on breeding insects but later shifted to transforming them into food products. In late 2019, Nimavert acquired Little Food, a company offering a full range of cricket products. Nimavert emphasizes the environmental and nutritional benefits of insects, particularly mealworms, as an alternative protein source

- **Wicked Cricket:** based in Munich, Wicked Cricket is encouraging a culinary revolution by promoting insects as a valuable food source. The company aims to change perceptions and introduce insects as a nutritious and sustainable option for consumers.

4.3.2 Type of product

The increasing possibility of widespread insect consumption has driven the food industry to develop more strategies for the controlled domestication of insects. The industry aims to commercialize these new foods in various forms that can be integrated into people's daily diets. Additionally, the food industry is continuously innovating to market insects for human consumption by reinventing traditional Western foods with insect ingredients. Examples of such insect-derived products include breads, biscuits, tortillas, energy bars, pâtés, sauces, pastas, sweet and savory snacks, chocolates, and meat products. Some of the specific types of products listed in the table are:

- **Breads**: Incorporating insect flour to enhance protein content.
- **Biscuits and Cookies**: Made with cricket or mealworm powder for added nutrients.
- **Tortillas**: Enriched with insect protein to boost nutritional value.

- **Energy Bars**: Packed with insect protein for a sustainable energy source.
- **Pâtés and Sauces**: Blended with insect powders for flavor and nutrition.
- **Pastas**: Utilizing insect flour to increase protein content.
- **Sweet and Savory Snacks**: Including flavored insect snacks like cricket chips.
- **Chocolates**: Infused with insect powders for a unique taste and added protein

These innovative products aim to normalize insect consumption by integrating them into familiar food formats, making it easier for consumers to accept and enjoy the nutritional benefits of insects. Here I reported some examples:

- **CRICKET POWDER by CIRCLE HARVEST:** This protein powder is made from 100% Australian-farmed Acheta Domesticus crickets. Each 20g serving delivers over 13g of easily digestible protein, along with essential nutrients such as calcium, iron, and a variety of micronutrients. It is particularly rich in vitamins B12 and B2 and contains three times the Omega-3 fatty acids found in salmon. Importantly, it has no added salt or sugar, making it a pure and natural protein supplement (Figure 5).
- **BLUEBERRY MINI BITES BY EXO:** with 30% less sugar, double conteont of proteins, and less than half the number of ingredients per serving compared to other similar products. This snack contains *Acheta Domesticus* extract (Figure 6).
- **MEALWORM POWDER BY DELIBUGS:** the powder contains proteins, vitamins, and healthy fats, with a remarkably high digestibility of 90%. Furthermore, the powder is free of chemicals, antibiotics, hormones, and pesticides (Figure 7).
- **PROTEIN BARS WITH WHOLE BUffALO WORMS BY JIMINI'S:** These bars are high in protein and fiber, with no added palm oil. They are

naturally gluten-free, milk-free, additive-free, and palm oil-free. Made from 94.5% organically grown ingredients, each box includes 12 bars, each weighing 40g, at a cost of 22.80 euros (Figure 8).

- **CHOCOLATE WITH MEALWORMS BY MICRONUTRIS:** dark chocolate recipe with mealworms offers a unique tasting experience: With their slight hazelnut flavor and crunchy texture, the edible insects enhance the intense cocoa by giving it a "puffed rice" effect (Figure 9).
- **GRASSHOPPERS SALT BY MERCI MERCADO:** The Merci Mercado Grasshopper Salt / Sal de Chapulin is a unique combination of toasted grasshoppers from Oaxaca with a mix of local spices and peppers that intensify the characteristic flavor of this edible insect (Figure 10).
- **CRICKET CORN CHIPS BY CIRCLE HARVEST:** 100% natural ingredients circle fruit and vegetable waste from food production processing back into their food system by feeding it to their mini livestock. High-protein snacks between meals can help reduce your appetite and decrease the number of calories you consume at your next meal (Figure 11).

Figure 5*:* Cricket powder by Circle Harvest

Figure 6: blueberry bites by Exo

Figure 7:mealworm powder by Delibugs

Figure 8:Protein bars with whole buffalo worms by Jimini's

Figure 9:Chocolate with Mealworms by Micronutris

Figure 10*:* Grasshoppers salt by Merci Mercado

Figure 11*:* cricket corn chips by Circle Harves

4.3.3 Nutritional Comparison of Insect-Based Food Products

The burgeoning market for edible insect products offers a fascinating array of nutritional benefits, providing a sustainable and nutrient-rich alternative to traditional protein sources. Below is an in-depth comparison of the nutritional values of various insect-based food products, highlighting their potential as a significant component of future diets.

