

Edible Insects: A Nutritious and Sustainable Approach of combating malnutrition and improving Health through Alternative Proteins

Roshini Singh¹, Arpita Singh², Raghvendra Pandey², Tanya Singh³, Kalash Mishra³, Nitesh pandey⁴, Dr. Sonal Prasad*

¹M.Tech. Biotechnology, Amity institute of Biotechnology, Amity University Uttar Pradesh, Lucknow campus, Lucknow-226010, Uttar Pradesh, India roshinisingh1005@gmail.com

²M.Tech. Biotechnology, Amity institute of Biotechnology, Amity University Uttar Pradesh, Lucknow campus, Lucknow-226010, Uttar Pradesh, India angelarpita0109@gmail.com

²B.Tech. Biotechnology, Amity institute of Biotechnology, Amity University Uttar Pradesh, Lucknow campus, Lucknow-226010, Uttar Pradesh, India raghvendrapandey567546@yahoo.com

³M.Sc. Biotechnology, Institute of Biosciences and Technology, Shri Ramswaroop Memorial University, Lucknow-Deva Road, Barabanki-225003, Uttar Pradesh, India. Email ID- tanumau2929@gmail.com

³M.Sc. Biotechnology, Institute of Biosciences and Technology, Shri Ramswaroop Memorial University, Lucknow-Deva Road, Barabanki-225003, Uttar Pradesh, India. Email ID- kalashmishra719@gmail.com

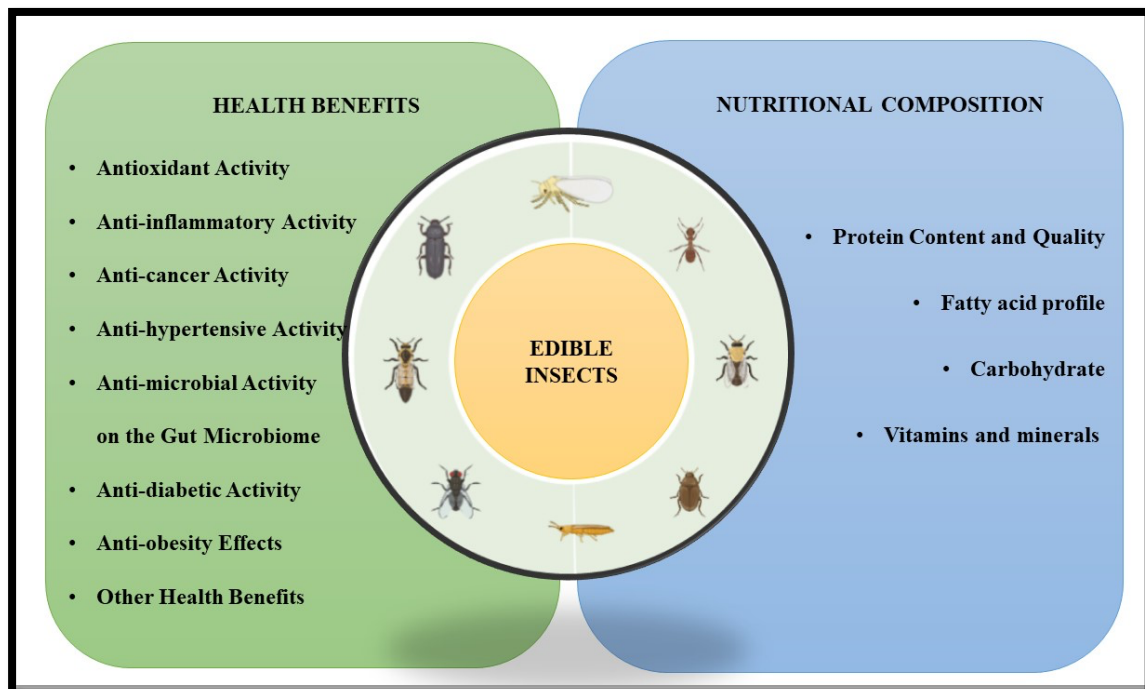
⁴M.Sc. Food Science and Technology, State Institute of Food Processing Technology, Bundelkhand University, Pin-284128, Uttar Pradesh, India.

