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Edible insects: A functional food for future

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Abstract
World population projected to reach 9 billion people. To accommodate and too feed9 billion people current food production will need to almost double. Land is scarce and expanding the area devoted to farming is rarely a viable or sustainable option. Oceans are overfished and climate change and related water shortages could have profound implications for food production. To meet the food and nutrition challenges of today, we need to find new ways of growing food. Edible insects have always been a part of human diets, but in some societies there is a degree of distaste for their consumption. Although the majority of edible insects are gathered from forest habitats, innovation in mass-rearing systems has begun in many countries. Insects offer a significant opportunity to merge traditional knowledge and modern science in both developed and developing countries. Insects are often considered a nuisance to human beings and mere pests for crops and animals. Yet this is far from the truth. Insects provide food at low environmental cost, contribute positively to livelihoods, and play a fundamental role in nature. However, these benefits are largely unknown to the public. Contrary to popular belief, insects are not merely "famine foods" eaten in times of food scarcity or when purchasing and harvesting "conventional foods" becomes difficult; many people around the world eat insects out of choice, largely be. Because insects are rich vitamins, minerals, amino acids and antioxidant potential and even some insects are used as probiotic foods for human consumption to keep the intestine with healthy gut microflora. At present Insect rearing for food and feed remains a sector in its infancy, is still at a relatively pioneering stage but future research should focus on key future challenges and it will likely to emerge as the field for insect food production.

Keywords: Edible insects, nutrition, antioxidants, pro-biotic

Introduction
Insects are traditionally consumed as a food source by nearly 2 billion people around the world and make up part of the diet in many countries (Halloran *et al*. 2014; Van Huis *et al*. 2013) [1-2]. Most insects contain many of the nutrients important to the human diet, including fats, proteins, fiber, vitamins, and minerals (Halloran *et al*. 2014; Van Huis *et al*. 2013; Raheem *et al*. 2019) [1-3]. In fact, the nutrient composition of many edible insects is comparable to that of other traditionally consumed animal and plant foods (Halloran *et al*. 2014; Raheem *et al*. 2019) [1-3].

According to Halloran *et al*. (2014) [1] found that most edible insects meet daily energy and nutrient requirements and contain polyunsaturated and monounsaturated fatty acids, essential amino acids, zinc, iron, and fiber. They can also serve as an alternative protein source to other animal protein sources such as chicken, beef, and fish (Halloran *et al*. 2014) [1].

A recent review by Raheem *et al*. further explains that most insects, especially crickets, meet or exceed recommended levels of most essential amino acids for adults, including histidine, isoleucine, leucine, lysine, threonine, tryptophan, and valine (Raheem *et al*. 2019) [3]. Raheem *et al*. also notes that edible insects are rich in protein and contain higher amounts of protein than soybeans, a traditional plant protein source. In addition, chitin, which is found in the exoskeletons of many different insects, is a good source of dietary fiber and can boost the immune system (Raheem *et al*. 2019) [3]. Many insects are also a good source of micronutrients such as B vitamins, zinc, and iron (Raheem *et al*. 2019) [3]. Insects can be processed into various forms, such as pastes, powders, and meals, which increases their shelf life and allows them to be easily used as substitutes in cooking and baking without altering the taste, texture, or appearance of a dish (Dossey, Tatum, and McGill 2016) [4].

Nutrients such as vitamins, minerals, fats, and proteins can also be isolated from insects, allowing for the potential use of insects as dietary supplements (Van Huis *et al*. 2013) [2]. In addition to their nutritional importance in the global diet, insects have the potential to act as a more environmentally friendly and sustainable source of nutrients in the human diet than other

commonly consumed animal nutrient sources (Halloran *et al*. 2014) [2] Insects are much more efficient at foraging (converting their food into ediblefood) than other animals, such as chickens, cattle, and pigs (Oonincx *et al*. 2015) [5]. Unlike other animal food sources that require plant-based feeds such as grains, insects can be raised from organic waste streams from humans and animals, making them more sustainable and cost-effective to raise Halloran *et al*. (2014) [1]; Van Huis *et al*. (2013) [2]; Raheem *et al*. 2019) [3]. By increasing the consumption of insect-based foods instead of animal foods, the grain used to feed animal food sources could even be used to feed humans, which is important as the world's population grows (Halloran *et al*. 2014) [1].

