Emerging Trends of Human Consumption of Insects and Their Future Conservation

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Abstract: In recent years, there has been a notable surge in the global interest surrounding the consumption of insects, known as entomophagy. This trend is propelled by its potential to address various pressing challenges. Entomophagy is deeply rooted in many cultures historically and is regarded as a sustainable solution to contemporary problems such as food security, environmental sustainability, and public health. In this context, this paper explores the emerging trends in human insect consumption and underscores conservation's pivotal role in securing the future of edible insects. This study unveils the multifaceted benefits of entomophagy by emphasizing the cultural significance of insects as a food source, their environmental advantages, and their potential to improve nutrition and reduce the ecological footprint of food production. Notably, various insects such as crickets, grasshoppers, termites, mealworms, and silkworm provide the primary sources of the human diet, including proteins, fats, vitamins, and minerals. Simultaneously, this review sheds light on the challenges posed by overexploitation, and habitat destruction, necessitating robust strategies for insect conservation. The paper advocates for sustainable harvesting, habitat restoration, public education and awareness, and innovative market strategies as critical tools for preserving insect biodiversity while promoting responsible insect consumption. Ultimately, entomophagy and insect conservation convergence presents an intriguing paradigm for a more sustainable and resilient global food system.

Keywords: Entomophagy, food security, nutritional supplements, conservation strategies, edible insects

Introduction

Numerous forecasts indicate that the population is expected to surpass 9 billion by 2050, globally . The growing population necessitates a nearly twofold increase in current food production . Moreover, environmental degradation and climate change resulting from industrialization also adversely impact food productivity . Insects, those tiny, often misunderstood creatures that share our planet, have been a part of human diets for centuries in various cultures across the globe . According to the 2013 FAO/WUR report on edible insects, which states that approximately two billion people are estimated to consume insects . Recently, there has been an increasing fascination with consuming insects as a sustainable and nourishing dietary option . This emerging trend, entomophagy, promises to address many of the challenges associated with traditional livestock production, from environmental sustainability to global food security . Moreover, edible insects represent another option, contributing to food security, particularly in Africa, where insect consumption has a rich historical tradition . In addition, edible insects represent a rich protein, fats, vitamins, and minerals reservoir . Crickets and grasshoppers, in particular, stand out for their high protein content, with edible insects typically containing between 35 to 60 g protein/ 100 g or 10 to 25 g/100 g of dry and fresh weight, respectively .

In many regions, insects have a long history of being culturally accepted as a food source . They offer

significant nutritional benefits for human consumption . Europe and the United States are witnessing the most rapid growth in the edible insect industry, driven in part by a trend toward reduced meat consumption . Despite the numerous benefits, several obstacles persist in developing insect-based foods due to their divergence from conventional Western dietary habits . The field of insect foods is currently in a transitional phase, with a promising approach involving the fusion of protein-processing technology with insects to create novel food products. Given the current scenario of a rapidly increasing global population, the challenge lies in achieving efficient and sustainable land use for agriculture while conserving biodiversity . Extensive scientific research and conservation efforts over the years have underscored that habitat loss, degradation, and the impacts of climate change are the primary stressors affecting insects and various other ecological groups .

For centuries, indigenous cultures across South America, Europe, Asia, and Africa have incorporated various insect species into their diets . Moreover, 2,000 insect species are consumed in 113 countries . To provide a specific example, a survey conducted in Thailand, identified a staggering insect species (164) being traded as food . Among these, the most frequently consumed insects include beetles, bees, caterpillars, ants, grasshoppers, crickets, and locusts . In regions like Zambia, Zimbabwe, and Nigeria, edible insects have become readily available in open markets and school cafeterias, establishing a profitable industry . Remarkably, insects contribute up to 50% of the dietary protein intake, and their market value surpasses other protein sources . The exploration of emerging trends in human consumption of insects and their future conservation is paramount due to its potential to address pressing global challenges. With a growing global population and increasing strain on conventional livestock production systems, entomophagy offers a sustainable alternative source of protein that is highly efficient in resource utilization. Understanding and promoting insect consumption can significantly contribute to mitigating the environmental impacts of traditional livestock farming, including greenhouse gas emissions and deforestation while providing a nutritious and culturally rich food source. Moreover, as the practice gains traction, it raises vital questions about conserving insect species and their ecosystems, as overharvesting and habitat destruction could threaten biodiversity. Therefore, delving into these emerging trends is the key to a more sustainable, diverse, and resilient future for our diets and the planet. Thus, this review highlights the prevailing trends concerning the utilization of insects as food resources within consumer behavior, industry practices, academic research and their conservation.

