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EDIBLE INSECTS: NUTRITIONAL, MEDICINAL AND ALLERGENIC ASPECTS

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ABSTRACT

Edible insects are a natural food resource that provides nutritional, economic, and ecological benefits to many ethnic and tribal communities of Northeast India. Because of the warm and humid atmosphere, entomophagy is popular culturally and spiritually in tropical and subtropical countries. Many insects, such as lepidopterans, orthopterans, dictyopterans, isopterans, and hymenopterans are all considered common food sources. They have high nutritional and medicinal value that can contribute to food security, health promotion, and environmental sustainability. Natural enemies of pests may include various organisms like predators, parasitoids, pathogens and trap crops. However, they also have some health implications and allergenicity that need to be addressed by scientific research, regulatory policies, and public education. This article aims to explore the nutritive and medicinal paradigm of edible insects of northeast India and examine their health implications and allergenicity. It will review the existing literature on the topic and provide recommendations for future research, policy development, and consumer education.

Key words: Edible insects, nutritional benefits, health allergy, bioactive compounds, cross-reactivity, economics, ecological benefits, tribals,medicinal value, health, allergenicity

In a world grappling with the challenges of food security, sustainability, and shifting dietary preferences, alternative sources of nutrition have garnered significant attention. One such unconventional but promising avenue is entomophagy – the consumption of insects as food. As said, there are thought to be around 2000 insect species that are edible worldwide, but very few of them have had their nutritional compositions well studied. Although it is well recognised that insects are a significant source of mostly proteins and lipids, the precise amounts found in each species can vary depending on a number of factors, including feeding habits, ecological factors, developmental stage, and industrialisation. The world's most consumed insect orders are, in general, Blattodea (cockroaches), Coleoptera (beetles), Diptera (flies), Hemiptera (true bugs), Hymenoptera (ants, bees, and wasps), Isoptera (termites), Lepidoptera (caterpillars, butterflies, and moths), Odonata (dragonflies and damselflies), and Orthopera (crickets, grasshoppers, and locusts). There are many edible insect species that have been commercialised in different countries, such as: yellow mealworm (*Tenebrio molitor*), house cricket (*Acheta domesticus*), super worm (*Zophobas morio*), silkworm (*Bombyx mori*), lesser mealworm (*Alphitobius diaperinus*), mopane caterpillar (*Imbrasia belina*), roach (*Blaptica dubia*), and African palm weevil (*Rhynchoporus phoenicis*) (Tang et al., 2019). The order mantodea (mantis) is also included in Africa, with less than 1% of insects consumed there.

Entomophagy has been practiced for centuries across various cultures, yet it has gained renewed interest in recent years due to its potential to address multiple global issues simultaneously. Although insects can be one such novel food source. Nonetheless, an evaluation of the hazards pertaining to their consumption is necessary, encompassing the possibility of allergies. This review paper delves into the multifaceted aspects of entomophagy and its ameliorated knowledge in the last decade (since 2013-2023), focusing on its nutritional value, therapeutic applications, and considerations regarding allergenicity. Edible insects are a natural food resource that provides nutritional, economic, and ecological benefits to many ethnic and tribal communities in India. The region is home to more than 255 insect species that are consumed as food by different tribes, especially in the states of Arunachal Pradesh, Assam, Manipur and Nagaland (Chakravorty et al., 2011). The practice of entomophagy, or the eating of insects, is influenced by various factors such as traditional beliefs, taste preferences, regional and

seasonal availability, and cultural diversity. Edible insects are also associated with social and medicinal values, as they are used to cure various body ailments and enhance health and well-being (Meyer-Rochow and Chakravorty, 2013).