Email ID- niteshpandey55772@gmail.com

* **Corresponding author**- Faculty of Biosciences, Institute of Biosciences and Technology, Shri Ramswaroop Memorial University, Lucknow-Deva Road, Barabanki-225003, Uttar Pradesh, India sonalpd10@gmail.com

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Graphical abstract



Abstract

Edible insects are gaining recognition as a sustainable and healthy alternative to traditional animal proteins, with various implications for global food security. This review examines their nutritional composition, emphasizing their high protein content, important fatty acids, vitamins, and minerals. Edible insects are an excellent source of nutrients such omega-3 and omega-6 fatty acids, B vitamins, iron, and zinc, all of which are essential for good health. However, their use has both advantages and disadvantages; potential health benefits include increased nutrient intake and dietary variety, whereas allergens, antinutritional factors, and food safety must be considered. The adoption of insects in modern diets is heavily influenced by cultural and societal factors. Traditional practices in different societies suggest its feasibility as a food source, while Western reluctance originates from cultural preconceptions and sensory aversions. Educational campaigns, novel food products, and successful marketing are all examples of strategies for increasing acceptability. Edible insects have great potential as a sustainable food source, but their effective integration into diets will require overcoming health concerns and cultural hurdles, ultimately contributing to a more secure and diverse global food system.

Keywords: Entomophagy, Edible insects, Nutritional Composition, Environmental sustainability, Consumer acceptance

1. Introduction

By 2050, it is estimated that there will be more than 9 billion people on the planet, which would result in a substantial rise in food consumption and perhaps necessitate a doubling of current food production levels (Belluco et al., 2013; Kim et al., 2019). The situation becomes even more challenging by the adverse effects of global warming, which are decreasing the agricultural land, and the environmental damage brought on by industrial activity, both of which have a detrimental influence on the productivity of food production. These issues underscore the urgent need to identify and develop sustainable food resources to ensure global food security (Dobermann et al., 2017).

Food scarcity has historically been associated with worldwide population expansion; however, recent demographic trends, especially in Europe and Asia, indicate declining populations. Because of this, the emphasis is now on tackling more comprehensive nutrition and health-related issues rather than just making sure there is enough food. For example, the growth in obesity rates worldwide has drawn attention to the health risks—such as diabetes, cardiovascular disease, and cancer—that come with making poor dietary choices. This change emphasizes the need for substitute food sources that are both nutrient-dense and sustainable (Lange & Nakamura, 2023)

According to (Nyangena et al., 2020), proteins are essential for immune system function, energy synthesis, tissue growth, physical development, and food absorption in humans. However, there are substantial environmental costs associated with the large-scale production of animal proteins, such as increased land use and greenhouse gas emissions. Furthermore, the human body is unable to produce adequate amounts of essential amino acids (EAAs), which are required for a number of biological processes. As a result, nutrition is the primary source of EAAs, which are mostly found in animal proteins. There is an increasing need to investigate alternate protein sources due to the negative environmental effects and constraints associated with traditional animal farming (Kim et al., 2021)

Among these alternatives, edible insects have emerged as a viable option. When compared to traditional animal proteins, insects have a number of benefits. These include lower adverse effect on the environment because they require less land and emit less greenhouse gases, as well as a decreased risk of infectious diseases linked to livestock. Insects have long been an essential component of many civilisations diets, especially those in Asia, Africa, and Latin America, where they offer significant nutritional benefits (Jantzen da Silva Lucas et al., 2020a). However, the use of insects as a prevalent food source has declined in recent times due to developments in food production methods.

Entomophagy, the practice of eating insects, is still common in many regions of the world, with some 2 billion people frequently include insects in their diets. In addition to being high in necessary amino acids, edible insects also adhere to the sustainability, health, palatability, and accessibility standards (Rutten et al., 2018). In order to improve the commerce, consumption, and acceptance of insects as food, the Food and Agriculture Organisation (FAO) has acknowledged the potential of edible insects as a food source and has advocated for additional research into contemporary food science techniques.

