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EC NUTRITION
Review Article

Insects as a Viable and Sustainable Protein and Food Source for Human Consumption

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Received: May 30, 2022; **Published:** June 30, 2022

DOI: 10.31080/ecnu.2022.17.01046

Abstract

Insect ingestion by humans is a long-standing and widespread phenomenon that varies widely depending on local preferences for edible insects. Entomophagy, or eating insects as food, makes sense because it is nutrient-dense, long-lasting, and environmentally friendly. Furthermore, a growing population that will surpass current food production by 2050 and a progressive reduction in the regions used for food production worldwide have encouraged many countries to investigate insects as a food source.

Insects have a comparable nutritional content compared to traditional meats and, in certain circumstances, are even healthier than beef or chicken. These insects are high in the necessary proteins, lipids, minerals, and vitamins necessary for human development. The nutritional value of insects, on the other hand, varies significantly from one bug to the next. A majority of insects are digestible by human gut enzymes and aid in maintaining the gut microbiome.

Antihypertensive, antimicrobial, immunostimulatory, and antioxidant activities have been discovered in various bioactive chemicals found in insects. Although insect farming is beneficial, consideration of microbial pollutants, monitoring for possible negative consequences of insect ingestion, and new factors in specific safety regulations are paramount. However, given its growing popularity, entomophagy may one day become an accepted component of diverse civilizations around the world.

Keywords: *Bugs as Food; Dietary Deficiency of Protein; Ecologically Compatible Foods; Food Shortage; Nutrient-Dense Food Source*

Abbreviations

ACE: Angiotensin-Converting Enzyme; AMP: Antimicrobial Peptide; EAA: Essential Amino Acids; EU: European Union

Introduction

Insect consumption is a practice that has been around for thousands of years; however, but has seen more widespread attention more attention in recent years. Insects have been a source of food throughout history [1]. An insect-eating culture is documented from the earliest Chinese annals to Mexican codices through the chronicles of naturalists and travelers to the ancient Egyptian papyri. Thousands of years ago, hunters and gatherers ate bugs to survive. The Bible mentions the consumption of insects in the past. Leviticus 11:22 says, “Even these of them ye may eat; the locust after his kind, and the bald locust after his kind, and the beetle after his kind, and the grasshopper after his kind”.

Interestingly, insects are included in almost every religion's list of forbidden foods, though this varies considerably and there are extensive exceptions across specific beliefs. Observing which insects the animals ate probably taught early peoples what was edible. It is also known that Romans, Greeks, French, Native American tribes, Chinese, and Australian aboriginal people consumed insects. In particular, the Romans enjoyed ingesting beetle larvae. Aristotle wrote about procuring the tastiest cicada nymphs. Marmosets and tamarins have also shown evidence of entomophagy [2]. Identifying the wild silkworm, *Theophila religiosa*, observed in ruins in Shaanxi province, indicates that silkworm pupae have been consumed in China since 2000–2500 BC [3].

Humans have been consuming these creatures for thousands of years, which the UN Food and Agriculture Organization defines as entomophagy. The term “entomophagy” refers to the act of organisms eating insects. However, it is commonly used to refer to the act of consumption of insects by humans specifically. Anthropoentomophagy is eating insects or products derived from insects for human consumption [4]. More than 2 billion people consume over 2,100 insect species, both raw and cooked, in approximately 13 countries, predominantly in parts of Asia, Africa, and Latin America [5,6]. Thousands of years ago, people ate bugs to increase their protein and healthy fat intake. Both men and women hunted for these bugs as a source of protein and fat. However, humanity evolved away from hunting and gathering (including insects) toward plant- and animal-based agriculture. This cultural shift in human food acquisition strategies eliminated insects from the native diet in many regions.

Discussion

Various insects as human food

Insects are readily available throughout the year in large quantities, making them an excellent protein-rich food option. When insects are consumed (in other parts of the world), they mainly may be gathered in large numbers. Examples are social insects, such as ants, termites, and locusts, that migrate in hordes of millions of individuals. Some human societies utilize insects as a significant source of protein. They are found predominantly in tropical climates. To survive thousands of years ago, men and women gathered these bugs to increase their protein and healthy fat intake.