Protein Content

Insects are renowned for their high protein content, which can vary widely depending on the species and developmental stage. For example:

- **Roasted Crickets**: Products like the roasted crickets from Cricket Flours and Bud's Cricket Powder boast about 65% protein by weight, making them an excellent protein source for both fitness enthusiasts and those seeking to increase their protein intake naturally. Bud's Cricket Powder notes that their product contains more protein per serving than beef, highlighting the efficiency of crickets as a protein source.
- **Black Soldier Fly Larvae**: These larvae, offered by companies like Cricket Flours, contain around 43% protein by weight and are also rich in iron and zinc, making them a highly nutritious option.
- **Mealworms**: Freeze-dried mealworms, such as those sold by Delibugs, contain approximately 45.1g of protein per 100g. This high protein content, combined with a rich profile of essential nutrients, makes mealworms a versatile ingredient for various food products.

Energy and Fat Content

The caloric content of insects is influenced mainly by their fat content:

- **Energy-Rich Insects**: The energy provided by insects can range from 290 kilocalories per 100g (similar to dried lentils) to 762 kilocalories per 100g (comparable to butter). For instance, the freeze-dried grasshoppers from Delibugs contain 595 kcal per 100g, indicating their high energy density.

- **Fat Content**: Insects can contain between 10% and 60% fat. The type of fat is predominantly unsaturated, including essential lipids like linoleic acid. For example, Delibugs' grasshoppers contain 38.1g of fat per 100g, while their mealworms contain 37.3g of fat per 100g, emphasizing their role as a good source of healthy fats.

Vitamins and Minerals

Insects are packed with a variety of vitamins and minerals:

- **Vitamins**: Edible insects are particularly rich in B vitamins. For example, the cricket powder from Human Improvement contains high levels of Vitamin B12, essential for maintaining energy levels and neurological function. Additionally, products like the cricket powder from Nutribug boast significant amounts of Vitamin B12, iron, and calcium.
- **Minerals**: The mineral content in insects includes iron, zinc, calcium, potassium, magnesium, copper, sodium, phosphorus, selenium, and manganese. For example, the cricket powder from EXO provides a rich source of iron, zinc, and other essential minerals, which are crucial for various bodily functions.

Fiber Content

Insects contain dietary fiber, primarily in the form of chitin, which is the main component of their exoskeleton:

- **Chitin**: This fiber is beneficial for digestive health. Products like the roasted crickets from Eat Grub contain high amounts of dietary fiber, which aids in digestion and contributes to overall gut health.

Examples of Insect-Based Products

Here are some specific products that exemplify the diverse nutritional benefits of edible insects:

- **Cricket Protein Powder**: Circle Harvest's cricket protein powder is rich in B12, iron, and calcium, making it an excellent addition to smoothies and baked goods for an extra nutritional boost.
- **Energy Bars**: EXO's protein bars, such as their Blueberry Mini Bites, contain 30% less sugar and double the protein compared to traditional energy bars, making them a healthier snack option.
- **Protein Pasta**: Nutribug's cricket protein pasta delivers 14g of protein per 100g, more than what is found in eggs, and includes other essential nutrients like omega-3 fatty acids and B12 vitamins.
- **Granola**: Jimini’s buffalo worm granola provides a high-protein, fiber-rich breakfast option, with 13g of protein per 100g.

4.3.4 Comparative Analysis of Claims on Edible Insect Products

The market for edible insects has seen significant growth, driven by their nutritional benefits and sustainable production methods. This analysis explores the various claims made by different insect-based products, highlighting their nutritional profiles and marketing strategies.

Protein Content

One of the most prominent claims across edible insect products is their high protein content. For instance:

- **Bud’s Cricket Powder** emphasizes that their cricket powder contains more protein than beef, providing a rich source of calcium, iron, and vitamin B12. They also highlight the sustainable nature of cricket farming, which uses significantly less water than traditional livestock farming.
- **Eat Grub's Cricket Protein Powder** boasts 100% cricket powder with high protein and fiber content, emphasizing its rich vitamin B12 and iron levels. This product is marketed for its clean protein, suitable for a health-conscious audience.

Micronutrient Density

Edible insect products often claim to be rich in essential micronutrients:

- **Circle Harvest's Cricket Corn Chips** claim to offer 14% of the recommended daily intake of vitamin B12 and iron per serving, positioning them as nutrient-dense snacks.
- **Jimini’s Protein Pasta with Buffalo Worm Powder** provides 15 grams of protein per 100 grams and highlights its source of iron, calcium, omega-3, and vitamin B12.