In addition, insect farming requires little land and water and produces fewer greenhouse gasses than raising pigs and cattle (Oonincx *et al*. 2010) [5]. According to Mason *et al*. the water requirement per gram of protein for crickets is only 0.7–0.8 g, while the water requirement per gram of protein for cattle is about 16.8 g. Methane and carbon dioxide emissions per kilogram of crickets produced are also significantly lower than cattle: 0.7 g for crickets versus 114 g for cattle and 7.6 g for crickets versus 285 g for cattle, respectively (Mason *et al*. 2018) [7].

Overall, the use of insects as a food source has many positive nutritional and environmental effects. Insects may even be a more affordable source of high-quality protein and micronutrients, which could address global protein and micronutrient shortages (Van Huis *et al*. 2013) [2].

In addition, edible insects could be used as dietary supplements and substitutes in human diets to improve health and well-being due to their potential health benefits, such as their ability to boost immune function. As the issue of sustainable food sources becomes increasingly important due to the environmental footprint of animal and plant proteins, there is a need to explore alternative food sources that can provide similar nutritional value and serve as substitutes for animal foods. Currently, there is a gap in the literature on crickets and other edible insects as protein alternatives in human diets.

This review aims to provide additional insight into the nutritional composition of edible insects, their potential use as meat substitutes or supplements, their associated health and wellness benefits, and their potential role in athletic performance. Despite the environmental and economic benefits of insect-based foods, little research has examined their potential health benefits for human consumption or as animal feed. Several other reviews have examined the nutrient composition of edible insects and compiled information on their nutrient diversity (Kinyuru *et al*. 2015; Belluco *et al*. 2013; Churchward-Venne *et al*. 2017) [8-10], so we chose to focus our discussion mainly on the potential health benefits of consuming insect-based foods for humans and animals. In this context, we did not attempt to limit our discussion to human and animal well-being or disease categories. Instead, we sought to elucidate the mechanisms of action of whole insects or insect isolates in various experimental settings and their potential impact as foods or dietary supplements.

Our discussion is a narrative review of the current literature. For this review, recent studies were selected that provided relevant information on the nutritional composition and potential health benefits of edible insects in animal studies and human studies.

1. Nutritive aspects of Edible Insects:

Edible insects contain relatively large amounts of nutrients important for human nutrition, and it is estimated that about 77-98% of insects are digestible, depending on the species (Doberman, Swift, and Field 2017) [11]. Some edible insects, such as crickets (*Acheta domesticus*), have been shown to be significantly more nutritious than conventional foods such as beef and chicken, as measured by the amount of carbohydrates, energy, saturated fat, and sodium they provide (Payne *et al*. 2016) [12]. Many of these edible insects are rich in protein, containing an estimated 7-48% of dry weight in protein (Kinyuru *et al*. 2015; Churchward-Venne *et al*. 2017; Doberman, Swift, and Field 2017) [8, 10, 11]. Crickets, for example, have an average protein content of about 65% of dry weight, which is superior to other animal and plant sources such as beef, eggs, milk, and soybeans, where protein is about 50, 52, 30, and 45% of dry weight, respectively (Churchward-Venne *et al*. 2017; Rumpold and Schluter 2015) [10, 13]. It is recommended that human diets contain at least 40% essential amino acids, and the levels of most edible insects typically range from 46% to 96% (Kinyuru *et al*. 2015) [8]. Crickets, for example, not only meet the requirements of the World.

In particular, the leucine content of insects from the Orthoptera group, which includes crickets, is about 13 mg/g higher than the leucine content of soy protein and comparable to the amount found in animal sources such as skim milk (Churchward-Venne *et al*. 2017) [10]. Lysine is another essential amino acid that can be low in plant protein sources and tends to be found in greater amounts in edible insects (Kinyuru *et al*. 2015) [8]. Crickets meet most essential amino acid requirements but may not be as good a source of methionine, serine, and tryptophan as other animal sources such as beef and eggs (von Hackewitz 2018) [14]. While crickets appear to be an excellent source of high-quality protein, it is important to note that the protein and amino acid content of crickets, like other edible insects, depends on environmental factors, including the insect's life stage, diet, and sex (Kinyuru *et al*. 2015; Dobermann, Swift, and Field 2017; von Hackewitz 2018) [8, 11, 14].