Nutritional value of insects as food resources

Beyond their environmental advantages, insects also offer a range of nutritional benefits (Van Huis and Oonincx, 2017). Insects boast substantial protein content, ranging from 35% to 61%, and notable lipid levels fall between 13% and 33% (Ojha et al., 2021). Furthermore, insects contain a noteworthy quantity of "animal" fiber in the form of insoluble chitin. In addition to their macronutrient content, certain insect species are recognized for their abundant mineral and vitamin profiles (Ojha et al., 2021). For instance, crickets are a good source of protein, containing all nine essential amino acids (Mafu et al., 2022). They are also rich in B vitamins, iron, and zinc (Figure 1). In addition to being nutritious, insects are low in fat, making them an attractive option for those seeking a lean protein source. Edible insects are noteworthy for their potential health advantages, primarily attributed to their abundant content of vitamin B12, essential amino acids, iron, dietary fiber, zinc, omega-3 and 6, fatty acids, as well as antioxidants (Nowakowski et al., 2022) (Table 1). Recent reports highlight the utilization of palm weevil larvae as an ingredient in snacks, aimed at augmenting the snacks' protein and mineral content owing to the larvae's exceptional nutritional value (Akande et al., 2020). Furthermore, cookies containing palm weevil larvae have been shown to possess enhanced nutritional profiles while also receiving commendable sensory evaluation scores and widespread acceptance (Ayensu et al., 2019). Specifically, *Cirina butyrospermi* has the potential to serve as a valuable source of crucial polyunsaturated fatty acids, offering numerous health advantages, and its substantial protein content underscores the significance of giving this species greater recognition in nutritional research (Anankware et al., 2021). Incorporating edible insects into human nutrition holds the potential for a wide range of advantages (Tang et al., 2019),

encompassing reduced greenhouse gas emissions, decreased land and water use in agriculture, better management and prevention of chronic diseases such as cancer, diabetes, and cardiovascular conditions, and enhanced immune system function (Nowakowski et al., 2022). Moreover, insects contain bioactive compounds that could mitigate health hazards. The safety risks of insect consumption are minimal primarily linked to allergenic concerns (Van Huis et al., 2021).

Table 1. Different edible insects and their nutritional value

Insects species	Proteins	Carbohydrates	Fats	Lipids	Vitamins	Minerals	Reference
Crickets	55-73%	2.5-15%	58%	10-23%	A, B, C, D. E and K	Macro- and micro-mineral elements, including Ca, K, P, Mg, Fe, Na, Zn, Mn, and Cu	Macro- and micro-mineral elements, including Ca, K, P, Mg, Fe, Na, Zn, Mn, and Cu.
Mealworms	51-53%	11.5%	28-33%	40-44%	B12, Niacin and as high in riboflavin, pyridoxine, folate	Zn, Mg, and Ca	(Mariod, 2020, Grau et al., 2017, Alves et al., 2016, Son et al., 2021)
Grasshoppers	36-40%	2.6-3.9%	48.2%	89.4%	Niacin, retinol, riboflavin, B5, B6, B9, and B12	Ca, Mg, K, Na, P, Fe, Zn, Mn, and Cu,	(Ssepuuya et al., 2017, John N Kinyuru, 2010, Kababu et al., 2023)
Termites	29.75-56.44%	34.84-67.09%	44.82-47.31%	1.80-2.90%	A and C	Ca, Na, Mg, Zn, Fe, Cu, and Mn	(Ntukuyoh, 2012, Kinyuru et al., 2013)
Silkworm	48-94.98%	230 kcl/100 g	12.1-35.7%	25-32.2%	A, B1, B2, B3, B5, B7, B9, B12, C, and E	P, Fe, Ca, Zn, Mn, and Cr	(Hăbeanu et al., 2023, Mahanta et al., 2023, Paul and Dey, 2014)