Sustainability

Sustainability is a key selling point for many insect-based products. For example:

- **Human Improvement's Vanilla Protein Powder** claims to be one of the most sustainable protein sources, using minimal resources and reducing greenhouse gas emissions. They highlight the high protein and micronutrient content, such as B12 and zinc, which support overall health and energy levels
- Circle Harvest emphasizes its closed-loop farming system, where food waste

from fruit and vegetable production is used to feed crickets, integrating sustainability into their entire production process.

Versatility and Convenience

Insect-based products are marketed for their versatility and convenience:

- **Nutribug’s Cricket Protein Bars** are promoted as convenient, high-protein snacks with no added sugars or sweeteners, suitable for a gluten-free diet. This makes them an attractive option for health-conscious consumers looking for quick and nutritious snack options.
- **Exo's Prebiotic Protein Bars** emphasize their dairy-free, gluten-free, and sustainably produced ingredients. The bars are marketed as convenient snacks that offer high protein and fiber content, helping to reduce cravings and support digestive health

Specific Health Benefits

Many products make specific health claims related to their nutrient content:

- **Jimini’s Fig & Chocolate Protein Bars** claim to be high in protein and fiber, with no added palm oil, making them a clean, healthy snack. They highlight the use of organically grown ingredients, appealing to consumers looking for natural and wholesome food options.
- **Hey Planet’s Salty Peanut Butter Protein Bar** claims to provide 16-17% planet-friendly protein, rich in iron, fiber, and vitamin B12, without any added sugar. They emphasize their products' gluten-free, soy-free, and lactose-free attributes, catering to a wide range of dietary needs

Examples of Products and Their Claims

1. **Bud's Cricket Powder**: Claims to provide more protein than beef, more calcium than dairy milk, and more omega-3 than salmon. It also highlights its sustainability by using 2,000 times less water than beef.
2. **Jimini's Crickets Cayenne Pepper**: Boasts high protein and fiber content, with nutritional values per 100g including 42g of protein and 9.5g of fiber.
3. **Circle Harvest's Cricket Protein Powder**: Marketed as a green and clean protein source, using minimal energy, water, and land. It is also rich in essential vitamins and minerals.

The edible insect market is diverse, with products ranging from protein powders and bars to snacks and pasta. The common themes across these products include high protein content, rich micronutrient profiles, sustainability, versatility, and specific health benefits. These claims are supported by detailed nutritional information, appealing to health-conscious and environmentally-aware consumers. As the market grows, these attributes will continue to drive the popularity and acceptance of insect-based foods.

This comparative analysis demonstrates that edible insect products are not only nutritious and sustainable but also versatile and convenient, making them a viable option for future food consumption.

Conclusions

Population growth, urbanization, and the rise of the middle class have significantly increased global demand for food, particularly for animal protein sources. Traditional animal food production methods, such as fishmeal, soybeans, and cereals, must be further optimized in terms of resource efficiency and expanded to include alternative sources. By 2030, the world will need to feed more than 9 billion people, in addition to billions of farmed animals raised annually for food and recreational purposes like pets. Furthermore, issues such as water and land pollution from intensive livestock production and deforestation from overgrazing contribute to climate change and other environmental challenges. One viable solution to these food and feed safety challenges is the cultivation of insects.

Insects are ubiquitous and reproduce rapidly, boasting a high growth rate and efficient food conversion, all while maintaining a low environmental impact throughout their life cycle. They are highly nutritious, rich in proteins, fats, and minerals, and can be raised on food scraps. Insects can be consumed whole, in pieces, or processed into powders or pastes and incorporated into various food products. The large-scale use of insects as food ingredients is technically feasible, and industries worldwide are already engaged in this production. For instance, using insects as feed for aquaculture and poultry is expected to become increasingly common over the next decade.

The use of insects for food and feed production offers numerous environmental, health, and social benefits. Insects have a high nutritional conversion efficiency because they are cold-blooded animals. The nutritional conversion rates for meat (the amount of feed needed to produce a 1 kg weight increase in an animal) vary widely depending on the animal type and farming practices. On average, insects can convert 2 kg of food into 1 kg of body mass, whereas cattle require 8 kg of food to achieve the same weight gain. The greenhouse gas emissions from most insects are significantly lower than those from conventional livestock. For example, pigs produce 10-100 times more greenhouse gases per kg of body weight than mealworms do.

Insects can be fed organic waste such as food scraps, human waste, compost, and animal manure, converting them into high-quality proteins that can be used for animal feed. Additionally, insects use less water than conventional livestock. Mealworms, for instance, are much more resilient to water scarcity than cattle. Insect farming is also less dependent on land availability compared to traditional livestock farming.