A report released in 2013 by the United Nations Food and Agriculture Organization mentioned over 1,900 edible insect species on Earth, hundreds of which are already part of the diet in many countries [6,7]. The most commonly consumed insects are the various species of cricket (*Acheta domesticus, Gryllus assimilis, Gryllodes sigillatus, G. Bimaculatus, G. locorojo*), the honeycomb moth (*Galleria mellonella*), the longhorn grasshopper (*Ruspolia differens*), the migratory locust (*Locusta migratoria*), the mealworms (*Tenebrio molitor, Alphitobius diaperinus, Zophobas atratus*), the housefly (*Musca domestica*), and the black soldier fly (*Hermetia illucens*) [8]. Eighty-eight percent of edible insects are terrestrial, whereas 12% are aquatic. Insects belonging to different orders are consumed at different life cycle stages [8].

For example, various African cultures consume locusts (grasshoppers) regularly. Individual locusts are collected early during the day before they become active and are subsequently boiled before being cleaned and salted. Even the legs are ground and mixed with peanut butter and salt for usage. Additionally, locusts are becoming a food source in South Korea, and rice farmers gather and sell them to supplement their income from rice cultivation.

Termites can be observed in enormous colonies in dry regions of Africa and Australia and are readily available food, which has long been a popular food in those areas. Some termite queen castes can measure up to 3 inches in length, and are the most nutritionally promising. Termites are high in both protein and fat and yield a high caloric value. Caterpillars are also commonly consumed by humans in many parts of the world. Giant Skipper caterpillars are considered a delicacy in Mexico and are harvested from the thick leaves of the maguey plant. They are bought fresh in markets and fried before consumption. They are commercially available in cans. Although having hard outer bones like adults, beetles are great food for grubs. Goliath beetle, a form of the scarab, is hunted with zeal among the roots of banana trees in Africa. The completely mature larva can grow to 5.5 inches long. The pupae of a small Shore Fly, *Ephydra hians*, were widely eaten by Native Americans in the Western United States.

What peoples prefer eating insects and those that do not?

Romans, Greeks, French, Native American tribes, Chinese and Australian Aborigines have eaten insects [9]. Half of the world's population consumes insects, with a higher prevalence in tropical climates. These insects include beetles (Coleoptera: 31%), caterpillars (Lepidoptera: 18%), bees, wasps, and ants (Hymenoptera: 14%), grasshoppers, locusts, and crickets (Orthoptera: 13%), cicadas, leafhoppers, planthoppers, scale insects, and true bugs (Hemiptera: 10%), termites (Isoptera: 3%) and dragonflies [10]. Africa, Asia, and Latin America have the highest insect consumption rate [11]. Different habits are followed worldwide when eating insects (Table 1).

Name of country	Insect consumption habit
Mexico	Occasionally, >549 species are offered to be added to tacos and other culinary delights.
Colombia and Brazil	Home to Leafcutter ants, sold as popcorn when watching a movie.
Asia (China, Japan, and South Korea)	The larvae of the beehives are consumed. Silkworms are occasionally served as street food, like tofu, or added to traditional dishes.
Southeast Asia and Africa	Termites have been consumed for many years.
Kenya, Ghana	They are consumed straight from their mound and can be roasted, fried, or transformed into a loaf of delicious bread.

Table 1: *Insect consumption habits in different countries.*

Despite their popularity in underdeveloped countries, consumer acceptance in Western countries is low, where eating insects has a significant stigma and insects are regarded as pests. Setting cultural stigmas aside, the demands of world food production pressure suppliers to reconsider insects as a more sustainable source of protein. Insects are consumed by approximately 2 billion people on the planet. Insects are high in nutrients and are a more environmentally friendly option than meat or fish. Use and acceptance of entomophagy has increased since academics began studying insects in Western countries and their use for animal and human feed. The presentation of insect-based foods at dinner parties and conferences has become an increasing trend in recent years.

Quantity and quality of insect-derived protein versus animal-derived protein

Insects are not only nutrient-dense and delicious, but can also be considered a sustainable supply for human protein. Most insect species are rich in proteins, fatty acids, vitamins, fiber, and minerals. Insect protein concentrations are comparable to traditional animal and plant-based protein-dense foods such as beef, eggs, milk, and soy [12]. Furthermore, the content of all essential amino acids (EAA) in insects complies with World Health Organization guidelines [13]. The feeding substrate and processing can influence the overall protein concentration and amino acid composition [14] and processing [15]. Therefore, insects are a suitable alternative source of high-quality proteins and nutrients for people in underdeveloped and developed countries [16]. For example, termites, grasshoppers, caterpillars, weevils, and houseflies are excellent protein sources by weight to beef, pork, chicken, and lamb [16].