In recent years, researchers have focused on enhancing insect-based food processing technologies in order to boost shelf life and market appeal. Isolating lipids and proteins from insects for use as food ingredients is one promising strategy. However, entomophagy will need to be widely accepted, which will involve tactics to change consumer attitudes and motives as well as a thorough study of the physicochemical properties of insect proteins and lipids (Toti et al., 2020). In order to better understand the potential of edible insects as a sustainable and nutrient-dense source of protein, this review looks at their nutritional composition, environment benefits, and the possibilities and challenges that come with

incorporating them into contemporary diets(Patel et al., 2019).

2. Nutritional Composition of Edible Insects

Edible insects are gaining popularity for their outstanding nutritional profile, which includes high-quality protein, lipids, vitamins, minerals, fibre, and trace elements as shown in Figure 1.(Jantzen da Silva Lucas et al., 2020b). According to (Payne et al., 2016), edible insects frequently have higher nutritional values compared to those of traditional diets. In terms of digestion, insect protein can be compared to other well-known protein sources including milk, soy, and casein. Halloran et al. discovered that edible insects not only exceed daily energy and nutrient requirements, but are also high in important amino acids, polyunsaturated and monounsaturated fatty acids, zinc, iron, and fibre. This nutritional richness establishes insect-derived proteins, lipids, and other nutrients as a viable alternative to conventional sources(Ordoñez-Araque et al., 2022). In addition to these essential nutrients, insects contain beneficial compounds like chitin, phenols, antioxidants, and antimicrobial peptides, which may help in boosting the immune system and prevent disease in humans.(Sosa & Fogliano, 2017)