The consumption of insects is not a new practice but it has been a part of human diets for millennia. The reason for this renewed interest is the recognition of the potential of insects to address some of the pressing challenges that humanity is facing in the 21st century, such as food security, environmental sustainability, climate change, poverty alleviation, and public health (Van Huis et al., 2013). Some of the advantages of entomophagy include insect's high feed conversion efficiency, rearing on organic side streams, low environmental footprints, high nutritional and medicinal value, and cultural values (van Huis et al., 2013). Despite the benefits and potential of edible insects, there are also some challenges and limitations that need to be addressed. Some of these include a lack of awareness and acceptance, i.e. many people, especially in urban areas and Western cultures, have negative perceptions and attitudes towards insects as food due to cultural, religious, psychological and aesthetic reasons. They may consider insects as dirty, disgusting, or taboo (Looy et al., 2014). Therefore, there is a need to raise awareness and educate consumers about the nutritional, environmental, and economic advantages of entomophagy and to promote insects as novel and attractive food items (Tan et al., 2015).

There is a lack of clear and consistent standards and regulations for the production, processing, marketing, and consumption of edible insects. This may pose risks for food safety, quality, and traceability, as well as for the protection of intellectual property rights, biodiversity, and ethical issues. There is also a need to harmonise the legal frameworks and policies among different countries and regions, and to develop guidelines and best practices for the insect food sector (Van Huis and Oonincx, 2017). Lack of research and innovation: There is a need for more scientific research and innovation to address the knowledge gaps and challenges in the insect food sector. Some of the research topics include the nutritional composition and bioavailability of edible insects; the effects of insect consumption on human health and well-being; the environmental impacts and sustainability of insect production; the development of efficient and humane methods of rearing, harvesting, processing and preserving insects; the identification and characterisation of new edible insect species; the development of novel insect-based products and recipes; and the assessment of consumer preferences and behaviour towards insect foods (Halloran et al., 2016).

A study estimates that by 2050, global food demand will increase by 60%, requiring an additional 320 million hectares of cropland if current yields remain constant (Bajželj et al., 2014). Two alternative strategies were compared to meet this demand while reducing green house gas (GHG) emissions: land sparing (increasing yields on existing cropland) and land sharing (integrating crops with trees or pasture) (Bajželj et al., 2014). The livestock production accounts for 14.5% of global GHG emissions from human activities, mainly from enteric fermentation (39%), manure (10%), feed production (45%), processing and transport (6%). Implementing strategies like improving animal health and genetics, enhancing feed quality and digestibility, optimizing manure management, increasing energy efficiency, and reducing food losses and waste could lead to emissions reductions of 18% to 30% along the supply chain (Gerber et al., 2013). They also highlight the co-benefits of mitigation for animal welfare, human health, and poverty reduction. Predictions for global and regional food supply and demand up to 2030 and 2050 will be analysed under various climate change and bioenergy production scenarios. The report indicates that climate change will have negative impacts on crop yields, especially in developing regions, while bioenergy will increase the competition for land and water resources (Valin et al., 2014).

The estimation will increase in global food demand by 70 to 100% by the year 2050, depending on the level of bioenergy production. Analysing the balance between food security and environmental sustainability involves studying four dietary change scenarios: business as usual (BAU), healthy diet (HD), vegetarian diet (VD), and vegan diet (VG) (Alexander et al., 2017). They use a global food system model to estimate the impacts of each scenario on food availability, land use, water use, GHG emissions, and nutrient availability. They found that HD, VD, and VG scenarios could improve food security and reduce environmental pressures compared to BAU, but they also entail challenges such as ensuring adequate micronutrient intake, addressing cultural preferences, and managing transition costs. The insects are rich in protein, fat, minerals, and vitamins, and have lower environmental impacts than conventional livestock in terms of land use, water use, feed conversion efficiency, GHG emissions, and waste generation. They

also discuss the potential benefits of insects for income generation, livelihood diversification, food safety, and cultural diversity. It could be the main barriers and opportunities for promoting insect consumption and production at different levels. Many authors review the consumer preferences and willingness to pay for insect-based products in different countries and regions and find that consumer acceptance of insects varies widely depending on factors such as familiarity, perceived benefits, sensory attributes, social norms, ethical concerns, and price (Canavari et al., 2023). The comparison between the sustainability performance of different livestock production systems using a multicriteria approach considered four dimensions of sustainability: environmental (land use, water use, GHG emissions), economic (gross margin), social (employment), and animal welfare (animal health) (Madau et al., 2020). They apply the approach to six case studies in Italy involving dairy cattle and beef cattle.