The nutritional content of insects depends on their life stage, habitat, and diet. However, it is widely established that insects provide high-quality protein and nutrients comparable to those found in meat and fish. Insects are particularly beneficial as dietary supplements for undernourished children, as many species contain high amounts of fatty acids, comparable to those found in fish. They are also rich in fiber and micronutrients such as copper, iron, magnesium, manganese, phosphorus, selenium, and zinc. Insects pose a low risk of transmitting zoonoses (diseases transmitted from animals to humans) such as H1N1 (avian influenza) or BSE (mad cow disease).

Collecting and breeding insects can offer important strategies for diversifying livelihoods. Insects can be directly and easily collected in nature, and the basic techniques for collection and breeding require simple methods and minimal capital investment. Insects can be gathered from the wild, raised, prepared, and sold by the poorest members of society, such as women and landless workers in rural or urban areas. These activities can directly improve diets and provide cash income by selling surplus products in local markets. Collecting and breeding insects thus present entrepreneurial opportunities in developed, transitional, and developing economies. Insects can be prepared as food or feed relatively easily. Some species can be consumed whole, while others can be processed into paste or ground before consumption, or their proteins can be extracted and used separately.

In conclusion, the integration of insects into our food and feed systems offers a promising solution to address the challenges posed by increasing global food demand, environmental sustainability, and nutritional security. By leveraging the unique advantages of insects, we can move towards a more sustainable and resilient food system.

Webliography

- Acosta-Estrada BA, Reyes A, Rosell CM, Rodrigo D, Ibarra-Herrera CC. Benefits and Challenges in the Incorporation of Insects in Food Products. Front Nutr. 2021 Jun 30;8:687712. doi: 10.3389/fnut.2021.687712. PMID: 34277684; PMCID: PMC8277915.
- Adrienne Katz Kennedy. 2023. Bug And Insect-Eating Practices Across The Globe.
- Alhujaili A, Nocella G, Macready A. Insects as Food: Consumers' Acceptance and Marketing. Foods. 2023 Feb 19;12(4):886. doi:10.3390/foods12040886. PMID: 36832961; PMCID: PMC9956212.
- Bartkiene, E.; Zokaityte, E.; Kentra, E.; Starkute, V.; Klupsaite, D.; Mockus, E.; Zokaityte, G.; Cernauskas, D.; Rocha, J.M.; Guiné, R.P.F. Characterisation of Lacto-Fermented Cricket (*Acheta domesticus*) Flour and Its Influence on the Quality Parameters and Acrylamide Formation in Wheat Biscuits. *Fermentation* 2023, *9*, 153. https://doi.org/10.3390/fermentation9020153
- Belluco S., Losasso C., Maggioletti M., Alonzi, C. C., Ricci, A., & Paoletti, M. G. (2015). Edible insects: a food security solution or a food safety concern Anim. Front., 5(2), 25-30.
- Bresciani A, Cardone G, Jucker C, Savoldelli S, Marti A. Technological Performance of Cricket Powder (*Acheta domesticus* L.)in Wheat-Based Formulations. Insects. 2022 Jun 14;13(6):546. doi: 10.3390/insects13060546. PMID: 35735883; PMCID: PMC9224782.
- Committee on World Food Security (CFS). *CFS voluntary guidelines on food systems and nutrition*. Rome, Italy: CFS; 2021.