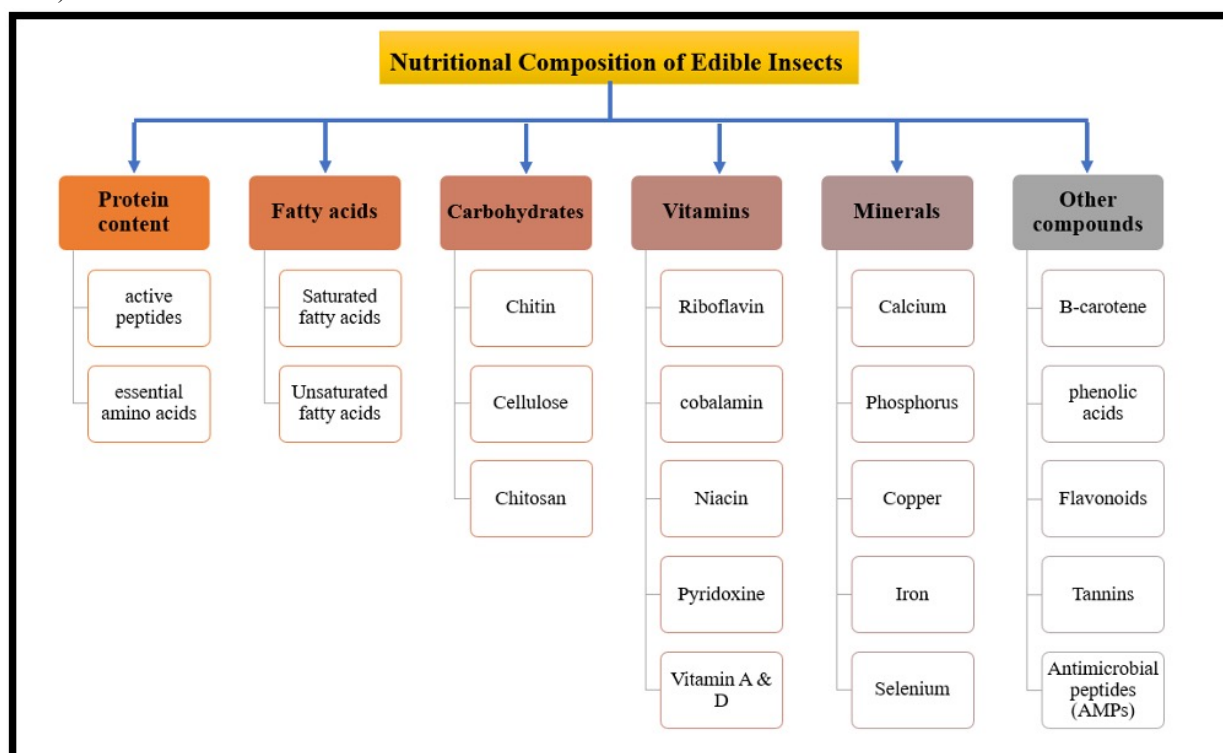


Figure 1: Nutritional Composition of Edible Insects

2.1. Protein Content and Quality

Edible insects are known for their high protein content, making them a great alternative to standard protein sources. According to (Schlüter et al., 2017), edible insects have an average protein content of 35% to 60% of their dry weight or 10% to 25% of their fresh weight. This is substantially higher than the protein level of several plant sources, including grains, soybeans, and lentils. Some insects even exceed the protein content of meat and chicken eggs at the top end of this range. As an example, insects belonging to the Orthoptera order, such as locusts, grasshoppers, and crickets, have a high protein content (Rumpold & Schlüter, 2013). According to Table 1, the dried *Tenebrio molitor* consists of more protein compared to live *Tenebrio molitor* (Mariod, 2020).

However, the digestibility of insect protein varies greatly due to the presence of a hard exoskeleton rich in chitin, a component that humans struggle to digest (van Huis, 2016). Although the efficiency of chitin digestion by humans is still unknown, processing to remove the exoskeleton is a feasible alternative that greatly improves protein digestibility. Research has indicated that the digestibility of insect protein might vary from 77% to 98% in the absence of the exoskeleton (Yang et al., 2023).

Edible insects are highly nutritious due to their high protein content as well as their unique amino acid balance. The majority of the 200+ species of edible insects have essential amino acids (EAAs) in recommended concentrations. Moreover, the quality of a protein availability is determined in a substantial way by the absorption of these processed amino acids (Yi et al., 2016). In vitro studies have shown that more than half of insect proteins can be digested in human intestinal

circumstances, highlighting their potential as a reliable protein supply (Nongonierma& FitzGerald, 2017)

Despite their nutritional benefits, insect proteins present several issues, particularly in terms of allergies (Mintah et al., 2020). Certain insect species include tropomyosin, a myofibrillar protein that is frequently present in shrimp and other arthropods and can trigger cross-reactivity in those who are allergic to shellfish (Pedrosa et al., 2015). Due to the great sequence similarity between shrimp and mites and insects, tropomyosin is a prominent allergen that may cause allergy reactions in susceptible people.

The extraction and isolation of insect proteins presents another challenge when utilising them. After drying, insects usually contain 50% to 70% protein, however the exact amount of protein can vary depending on the extraction method used (Kim et al., 2020). The most popular approach for removing proteins from insects is the alkaline extraction method. This method requires controlling the pH of the insect slurry so that the proteins precipitate at their isoelectric point. The yield of protein obtained by this process varies depending on the insect species, and additional procedures are required to attain higher protein purity, despite the method being straightforward, affordable, and scalable for industrial production (Jantzen da Silva Lucas et al., 2020c)

Ultrasonic treatment is another approach for extracting insect proteins, and it has been proven to considerably boost protein extraction yield. For instance, without changing the amino acid profile, ultrasound therapy boosted protein extraction by 89% from silkworm pupae, 28% from yellow mealworms, and 34% from crickets. Moreover, protein structures can be changed by ultrasonic extraction, which may lessen allergic reactions by changing the accessibility of allergens' epitopes. Overall, the high protein content, essential amino acid profile, and potential for enhanced digestibility make edible insects a promising alternative to traditional protein sources. However, challenges related to allergenicity and protein extraction need to be carefully managed to fully realize the benefits of insect proteins in human diets (Zielińska et al., 2015)