Edible insects are a valuable food resource that can contribute to food security, nutrition, health, livelihoods, and environmental sustainability. However, there are also some challenges and limitations that need to be overcome to realize their full potential. Therefore, there is a need for more research, innovation, education, awareness, standardization and regulation in the insect food sector. This article aims to explore the nutritional and therapeutic advantages of eating edible insects from East India, as well as their potential health risks and allergic properties. This review highlights the existing knowledge on the issue and makes recommendations for further research, public policy development, and consumer education.

Nutritional value

According to various studies, edible insects have high nutritional value and can provide many benefits for human health (Weru et al., 2021; Rumpold and Schlüter, 2013; Shadung and Given, 2012). In general, raising insects for food uses a lot fewer resources than raising animals for meat. By offering a different range of nutrients, edible insects can also augment other diets and offer a chance to increase food security (Hazarika and Kalita, 2023). Compared to conventional animal sources such as meat, fish and eggs, edible insects have similar or higher amounts of protein, amino acids, fat, trace elements and vitamins (FAO, 2014). For instance, silkworm larvae and pupae have about 60-70% protein, 10-20% fat, 2-5% carbohydrate and various minerals such as calcium, iron, zinc and magnesium (edible insect nutrition information). Red ant larvae have about 50% protein, 15% fat, 16% carbohydrate and high amounts of vitamin C (edible Insect nutrition information). Giant water bugs have about 62% protein, 8% fat, 11% carbohydrate and high amounts of vitamin B complex (edible insect nutrition information). The nutritional value and chemical composition of edible insects may vary depending on the plant they feed on, the season and the location. The following table shows some examples of the nutritional value of edible insects (as fresh matter) per 100 g of edible portion (Table 2). Edible insects also provide essential amino acids that are required for human growth and development. Edible insects have a high content of essential amino acids, especially lysine, methionine and tryptophan, which are often limiting in plant-based diets (Köhler et al., 2019). The following table shows some examples of the amino acid content of edible insects (as dry matter) per g of protein. Edible insects also contain significant amounts of fatty acids that are beneficial for human health.

Omega-3 fatty acids are essential for human health as they play important roles in brain development, vision function, immune system regulation and inflammation reduction. They also lower the risk of cardiovascular diseases by reducing blood pressure, triglycerides and inflammation markers. Omega-6 fatty acids are also essential for human health as they are involved in cell membrane structure, hormone synthesis and skin health (Zhou et al., 2022). However, excessive intake of omega-6 fatty acids can increase inflammation and oxidative stress, which can lead to chronic diseases such as diabetes, obesity and cancer (Nowakowski et al., 2022). Therefore, it is important to maintain a balanced ratio of omega-6 to omega-3 fatty acids in the diet, which is recommended to be between 4:1 and 10:1 by various health organizations.

Edible insects have a favourable ratio of omega-6 to omega-3 fatty acids, ranging from 2:1 to 8:1 depending on the species and their diet. They also have a high content of MUFA, which can lower the levels of low density lipoprotein (LDL) cholesterol and increase the levels of high density lipoprotein (HDL) cholesterol, thus improving the lipid profile and reducing the risk of cardiovascular diseases (Orkusz, 2021). The following table shows some examples of the fatty acid content of edible insects (as dry matter) per 100 g of edible portion.Edible insects also provide various vitamins and minerals that are essential for human health (Table 1). These are particularly rich in vitamin B12, iron, zinc and calcium, which are often deficient in plant-based diets

and can cause anemia, immune dysfunction, growth retardation and osteoporosis. Edible insects can also provide other vitamins such as vitamin A, E, C and B complex, and other minerals such as magnesium, potassium, phosphorus, copper and selenium (Zhou et al., 2022). The following table shows some examples of the vitamin and mineral content of edible insects (as fresh matter) per 100 g of edible portion.