Most edible insects are high in unsaturated fats, especially polyunsaturated fatty acids (PUFAs) (Kinyuru *et al*. 2015; Dobermann, Swift, and Field 2017; Rumpold and Schluter 2015) [8, 10, 13]. These include linolenic acid and linoleic acid, commonly referred to as omega-3 and omega-6 fatty acids, respectively. PUFAs are heart-healthy fats most commonly found in vegetable oils, nuts, seeds, and fish; however, edible insects do not contain eicosapentaenoic acid(EPA) or docosahexaenoic acid (DHA), which are typically found in fish (Kinyuru *et al*. 2015; Doberman, Swift, and Field 2017) [8, 11]. Compared to their saturated fatty acid content, edible insects contain more PUFAs, suggesting that edible insect species likely have lower cholesterol content (Kinyuru *et al*. 2015) [8]. In particular, insects from the Orthoptera group, including crickets, contain only about 13.4% of their dry mass fat (Rumpold and Schluter, 2015) [13].

In addition to their high protein and unsaturated fat content, edible insects are rich in various vitamins and minerals. Most insects, especially crickets, are rich in iron, with iron content three times that of beef (Payne *et al*. 2016; Voelker 2019) [12, 17]. The iron found in edible insects is heme iron, which is more easily digested by humans than the form of iron commonly found in plants (Doberman, Swift, and Field 2017) [11]. Crickets contain about 8.75 mg of iron per 100 grams of dry matter, and crickets are estimated to have 180% higher iron content than beef, making them a comparable, if not better, source of iron than traditional animal sources (Mwangi *et al*. 2018; Payne *et al*. 2016) [16]. Crickets are also rich in vitamin B12, containing about 5.4 mg of vitamin B12 per 100

grams of dry matter (Mason *et al*. 2018; Kinyuru *et al*. 2015) [7, 8].

Another study by Schmidt *et al*. found that crickets contain approx. 2.88 mg/100 g dry matter of vitamin B12, which is within the recommended range for adults (Schmidt *et al*. 2019).

According to reports by Voelker and Mason *et al.*, nutrient analysis of cricket powder has shown that crickets contain about 10 times more vitamin B12 than beef (Mason *et al*. 2018; Voelker 2019) [7, 17]. Crickets also contain high amounts of other B vitamins such as thiamine, riboflavin, and folic acid, making them an excellent source of B vitamins (Kinyuru *et al*. 2015; Payne *et al*. 2016; Rumpold and Schluter, 2015) [8, 12, 13].

In addition, home chrism is a good source of calcium, zinc, sodium, vitamin A, and vitamin C (Dobermann, Swift, and Field 2017; Payne *et al*. 2016; von Hackewitz 2018) [11, 12, 14]. Compared to meats such as chicken, pork, and beef, crickets contain greater amounts of calcium, sodium, iron, riboflavin, vitamin A, and vitamin C (Payne *et al*. 2016; Voelker 2019) [12, 17]. Montowska *et al*. evaluated the mineral content of three edible cricket powders from different commercial suppliers and found that 100 grams of cricket powder provided 14-22% of the RDA for calcium, which is comparable to tofu, salmon, cottage cheese, and fortified orange juice (Montowska *et al*. 2019) [15]. Crickets and other edible insects contain comparable or even higher amounts of iron and zinc than conventional animal sources, falling within the recommended range for adults (Mwangi *et al*. 2018; Montowska *et al*. 2019) [15]. Latunde-Dada *et al*. also reported that grasshoppers, crickets, and mealworms containedmuch more chemically available calcium, copper, zinc, magnesium, and manganese than beef loin, while the bioavailability of iron, calcium, and manganese was comparatively higher in crickets and beef loin than in grasshoppers, mealworms, and buffalo worms (Latunde-Dada, Yang, and Vera Aviles 2016) [16]. Finally, chitin, a substance found in the hard exoskeleton of crickets, is indigestible and serves as a good source of dietary fiber (Kinyuru *et al*. 2015) [8]. According to Voelker, about 8.5% of the weight of cricket powder consists of dietary fiber, which likely comes from their chitin exoskeleton (Voelker 2019) [17].

2. Edible insects as pro-biotic food for healthy gut microflora

Several components of edible insects have the potential to have beneficial effects on human health, such as chitin, short-chain fatty acids, medium-chain fatty acids, and glycosaminoglycans.