Edible insects, particularly those belonging to the order Orthoptera (grasshoppers, crickets, and locusts), are high in protein and can be a suitable meat alternative. Protein levels ranging from 13% to 77% of dry mass have been observed in various insect orders and many species in the order Hymenoptera (Table 2) [17,18]. The total protein content based on dry matter varied from 38.4% (wax moth, *Galleria mellonella*) to 62.2% (migratory locust, *Locusta migratoria*).

Insect order	Protein content (%)
Coleoptera: Beetles, weevils	23 – 66%
Lepidoptera: Butterflies, moths	14 – 68%
Hemiptera: True bugs	42 – 74%
Hymenoptera: Bees, wasps, ants	13 – 77%
Odonata: Dragonflies, damselflies	46 – 65%
Orthoptera: Grasshoppers locust, crickets	23 – 65%

Table 2: *Crude protein content (% dry matter) by insect order [18].*

The amino acid content and digestibility of the protein component of the diet determine the quality of the protein and, consequently, the nutritional value. EAAs are essential indicators of food quality. The amino acid composition of edible insects, like proteins, varies significantly between species and orders. EAAs account for approximately 46 to 96% of the total amino acids among 100 edible insect species [18]. In many situations, the amino acid content of the edible insects investigated is comparable to beef, egg, and soya, if not higher.

All insect species (*Tenebrio molitor*, *Glyptotendipes testaceus* and orthopteran species) exhibit high amino acid levels for isoleucine, leucine, phenylalanine, tyrosine, and glycine [17]. Insects can be an alternative protein source compared to plant protein sources, such as dry soybeans (protein content = 35.8%). Most of the listed insect species have higher amino acid content than soya.

Insect digesting capabilities of the human gut

The digestibility of insect protein ranged from 76% to 90% [19]. Although its digestibility was slightly lower than that of egg protein (95%) or beef (98%), it was still higher than that of several plant proteins [20]. In comparison to casein and soy, several studies have demonstrated that the protein quality of insects is promising in terms of availability and digestibility; variability in this protein quality can be enhanced by removing chitin [21,22]. Therefore, additional research on the quality of insect proteins is required before insects are considered an alternative protein source—including the amino acid profiles of edible insects and their digestibility and suitability for human consumption.

Effect of edible insects on the human gut microbiota

Edible insects can function as a prebiotic by influencing the bacterial microbiome of the human intestine. Chitin, a polymer of N-acetylglucosamine present in many insects, is the main component of its insect exoskeletons. Chitin can reach the large intestine intact due to its resistance to mammalian digestive enzymes, where it could function as a prebiotic to encourage the growth of beneficial members of the intestinal microbiota [23]. This insoluble fiber acts as a prebiotic food source to promote the development of beneficial bacteria or probiotics. This effect was recently demonstrated in humans when eating edible bugs increased the relative abundance of fecal Bifidobacterium, a genus known for its health benefits [24].

Due to the diversity of insects, different edible bugs may have other effects on the human gut microbiota, which will require independent research. Various insects have been shown to alter the human gut microbiota *in vitro* [25]. Consuming cricket flour can benefit the human microbiome [24].

Nutritional benefits of insect consumption

Insects have been identified as a new and alternative source of animal protein. Edible insects are highly dense in nutrients and high in crude protein, averaging 40 to 75% by dry weight, more elevated than dried beef [26–28]. Most are high in polyunsaturated fatty acids and provide all EAAs for human nutrition [29]. Minerals such as potassium, calcium, magnesium, phosphorus, iron, and zinc are commonly present in insects, along with vitamins such as biotin, riboflavin, pantothenic acid, and folate [27].

The nutritional value of insects varies widely depending on species, life stage, and feed; and there is insufficient information on nutrient absorption at this point.

Unlike other animal products, insects contain significant amounts of nutritional fiber. A diet rich in fiber, as expected, improves the health of the gut microbiome by increasing the microbial diversity [30], and the high intake of fiber has been associated with a lower risk of some cancers and heart disease [31,32].