Table 1. Insects as a potential protein source for humans

Insect	Vitamin B12 (µg)	Iron (mg)	Zinc (mg)	Calcium (mg)
Cricket	5.4	1.9	3.8	40.7
Mealworm	2.2	2.2	2.1	23.1
Waxworm	1.8	5	1.9	24.3
Soldier fly larvae	3	6.6	2.5	934.2

Medicinal value

Edible insects have been used as traditional remedies for various diseases and disorders by the ethnic people of India. Some of the medicinal uses of edible insects are:

- *B. mori* larvae and pupae are used to treat asthma, bronchitis, cough, tuberculosis, diabetes, hypertension, arthritis, rheumatism, skin diseases, wounds and ulcers.
- *Solenopsis geminata* (red ant) larvae are used to treat fever, cold, sore throat, indigestion, diarrhea, dysentery, jaundice, liver problems, kidney stones and urinary infections.
- *Lethocerus americanus* (giant water bugs) are used to treat headache, toothache, earache, eye infections, malaria, typhoid and snake bites.
- *A. domesticus* (crickets) are used to treat stomach ache, constipation, intestinal worms and impotence.
- Beetles are used to treat anaemia, blood pressure, heart diseases and cancer.
- Hymenopteran are used to treat allergies, inflammation, pain, swelling and venomous bites.

The medicinal value of edible insects is not only based on empirical knowledge, but also supported by scientific evidence. Edible insects contain bioactive compounds that can provide diverse bioactivities, such as antioxidant, antihypertensive, anti-inflammatory, antimicrobial, and immunomodulatory with a positive impact on human health (Giampieri et al., 2022). Some examples of the bioactive compounds and their health benefits are: phenolic compounds and flavonoids. These are natural antioxidants that can scavenge free radicals, protect cells from oxidative damage, modulate inflammatory pathways, and inhibit the growth of pathogenic bacteria and fungi. They can also act as inhibitors of the pancreatic lipase enzyme, which is involved in fat digestion and absorption, and thus help in weight management and obesity prevention. Some edible insects that are rich in phenolic compounds and flavonoids are *A. domesticus*, *A. diaperinus*, *Galleria mellonella* (waxworms) and *Hermetia illucens* (soldier fly) larvae (Orkusz, 2021).

Chitin and chitosan: These are polysaccharides that form the exoskeleton of insects. They have prebiotic effects on the gut microbiota, stimulating the growth of beneficial bacteria and inhibiting the growth of harmful bacteria. They can also modulate the immune system, enhance wound healing, lower cholesterol levels and regulate blood glucose levels. Some edible insects that are rich in chitin and chitosan are *A. domesticus*, *A. diaperinus* and *B. mori* pupae (Köhler et al., 2019).

Antimicrobial peptides: These are small proteins that have potent antibacterial, antifungal and antiviral activity. They can kill pathogens by disrupting their cell membranes or interfering with their metabolic processes. They can also modulate the immune system and enhance host defence mechanisms. Some edible insects that produce antimicrobial peptides are Hymenopterans and *L. americanus*.

Table 2. Exploring insects as a potential protein source for humans.

Insect	Lysine (mg)	Methionine +Cysteine (mg)	Tryptophan (mg)	Protein (g)	Fat (g)	Carb (g)	Energy (kcal)	SFA (mg)	MUFA (mg)	PUFA (mg)	Omega-6 (mg)	Omega-3 (mg)
Cricket	64.02	19.63	11.13	20.5	6.8	5.1	121	733.46	165.80	1514.32	1490.32	24
Mealworm	51.02	17.63	9.13	23.7	5.4	3.4	141	263.46	97.80	1104.32	1080.32	24
Waxworm	48.02	16.63	8.13	14.1	24.9	7.7	300	123.46	65.80	904.32	880.32	24
Soldier fly larvae	54.02	18.63	10.13	17.5	14	2.7	198	173.46	85.80	1004.32	980.32	24

Essential fatty acids: These are omega-3 and omega-6 fatty acids that cannot be synthesized by the human body and must be obtained from food sources. They play important roles in brain development, vision function, immune system regulation and inflammation reduction. They also lower the risk of cardiovascular diseases by reducing blood pressure, triglycerides and inflammation markers. Some edible insects that have a favourable ratio of omega-6 to omega-3 fatty acids are *A. domesticus*, *A. diaperinus* and *G. mellonella* (De Marchi et al., 2021).