- EFSA. Risk profile related to production and consumption of insects as food and feed. 2015
- E.M. Costa-Neto, F.V. Dunkel. 2016. Chapter 2 - Insects as Food: History, Culture, and Modern Use around the World. Insects as Sustainable Food Ingredients Production, Processing and Food Applications. ScienceDirect.
- Escobar-Ortiz A, Hernández-Saavedra D, Lizardi-Mendoza J, Pérez-Ramírez IF, Mora-Izaguirre O, Ramos-Gómez M, Reynoso-Camacho R. Consumption of cricket (Acheta domesticus) flour decreases insulin resistance and fat accumulation in rats fed with high-fat and -fructose diet. J Food Biochem. 2022 Sep;46(9):e14269. doi: 10.1111/jfbc.14269. Epub 2022 Jun 20. PMID: 35722751.
- Gnana Moorthy Eswaran U, Karunanithi S, Gupta RK, Rout S, Srivastav PP. Edible insects as emerging food products-processing and product development perspective. J Food Sci Technol. 2023 Aug;60(8):2105-2120. doi: 10.1007/s13197-022-05489-y. Epub 2022 Jun 20. PMID: 37273559; PMCID: PMC10232397.
- Guiné RPF, Florença SG, Costa CA, Correia PMR, Cruz-Lopes L, Esteves B, Ferreira M, Fragata A, Cardoso AP, Campos S, Anjos O, Bartkiene E, Djekic I, Matran IM, Čulin J, Klava D, Chuck-Hernández C, Korzeniowska M, Boustani NM, Papageorgiou M, Gutiérrez BP, Černelič-Bizjak M, Damarli E, Ferreira V. Edible Insects: Perceptions of Marketing, Economic, and Social Aspects among Citizens of Different Countries. Foods. 2023 Nov 23;12(23):4229. doi: 10.3390/foods12234229. PMID: 38231666; PMCID: PMC10706764.
- Jones AD, Hoey L, Blesh J, Miller L, Green A, Shapiro LF. A Systematic Review of the Measurement of Sustainable Diets. Adv Nutr. 2016 Jul 15;7(4):641-64. doi: 10.3945/an.115.011015. PMID: 27422501; PMCID: PMC4942861.
- Lívya Alves Oliveira, Stephanie Michelin Santana Pereira, Kelly Aparecida

Dias, Stefany da Silva Paes, Mariana Grancieri, Luis Gonzalo Salinas Jimenez, Carlos Wanderlei Piler de Carvalho, Eugenio Eduardo de Oliveira, Hércia Stampini Duarte Martino, Ceres Mattos Della Lucia. 2024. Nutritional content, amino acid profile, and protein properties of edible insects (Tenebrio molitor and Gryllus assimilis) powders at different stages of development

- María Fernanda Ordonez Lopez, Sami Ghnimi, Changqi Liu. Willingness to consume insect-based food in France: Determinants and consumer perspectives. LWT - Food Science and Technology 185 (2023) 115179
- Micha R, Mannar V, Afshin A, Allemandi L, Baker P, Battersby J, Bhutta Z, Chen K, Corvalan C, Di Cesare M et al. *Global nutrition report: action on equity to end malnutrition*. Behrman N, editor. Bristol, UK: Development Initiatives; 2020.
- Nowakowski AC, Miller AC, Miller ME, Xiao H, Wu X. Potential health benefits of edible insects. Crit Rev Food Sci Nutr. 2022;62(13):3499-3508. doi: 10.1080/10408398.2020.1867053. Epub 2021 Jan 5. PMID: 33397123.
- Olivadese M, Dindo ML. Edible Insects: A Historical and Cultural Perspective on Entomophagy with a Focus on Western Societies. Insects. 2023 Aug 4;14(8):690. doi: 10.3390/insects14080690. PMID: 37623400; PMCID: PMC10455489.
- Ribeiro JC, Pintado ME, Cunha LM. Consumption of edible insects and insect-based foods: A systematic review of sensory properties and evoked emotional response. Compr Rev Food Sci Food Saf. 2024 Jan;23(1):e13247. doi: 10.1111/1541-4337.13247. PMID: 38284589.
- Sadigov R. Rapid Growth of the World Population and Its Socioeconomic Results. ScientificWorldJournal. 2022 Mar 23;2022:8110229. doi: 10.1155/2022/8110229. PMID: 35370481; PMCID: PMC8967589.
- Shah AA, Totakul P, Matra M, Cherdthong A, Hanboonsong Y, Wanapat M. Nutritional composition of various insects and potential uses as alternative

protein sources in animal diets. Anim Biosci. 2022 Feb;35(2):317-331. doi: 10.5713/ab.21.0447. Epub 2022 Jan 4. PMID: 34991214; PMCID: PMC8831828.

- Wang XQ, Guo JS, Li DT, Yu Y, Hagoort J, Moussian B, Zhang CX. Three-dimensional reconstruction of a whole insect reveals its phloem sap-sucking mechanism at nano-resolution. Elife. 2021 Feb 23;10:e62875. doi: 10.7554/eLife.62875. PMID: 33620311; PMCID: PMC8016479.
- Zhou Y, Wang D, Zhou S, Duan H, Guo J, Yan W. Nutritional Composition, Health Benefits, and Application Value of Edible Insects: A Review. Foods. 2022; 11(24):3961. https://doi.org/10.3390/foods11243961
- Żuk-Gołaszewska K, Gałęcki R, Obremski K, Smetana S, Figiel S, Gołaszewski J. Edible Insect Farming in the Context of the EU Regulations and Marketing-An Overview. Insects. 2022 May 7;13(5):446. doi: 10.3390/insects13050446. PMID: 35621781; PMCID: PMC9147295.