In a research study (Stull *et al*., 2018) [18] supplementation with 25 grams/day of dried, roasted cricket powder for 14 days increased the probiotic bacterium *Bifidobacterium animalis* and decreased tumor necrosis factor (TNF)-a in plasma.2018). The relative abundance of *B. animalis*, a probiotic associated with the prevention of respiratory infections, diarrhea, and antibiotic side effects, increased after the intervention, suggesting that cricket supplementation produced microbiota with the potential to improve gastrointestinal health (Stull *et al*. 2018) [18]. TNF-a is a critical proinflammatory cytokine that has been shown to contribute to the pathological processes of various diseases, including rheumatoid arthritis, inflammatory bowel disease, multiple sclerosis, and various cancers (Chu, 2013) [19]. Thus, Stull's findings suggest that crickets may exert a protective effect on inflammatory processes. Increased microbial diversity was also observed in rainbow trout fed black soldier fly (*Hermetia illucens*) larvae, and increased gut microbial biodiversity promoted resistance as they competed with pathogens for nutrients and colonization sites (Bruni *et al*. 2018) [20].

The antimicrobial effects of dry mealworm (*Tenebrio molitor*) and super mealworm (*Zophobas morio*) were investigated. It was found that0.4% dry mealworm and super mealworm larval probiotics were effective in reducing infection with E. coli and Salmonella in broiler chickens (Islam and Yang 2017) [21] These beneficial effects of insects on the gut microbiome and antimicrobial activity have been linked to their chitin content. Chitin, a polymer of b-1,4N-acetylglucosamine, is the main component of the exoskeleton of insects (Stull *et al*. 2018; Borrelli *et al*. 2017) [18, 22].

The dietary fiber content of cricket powder, for example, is similar in quantity to that of whole wheat and soy powder, and the dietary fiber consists entirely of chitin (unpublished, analysis performed by Maxxam Analytics, Mississauga, Canada).Chitin and its degradation products, such as chitosan, have been shown to have antimicrobial, antioxidant, anti-inflammatory, anti-cancer, and immune stimulatory effects.

3. Insects as a dietary intake for Antioxidant and inti-inflammatory properties

Many insect-based foods, including cricket powder, contain large amounts of bioactive peptides with antioxidant and antimicrobial properties. The biological effects of proteins from edible insects after enzymatic hydrolysis were studied in research (Nongonierma and Fitz Gerald 2017) [23]. For example, these antimicrobial peptides favoured and improve the gastrointestinal health of chickens and pigs while helping to increase their immune function and improve their ability to digest nutrients from feed (Gasco, Finke, and Van Huis 2018) [24]. Another study by Zielinska *et al*. on the anti-inflammatory properties of heat-treated insects showed that treating insects with heat increased the amount of bioactive peptides produced (Zielinska, Baraniak, and Karas 2017) [25]. The antioxidant properties of insect hydrolysates and peptide fractions may help reduce inflammation and oxidative stress by decreasing the amount of free radicals present in the body (Zielinska, Baraniak, and Karas 2017; Messina *et al*. 2019) [25, 26].

Water-soluble extracts of locusts, silkworms, and crickets have been found to have antioxidant capacity that is about five times greater than the antioxidant capacity of fresh orange juice *in vitro*, likely due to their higher protein/peptide content (Di Mattia *et al*. 2019) [27]. Enzymatic hydrolysis may also reduce the allergenicity of bioactive properties extracted from crickets (*Gryllo dessigillatus*) (Hall, Johnson, and Liceaga 2018) [28].

Taken together, insect powders and their peptide hydrolysates may prevent the onset of cancer, cardiovascular disease, and diabetes, which have been linked to oxidative stress and chronic inflammation.

4. Insect as a protein scoop for body builder

Due to their nutritional composition, insect powders could be used as a dietary supplement to resistance training to build muscle mass by increasing muscle protein synthesis. Muscle protein synthesis is stimulated by the availability of amino acids.

It has been shown that muscle protein synthesis is increased for 48 hours after resistance training. Consumption of supplements containing both carbohydrate and protein after resistance training has been shown to increase protein synthesis and insulin production (Koopman *et al*. 2005) [29].

Consumption of carbohydrates after resistance training increases insulin levels, which helps reduce muscle protein breakdown (Koopman *et al*. 2007) [35]. In addition, consumption of the amino acid leucine after resistance training has been shown to increase protein synthesis by acting as a signalling molecule in protein metabolism, stimulating muscle protein synthesis and inhibiting muscle protein breakdown (Koopman *et al*. 2007; Atherton *et al*. 2017) [35, 30].