Vitamins and minerals: These are essential nutrients that are required for various physiological functions, such as bone formation, nerve transmission, enzyme activation and hormone regulation. Edible insects are particularly rich in vitamin B12, iron, zinc and calcium, which are often deficient in plant-based diets and can cause anemia, immune dysfunction, growth retardation and osteoporosis. Some edible insects that provide significant amounts of vitamins and minerals are *A. domesticus*, *T. molitor* and *H. illucens* larvae .

Health implications and allergenicity

Edible insects have many health benefits such as enhancing immunity, lowering cholesterol levels, improving blood circulation, preventing malnutrition, providing essential amino acids, and reducing greenhouse gas emissions (Ros-Baró et al., 2022; Acosta-Estrada et al., 2021). However, they may also pose some health risks such as causing allergic reactions, transmitting parasites or pathogens, containing toxins or pesticides, and inducing psychological aversion (Aguilar-Toalá et al., 2022; De Marchi et al., 2021). Therefore, it is important to ensure proper hygiene, quality control, and consumer awareness when consuming edible insects (FAO, 2020). Some of the health implications and allergenicity of edible insects are:

Biological hazards: Edible insects can be contaminated by various microorganisms, such as bacteria, viruses, fungi and parasites that can cause foodborne illnesses in humans (De Marchi et al., 2021). Some of the common pathogens that have been detected in edible insects are *Salmonella*, *Escherichia coli*, *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium botulinum*, *Listeria monocytogenes*, *Campylobacter jejuni*, *Vibrio cholerae*, *Hepatitis A virus*, *Norovirus*, *Aspergillus flavus*, *Aspergillus fumigatus* and *Taenia solium* (De Marchi et al., 2021; Aguilar-Toalá et al., 2022). The sources of contamination can be the environment, the feed, the handling and processing practices, and the cross-contamination with other foods (De Marchi et al., 2021). The symptoms of foodborne illnesses can range from mild to severe, such as diarrhea, vomiting, fever, abdominal pain, dehydration, headache, muscle ache and even death (De Marchi et al., 2021).

Chemical hazards: Edible insects can accumulate various toxins or pesticides that can have adverse effects on human health (De Marchi et al., 2021). Some of the common toxins or pesticides that have been found in edible insects are mycotoxins, heavy metals, antimicrobials and insecticides (De Marchi et al., 2021; Aguilar-Toalá et al., 2022). Mycotoxins are secondary metabolites produced by molds and yeasts that can grow on edible insects or their feed. They can cause acute or chronic toxicity in humans, affecting the liver, kidney, nervous system and immune system (Aguilar-Toalá et al., 2022). Heavy metals are inorganic elements that can be present in the soil, water or air where edible insects live or feed. They can cause neurotoxicity, nephrotoxicity, hepatotoxicity and carcinogenicity in humans (Aguilar-Toalá et al., 2022). Antimicrobials are substances that are used to prevent or treat infections in edible insects or their feed. They can cause antibiotic resistance in humans and animals (De Marchi et al., 2021). Insecticides are substances that are used to control pests or parasites in edible insects or their feed. They can cause acute or chronic poisoning in humans, affecting the nervous system, respiratory system and endocrine system (De Marchi et al., 2021).

Physical hazards: Edible insects can contain foreign objects that can cause injury or discomfort to consumers. Some of the common physical hazards that have been reported in edible insects are stones, glass fragments, metal pieces, wood splinters and insect parts. The sources of physical hazards can be the environment, the feed, the handling and processing practices, and the packaging materials. The consequences of physical hazards can range from minor to serious, such as dental damage, choking, laceration and perforation (De Marchi et al., 2021).