Table 1: Studies regarding Nutritional Composition of Edible Insects

Insects name	Protein content	Fat content	Carbohydrate/ fibre content	Ash content	Moisture Content	References
1. <i>Rhynchophorusphoenicis</i> (palm weevil) larvae	10.51%	62.13%	22.14%	2.37%	11.94%	(Omotoso &Adedire, 2007)
<i>Allomyrinadichotoma</i> (larvae)	38.17±0.48 %	32.72±0.76 %	22.73±0.42%	4.14±0.04	2.25±0.01	(Youn et al., 2012)
<i>Protaetiabrevitarsis</i> (white-spotted flower chafer) larvae	(42.46%–57.86%)	(7.33%–26.70%)	(10.56%–23.71%)	-	-	(Jeong et al., 2020)
<i>Aeschna multicolor</i> (Dragonfly)	54.24	16.72	6.23	12.85		(Siddiqui et al., 2024)
<i>Gryllusbimaculatus</i> (field Cricket)	60 . 7 ± 0. 4	23 . 4 ± 0. 1	10 . 0 ± 0. 3	2 . 8 ± 0. 06	3 . 0 ± 0. 03*	(Udomsil et al., 2019)
<i>Hermetiaillucens</i> (black soldier fly) larvae	39.38–48.20%	25.69–38.36%	7.41%-9.96%	7.26–8.27%	3.21–7.10%,	(Zulkifli et al., 2022)
<i>Musca domestica</i> (housefly) larva	59.87±1.31	19.64±1.10	7.11±0.24	7.06±0.32	-	(Hussein et al., 2017)
<i>Tenebrio molitor</i> (Live-mealworm)	20%	13%	2%	-	62%	(Mariod, 2020)
<i>Bombyx mori</i> (silkworm)	21.5%	13%	14%	-		(Wu et al., 2021)
<i>Tenebrio molitor</i> (Dried-mealworm)	53%	28%	6%	-	5%	(Mariod, 2020)
<i>Apis mellifera</i> (Bee) larvae	35.3%	14.5%	46.1%	4.1%	-	(Guiné et al., 2022a)
<i>Apis mellifera</i> (Bee) pupae	45.9%	16.0%	34.3%	3.8%	-	(Guiné et

						al., 2022b)
<i>Acheta domesticus</i> (House Cricket)	71 . 7 ± 0. 5	10 . 4 ± 0. 1	4 . 6 ± 0. 2	5 . 4 ± 0. 3	6 . 3 ± 0. 04	(Udomsil et al., 2019)

2.2. Fatty Acid Profile

Edible insects comprise a majority of lipids, which are important sources of energy and support a variety of metabolic processes. On a fresh weight basis, edible insects usually have about 30% fat content. This fat content is high in unsaturated fatty acids like linoleic and linolenic acids. However, a wide range of factors, including species, sex, diet, developmental stage, and environmental conditions, affect the lipid content and fatty acid composition of insects.

During the larval stage, insects usually have higher fat content, with lipid levels ranging from 10% to 50% on a dry weight basis. For example, the fat content of beetles such as *Rhynchophorus palmarum* can vary during their larval stage, from 35 to 65 percent, and then declines when they reach adulthood. Similarly, larvae like mealworms, waxworms, and fly maggots gather substantial amounts of lipids as they grow. Pupae, such as silkworm and fly pupae, frequently have even more fat than other developmental stages. Research on insects, including honey bees, has demonstrated a decrease in fat content as the insects get older.

The fatty acid profiles of insects vary widely among species, but generally, they are rich in polyunsaturated fatty acids (PUFAs), particularly omega-3 and omega-6 fatty acids, which are beneficial for heart health and brain function (Tanga & Ekesi, 2024). For example, beetle larvae are typically dominated by oleic acid, while cricket larvae have higher concentrations of linoleic acid. Additionally, larvae of species like *Allomyrinadichotoma* and *Protaetiabrevitarsis* are rich in palmitic acid, whereas *Tenebrio molitor* larvae and crickets tend to have higher levels of linoleic acid (M. Li et al., 2023). Insect fats, also known as "insect oil" due to their liquid constitute at room temperature, are predominantly made of unsaturated fatty acids. These fats, which make up between 57% and 75% of the fat content of insects, are perfect for a variety of culinary uses, such as making butter, pasta, and desserts. Because of its high concentration of linoleic and linolenic acids, insect oil has a liquid consistency that makes it ideal for use as a food lubricant (Phuah et al., 2024). Insect fats have the potential to be an important source of nutrition, but compared to protein levels, less is known about their fatty acid compositions. This gap in research highlights the need for further studies to investigate the safety, applications, and utilization methods of edible insect lipids, particularly in the context of developing countries where energy deficiency is a more pressing concern than protein deficiency (Ochiai, 2024).