Similarly, muscle protein breakdown after resistance training was found to be significantly lower in subjects who consumed carbohydrate, protein, and leucine than in subjects who consumed carbohydrate and protein alone (Koopman *et al*. 2005) [29]. Leucine, isoleucine, and valine are the branched-chain amino acids (BCAAs). During prolonged endurance exercise, when glycogen stores are low or depleted, skeletal muscles can metabolize BCAAs for energy. BCAAs are also important for the immune system. Therefore, BCAA supplements have long been used by resistance athletes to reduce skeletal muscle damage and muscle fatigue (Foure and Bendahan 2017).

5. Insect ingredients as food preservative

Interestingly, in addition to the microbiological risks, some edible insects such as *Musca domestica* have an antibacterial peptide called Hf-1 that is effective against bacterial pathogens in food, including *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Shigella dysenteriae*, *Salmonella typhimurium*, and *Staphylococcus aureus*, highlighting the potential use of insects as food preservatives (Hou *et al*., 2007) [32].

6. Potential risks of insects for human consumption

Although edible insects offer a variety of health benefits and could act as an environmentally sustainable source of nutrients when used as a substitute for traditionally consumed animal products, consumer acceptance of insect foods in Western countries is rather low (Hartmann and Siegrist 2017; Lammers, Ullmann, and Fiebelkorn 2019) [36, 33].

According to Hartmann and Siegrist's review of current evidence on consumer acceptance of insect foods, Western countries show a low willingness to consume insects as a meat substitute (Hartmann and Siegrist 2017) [36]. Another study by Lammers *et al*. surveyed 516 men and women from Germany and found that only 15.9% of participants were willing to consume unprocessed insects; however, 41.9% of participants indicated they would be willing to consume an insect burger containing processed insects.

Edible insects, especially those collected from the wild, can also transmit parasitic food borne diseases to humans. For example, consumption of wild ants has been associated with *Dicrocoelium dendriticum* infection, while consumption of wild cockroaches has been associated with zoonoses caused by G. lamblia, Toxoplasma spp. and *E. histolytica* (Imathiu, 2020). To the best of our knowledge, the role of beneficial insects in the transmission of parasitic foodborne diseases has not yet been investigated.

Secondary metabolites produced by various food spoilage and phytopathogenic molds of the genera Aspergillus, Penicillium, and Fusarium. These toxins may be present in feed substrate or in the insect gut of moths or termites, among others (Imathiu, 2020; van Huis *et al*., 2013) [34, 2]. The best known and most dangerous mycotoxins are aflatoxins, proven carcinogens isolated in both fresh and dried insects as a result of unsanitary processing conditions, including exposure in an open environment (e.g., during sun drying or street sales) (Imathiu, 2020) [34].

Toxicological contaminations are a major risk when it comes to consuming insects as food. These contaminants can include poisons, pesticides, heavy metals, and anti-nutrients. Poisonous insects, such as bees and ants, can transmit their poison to humans through bites, while other insects can absorb harmful substances from the environment and accumulate them in their bodies. Pesticide residues are often found in wild harvested edible insects, which can feed on crops or vegetation treated with pesticides. Insect farming can help control the feeding and production of edible insects, ensuring that they are free of pesticide residue. However, heavy metals like arsenic, lead, cadmium, and mercury can still accumulate in the insect body, depending on the species, growth stages, and feed substrates. Therefore, it is important to be aware of the potential risks and to take necessary precautions when consuming insects as food.

Conclusion

Edible insects are an often-overlooked source of nutrition that could have a significant impact on the health of individuals and the environment. The potential benefits of consuming insects, such as the house cricket, are numerous. For one, substituting them for other animal and plant-based foods could reduce greenhouse gas emissions and conserve resources like land and water. Additionally, insects like the house cricket are rich in essential amino acids, unsaturated fats, fibre, vitamins, and minerals, making them a suitable alternative to traditional meat and plant-based foods. Consuming edible insects like the house cricket may also have positive effects on human health. They may improve gastrointestinal health, boost immune function, decrease the risk of bacterial infections, and even reduce chronic inflammation associated with cancer and cardiovascular disease. Furthermore, their high protein content and amino acid profile could make them useful in dietary supplements for older adults and those looking to build muscle mass.While more research is needed to fully understand the risks and benefits of consuming insects, the potential for positive impacts on both human health and the environment is significant. Future studies could compare the effects of consuming insects to traditional animal-based foods, or explore the use of insect protein isolates in combination with resistance exercise in older adults and females. Overall, the inclusion of edible insects in the human diet offers a range of potential nutritional and environmental benefits. It's an area that deserves further exploration and research to better understand the potential impacts on human health and the environment.

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