The majority of the insect exoskeletons contain chitin as insoluble fiber, which accounts for approximately 10% of their dry weight [33]. This may alter the gut microbiota by serving as prebiotics or non-digestible foods that encourage the growth of beneficial gut bacteria; however, it is yet to be proven.

Bioactive compounds from insects and their biological activity

Further research suggests that insect peptides can be used as antihypertensive, antibacterial, and antioxidant agents (Table 3), indicating their usefulness [34]. Bioactive peptides derived from insects and other sources have beneficial impacts on human health and food systems, including antioxidant, antibacterial, and antidiabetic qualities, angiotensin converting enzyme (ACE) inhibitor activity, and as a functional food component [35].

Insect	Bioactive compound	Activity
Amphiacusta annulipes, *Spodoptera littoralis*, silkworm (*Bombyx mori*), Dubia roach, Madagascar hissing cockroach, locust, superworm, and cricket (*Gryllodes sigillatus*)	Protein hydrolysates	Antioxidant
Tenebrio molitor larvae Lepidoptera (*Bombyx mori* and *Spodoptera littoralis*), Orthoptera (*Schistocerca gregaria*) and Hymenoptera (*Bombus terrestris*)	Tyr-Ala-Asn peptides Protein hydrolysates, Val-Phe-Pro-Ser and Val-Trp	ACE inhibition and reduction in blood pressure
Bombus pascuorum *Bombus terrestris* *Galleria mellonella*	Abaecin (a proline-rich peptide), hymenoptaecin (a glycine-rich peptide) Hemolymph	Antimicrobial activity

Table 3: *Bioactive compounds from insects and their physiological actions.*

Various factors, such as the source of the protein, the degree of hydrolysis, the peptide structure, the amino acid content, and the type of protease utilized, may influence the bioactivity of these peptides.

Antioxidant: The antioxidant properties of the Dubia roach, Madagascar hissing cockroach, locust, superworm, and cricket hydrolysates were demonstrated *in vitro* [36]. Additionally, peptides from *Spodoptera littoralis* (Lepidoptera) and crickets were found to have antioxidant properties. Although the processes by which protein hydrolysates exert antioxidant activity are unknown, the amino acid content and sequence of the peptides produced are known to be critical for their antioxidant action [37].

ACE inhibition: Insect hydrolysate-derived antihypertensive peptides have been shown to have a significant inhibitory action against ACE. Edible insect protein hydrolysates have been studied *in vivo* and *in vitro* for their antihypertensive characteristics. When rats were administered Tyr-Ala-Asn peptides from *Tenebrio molitor* larvae, their systolic blood pressure was significantly reduced [38]. Vercruysse., *et al*. (2005) discovered the inhibitory action against ACE in protein hydrolysates from Lepidoptera (*Bombyx mori* and *Spodoptera littoralis*), Orthoptera (*Schistocerca gregaria*) and Hymenoptera (*Bombyx mori* and *Spodoptera littoralis*) [39].

Antimicrobial activity: Antimicrobial peptides (AMPs) such as defensins, cecropins, attacins, lebocins, and other proline-rich peptides, gloverins, and moricins, are abundant in insects, and their use as antimicrobials has been extensively investigated in recent decades [34]. For example, Rahnamaeian., *et al*. (2015) studied abaecin (a proline-rich peptide) and hymenoptaecin, two AMPs isolated from *Bombus pascuorum* and *Bombus terrestris* (a glycine-rich peptide) [40].

Industrial and commercial applications of insects (Animal feed, cosmetics, medicine)

Food industry: Although the positive social image of novel foods encourages the consumption of insects, the consumer demand for edible insects must first be forged, resulting in the development of insect-based ingredients rather than the emergence of finished food products. For an insect-phobic culture, incorporating edible insects into already familiar meals may be more acceptable than giving insects as a dietary alternative [41].

Feed industry: Insects are a promising option for animal feed due to their high nutritional content, little space requirements, and low environmental impact. Insects are already a natural part of many animal diets, and insect-based animal feeds are especially appealing compared to traditional feeds. Black army flies, larvae, yellow mealworms, silkworms, grasshoppers, and termites are the most promising and well-studied possibilities for industrial feed production [42].