Food safety from edible insect

Humans have been consuming insects for centuries and surprisingly, the scientific literature is scarce addressing the food safety aspects of insect consumption (Mézes and Erdélyi, 2020). While the nutritional benefits of edible insects are evident, it is essential to acknowledge that concerns regarding food safety, including microorganisms, allergies, and toxicity, may become more prominent among consumers. In terms of allergies, certain edible insects have been found to contain proteins that can trigger allergic reactions in individuals who are also allergic to arachnids and crustaceans due to cross-reactivity (Ribeiro et al., 2018). Specific heavy metals raise concerns within the context of insect

consumption. Cadmium levels are of particular concern in black soldier flies, while arsenic is a notable issue regarding yellow mealworm larvae (van der Fels-Klerx et al., 2018). The investigated mycotoxins do not tend to accumulate significantly in these insects. Additionally, it has been observed that insect specimens may occasionally contain veterinary drugs, residues of pesticides, hormones, dioxins, and PCBs (van der Fels-Klerx et al., 2018, Meyer et al., 2021). Moreover, five categories of biological risk factors, ten chemical risk factors, and thirteen physical risk factors have also been recognized (Gałęcki et al., 2023). These risk maps are valuable tools for pinpointing potential hazards, such as foodborne pathogens, within diverse insect species and insect-based food products (Gałęcki et al., 2023) as well as necessitating a comprehensive assessment of allergenic risks before their safe introduction into the food market (Ribeiro et al., 2021). However, there are different other routes of contamination as indicated in Figure 1 (Gałęcki et al., 2023).

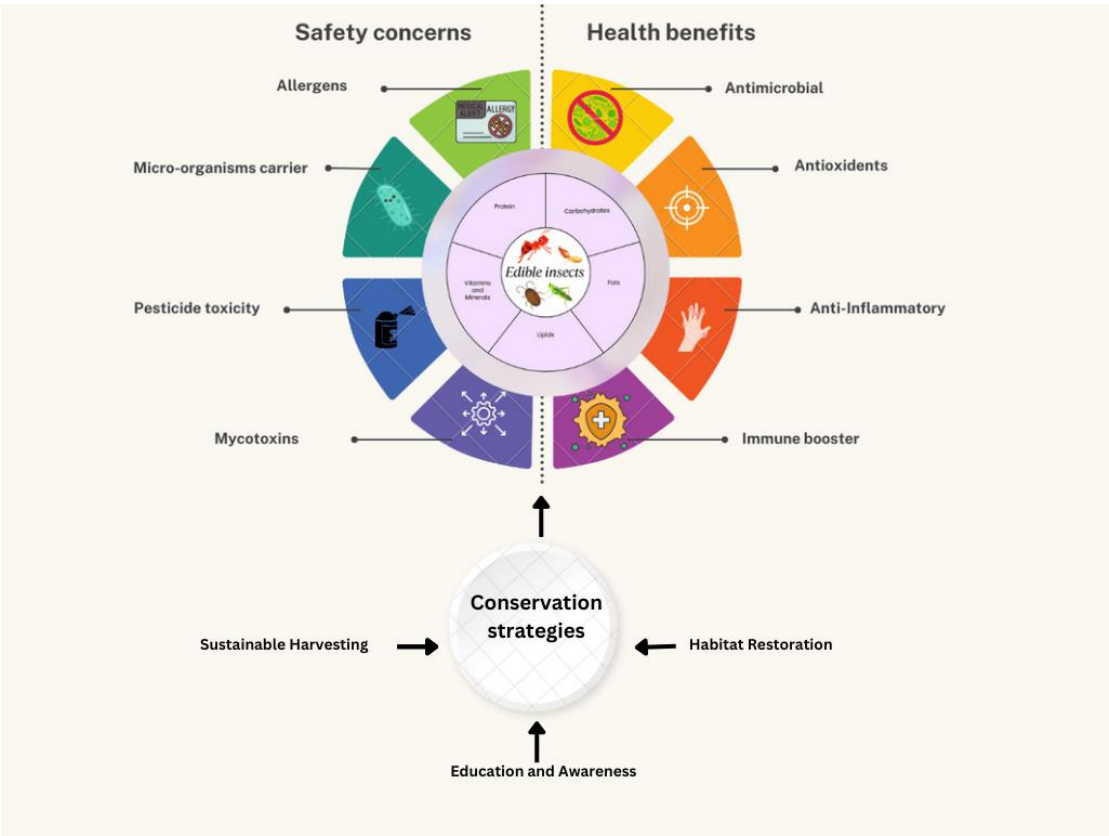

Figure 1: Schematic diagram of edible insects.

Promoting food safety and hygiene practices throughout the entire edible insect supply chain, including wild harvesting, is crucial to guarantee the availability of this highly nutritious and resource-efficient food to consumers without posing any health risks (Imathiu, 2020). Another pressing concern is the need for more regulations governing the edible insect supply chain, a deficiency prevalent in numerous countries, particularly developing nations. Addressing this issue urgently can enhance consumer trust and facilitate the international trade of this commodity (Imathiu, 2020). Furthermore, insect processing must adhere to the Hazard Analysis Critical Control Point (HACCP) principles and its prerequisite programs. Strict adherence to these guidelines will ensure the production of safe products, enabling consumers to harness the outstanding nutritional benefits of insects and their derived products.