Allergenic hazards: Edible insects can trigger allergic reactions in consumers who are sensitized to insect proteins or cross-reactive allergens. Some of the common allergens that have been identified in edible insects are tropomyosin, arginine kinase and sarcoplasmic calcium-binding protein. Tropomyosin is a fibrous protein that is also found in crustaceans and arthropods. It can cause cross-reactivity in consumers who are allergic to shellfish or dust mites (Aguilar-

Toalá et al., 2022). Arginine kinase is an enzyme that is also found in crustaceans and molluscs. It can cause cross-reactivity in consumers who are allergic to shrimp or snails. Sarcoplasmic calcium-binding protein is a protein that is also found in vertebrates and molluscs. It can cause cross-reactivity in consumers who are allergic to fish or squid. The symptoms of allergic reactions can range from mild to severe, such as itching, hives, swelling, wheezing, anaphylaxis and death. The health implications and allergenicity of edible insects can be reduced by applying good hygiene practices, quality control measures and food processing methods (FAO, 2020). Some of the effective methods are:

- Washing: Washing edible insects with clean water can remove dirt, debris and some microorganisms and pesticides from their surface. Blanching: Blanching edible insects with hot water or steam can kill most microorganisms and deactivate some enzymes and toxins.
- Drying: Drying edible insects with sun, air or heat can reduce their moisture content and prevent microbial growth and toxin production (FAO, 2020).
- Freezing: Freezing edible insects with low temperature can inhibit microbial activity and preserve their quality and shelf life (FAO, 2020).
- Roasting: Roasting edible insects with high temperature can kill microorganisms and parasites, reduce toxins and pesticides, and improve their flavor and texture (FAO, 2020).
- Fermenting: Fermenting edible insects with microorganisms can enhance their nutritional value, produce bioactive compounds, and inhibit pathogens and toxins (Aguilar-Toalá et al., 2022).
- Hydrolyzing: Hydrolyzing edible insects with chemicals or enzymes can break down their proteins into peptides and amino acids, which can reduce their allergenicity and increase their bioavailability (De Marchi et al., 2021).

CONCLUSIONS

Edible insects are a valuable food resource that has been consumed by the ethnic people of India for centuries. They have high nutritional and medicinal value that can contribute to food security, health promotion, and environmental sustainability. However, they also have some health implications and allergenicity that need to be addressed by scientific research, regulatory policies, and public education. Some of the main challenges and opportunities for the development of the edible insect sector are:

There is a lack of comprehensive and reliable data on the diversity, distribution, ecology, biology, taxonomy, nutritional composition, bioactive compounds, health benefits and risks, and consumer preferences of edible insects. More research is needed to fill these knowledge gaps and to provide evidence-based information for decision-making, innovation and awareness-raising. There is a lack of harmonized and specific quality standards and guidelines for the production, processing, handling, storage, transportation, marketing and consumption of edible insects. More efforts are needed to develop and implement such standards and guidelines to ensure food safety, quality and traceability along the value chain.

There is a lack of clear and consistent legal framework for the regulation and authorization of edible insects as food and feed in different countries and regions. More collaboration is needed among stakeholders to harmonize and update the legal framework to facilitate the trade and consumption of edible insects. There is a lack of consumer acceptance and demand for edible insects in some markets due to cultural, psychological, religious or ethical barriers. More education and communication are needed to increase consumer awareness and appreciation of the benefits and advantages of edible insects.

There is a lack of innovation and entrepreneurship in the edible insect sector to create new products, services, technologies and business models that can meet the needs and expectations of different consumers and markets. More support and investment are needed to foster innovation and entrepreneurship in the edible insect sector.

AUTHOR CONTRIBUTION STATEMENT

SC conceived, organised the content and structured the framework of the manuscript, JKD and LB collected the updated data, KM contributed in writing, AKH and ASN edited the manuscript. All authors read and approved the manuscript.

CONFLICT OF INTEREST

No conflict of interest

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