Medicinal applications: Cultures that consume insects associate them with various health benefits (Table 4) beyond nutrition [43].

Insect name	Medicinal effect
Caterpillar fungus	Immunostimulatory and anticancer properties
Male *Antheraea pernyi*	Aphrodisiac
Termites	Immunostimulatory effects
Silkworm powder	Diabetic medicine

***Table 4:** Medicinal properties of insects [44].*

Global impact and benefits of insect farming on the environment

More research is being performed on farming practices and how insects could be incorporated into humans' daily lives. The great majority of insects consumed today are gathered from the wild. However, insect horticulture, also known as mini-livestock farming, can improve productivity, resulting in year-round access to insect foods for consumers in both established and emerging bug-eating cultures. Although (mini-livestock) may benefit people and the environment, there are still many questions about its viability and utility as food and feed in the future.

To address global food security concerns in the face of climate change, humans need to be resourceful. Compared to conventional livestock, insect protein production has a high feed conversion ratio, emits fewer greenhouse gases, uses less water, and requires less land [45]. Their high feed conversion efficiency, short lifespans, ectothermic thermoregulation, and a large percentage of edible body mass contribute to insects' overall viability and appeal [46].

Microbial contaminants and adverse effects of insect consumption on humans

The allergenicity concerns of edible insects are one of the challenges limiting their culinary potential. In arthropods, 239 individual allergens have been recorded according to the standards of the WHO subcommittee. The most common allergens are muscle proteins (tropomyosin, myosin, actin, troponin C), cellular proteins (tubulin), circulatory proteins (hemocyanin, defensin), and enzymes (arginine kinase, triosephosphate isomerase, amylase, trypsin, phospholipase A, hyaluronidase) [47]. Isolated allergic episodes, including anaphylactic reactions, have been described in the medical literature concerning insect-eating and emerging evidence of insect-related allergies [48].

Insect food safety and regulations

Insects may develop on various substrates, including dung and biowaste; hence, introducing such insects into the food chain has risks. Legislative restrictions on the production and sale of insects for food and feed have been well defined and extensively reviewed to prevent such misconduct [49].

In the European Union (EU), insect-derived food items can only be marketed after a safety evaluation by the European Food Safety Authority per the Regulation (EU) 2015/2283. In the USA, Food, Drug, and Cosmetic Act (United States Code, Title 21) consider insects as food. However, they set the norms that food must be clean and wholesome, must have been produced, packaged, stored, and transported under sanitary conditions, and appropriately labeled (Sec. 403).

Furthermore, insect cultivation for human food must follow good manufacturing practices (cGMP, 21CFR110), insects raised for animal feed cannot be diverted to human food, and insects collected from the wild cannot be sold as food. Organic insect food is classified as a regulatory category in Mexico, with an indicative list of the species and life stages involved, such as eggs, larvae, nymphs, and adult insects. In Australia and New Zealand, insect food is classified as a novel food according to the Food Standard Code 1.5.1. In Asia and Africa, similar conventions are also emerging.

Conclusion

Insects have nutritional content comparable to customary meats and, in specific cases, are more nutritious than beef or chicken. Insects are rich in proteins, lipids, minerals, and vitamins, essential for human growth and maintenance. However, insects' nutritional value can differ considerably from one species to the next. Most insects are digestible by human gut enzymes and help preserve the gut microbiome.

Antihypertensive, antimicrobial, immunostimulatory, and antioxidant activities have been found in various bioactive chemicals seen in insects. Although insect farming is advantageous, microbial pollutants, the possible harmful effects on humans from insect consumption, and further safety regulations must be assessed and addressed. Nevertheless, given its growing favor, entomophagy seems poised to become an acknowledged food source of diverse global cultures.

Insect ingestion by humans is a historical and widespread practice, depending on edible insects' regional preferences. Entomophagy, or eating insects as food, is sensible and practical because it is nutrient-dense, long-lasting, and environmentally friendly. Furthermore, a growing population that will tax current food production by 2050 and the loss of regional food environments prompt many countries to investigate insects as viable and sustainable protein and food source.

Conflict of Interest Statement

The authors declare that this paper was written without any commercial or financial relationship that could be construed as a potential conflict of interest.

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Volume 17 Issue 7 July 2022