Delicious and sustainable: Persuasive strategies to encourage insect consumption:

Strategies to persuade consumers to embrace insect consumption encompass highlighting the nutritional adequacy of insects, incorporating insects discreetly into familiar products (Musundire et al.,

2021). Enhancing the flavor profile of insect-based products. Offering consumers, a captivating taste experience and promoting insect-based products primarily based on taste (Kröger et al., 2022). Furnishing comprehensive information about insect products, acknowledging that sustainability may not be the most compelling factor. Leveraging celebrity endorsements to endorse the product (Cuomo et al., 2019). Tailoring marketing efforts towards specific demographics, such as thrill-seekers or children. Devising market strategies, including using stylish imagery and selecting supermarkets for distribution (van Huis and Rumpold, 2023). In addition, uncover genuine health advantages, delve into authentic benefits, investigate ways to enhance insect farming and food processing methods, analyze cultural obstacles to widespread acceptance, and tackle pertinent food regulations and compliance issues (Mason et al., 2018). Moreover, the regulations do not permit the consumption of all potential insect species as food and animal feed (Lähteenmäki-Uutela et al., 2021). Governments are committed to guaranteeing food and feed safety, and each nation has its distinct sets of rules and procedures to achieve this objective (Lähteenmäki-Uutela et al., 2021). Nevertheless, countries' diverse regulatory requirements and disparities create complexities in developing international marketing strategies for insect-based products (Lähteenmäki-Uutela et al., 2021).

Strategies for insect Conservation:

There are reasons for optimism regarding insect conservation. Innovative approaches, modern technology, and improved data access enhance our understanding of global insect biodiversity. An expanding community of researchers from various fields sheds light on how environmental factors and human activities affect insect species and ecosystems (Didham et al., 2020). The main strategies for insects conservation (Figure 1) are given below:

1. Habitat Restoration:

Implementing regulations on insect harvesting to prevent overexploitation:

This involves creating and enforcing rules and guidelines that control the harvesting of insects . The aim is to ensure that the collection of insects is within sustainable levels, thereby preventing their populations from being depleted . Meanwhile, certain wild edible insects can be considered pests to valuable crops. Therefore, harvesting and incorporating these edible insect pests into our diet and using them for therapeutic applications could represent a noteworthy advancement in biological pest control .

Promoting responsible harvesting practices among insect farmers:

Encouraging those involved in insect farming to adopt responsible and sustainable methods when collecting insects . This can include guidelines on harvesting techniques, timing, and quotas to maintain healthy insect populations . Moreover, preserving traditional methods of conservation, harvesting, and consumption, establishing large-scale captive breeding programs, and fortifying resilient value chains to encourage the participation of local communities .

2. Habitat Restoration:

Efforts to restore and protect natural habitats that support insect populations:

This strategy focuses on rehabilitating and preserving the natural environments where insects live and thrive . Restoring these habitats provides insects with the necessary ecosystems to sustain their populations.

Promoting urban green spaces to create insect-friendly environments:

Green spaces with diverse vegetation and suitable habitats can support insect populations in urban areas. These spaces can act as refuges for insects in environments dominated by human development .

3. Education and Awareness:

Raising public awareness about the importance of insect conservation:

Educating the general public about why insects are crucial to ecosystems and the environment. This awareness can increase support for conservation efforts and a better understanding of insects' role in our world.

Educating consumers on responsible insect consumption:

Furthermore, to foster the expansion of the edible insect industry, engaging in consumer education and implementing effective marketing tactics is essential . This also includes knowing which insects are safe to consume and how to do so without harming the species or their ecosystems.

These strategies collectively aim to strike a balance between human activities, including insect consumption, and the preservation of insect populations and their habitats. By implementing these measures, we can help ensure insects' long-term survival and well-being while harnessing their potential benefits sustainably.

Conclusions

In conclusion, the emerging trends in human consumption of insects represent a promising avenue for addressing pressing global challenges, from food security and environmental sustainability to nutrition. However, as we embrace entomophagy, we must be equally committed to conserving insect species and their habitats. By implementing sustainable harvesting practices, restoring critical insect ecosystems, and raising public awareness, we can ensure that this culinary evolution remains in harmony with the imperative of preserving insect biodiversity. The future of insect consumption lies not only in the nutritional and ecological benefits it offers but also in our ability to strike a responsible balance between our appetites and the conservation of these invaluable creatures.

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Conflict of Interest statement

The author declares no conflict of interest.