2.3. Carbohydrate

While carbohydrates are not the predominant component of edible insects, they do play a substantial role in their nutritional profile (Yang et al., 2023). These macronutrients are necessary for the production of energy and constitute a substantial amount of the animal body. Carbohydrates are mostly found in two forms in edible insects: chitin and glycogen. The main building block of the exoskeleton of insects is chitin, a long-chain polymer of N-acetyl-D-glucosamine. Beyond nutrition, this biopolymer has significant uses in the creation of medical films and wound healing. Edible insects usually contain only 1% to 10% polysaccharides, yet even this low concentration can have significant health impacts (Triunfo et al., 2022). For instance, it has been shown that polysaccharides from silkworm pupae considerably improve humoral immunity.

Another form of carbohydrate that is present in insects is glycogen. It is stored in the cells and muscle tissues and acts as a ready source of energy when needed. According to (Mlcek et al., 2014), the average carbohydrate content varies depending on the species of insect, ranging from 6.71% in stink bugs to 15.98% in cicadas. Insects have a smaller carbohydrate content than proteins or lipids, but their special kinds of carbohydrates—like chitin and glycogen—help them fulfil their potential as an important source of nourishment.

2.4. Vitamins and Minerals

Minerals and vitamins are essential for sustaining healthy body processes and general wellbeing. Edible insects are becoming recognised as a valuable and overlooked source of vitamins and minerals, even though traditional sources including fruits, vegetables, meats, and grains are well-known for providing these vital components. Important vitamins and minerals like potassium, calcium, magnesium, zinc, iron, phosphorus, copper, and manganese are all abundant in insects, especially B12, A, and D (Kouřimská & Adámková, 2016). For communities in need of nutrient-dense diets, these nutrients can be isolated from insects and employed in dietary supplements (Nowakowski et al., 2022).

When compared to more traditional protein sources like chicken, pork, and beef, edible insects typically have higher concentrations of minerals including calcium, copper, zinc, and manganese. Certain species, such as *Odontotermes* (termites) and *Oecophyllasmaragdina* (weaver ants), are very rich in iron, zinc, and copper, and eating them can help

achieve the daily need for these minerals (Chakravorty et al., 2016). In addition, the minerals derived from insects have a high bioavailability, which means that the body can readily absorb and use them, much like it does with minerals derived from beef tenderloin (Nowak et al., 2016).

2.5. Other Compounds

Micronutrients serve a crucial function in preserving general health even though they make up a lesser percentage of the human diet. Essential metal ions like iron, copper, zinc, calcium, sodium, and manganese are abundant in edible insects, as are phosphorus and a range of vitamins like B1, B2, B6, D, E, K, and C. These insect nutritional levels are comparable to those of traditional meat sources (Mwangi et al., 2018). However, the species and environmental conditions can greatly vary in the concentration of these nutrients, emphasising the significance of origin and habitat in determining the nutritional value of edible insects (Meyer-Rochow et al., 2022).

Edible insects are not only rich in micronutrients but also a significant source of phenolic compounds, which have beneficial effects on human health. These compounds, including phenolic acids, flavonoids, and tannins, possess antimicrobial and antioxidant properties. Insects can produce these compounds more efficiently than plants, using fewer resources like water, land, and fertilizers.

Polyphenols are bioactive compounds which are classified as flavonoids, tannins, phenolic acids, and lignans, which are further divided into isoflavones, flavones, flavonols, flavonones, flavononols are best known for his or her anti-inflammatory, antioxidant, and anticancer properties (Prasad, Pandey, et al., 2024). The polyphenol content in insects varies with their diet and life stage, with bees, houseflies, yellow jackets, and crickets being prominent examples. Insects produce antimicrobial peptides (AMPs), which are short proteins with strong effects against various pathogens like bacteria, viruses, fungi, and parasites. These peptides play a crucial role in the insect immune system and are valuable for medical and agricultural applications, particularly in combating antibiotic resistance (Zhou et al., 2022). AMPs are classified into three main types: linear α -helical cecropins, defensins, and glycine- and proline-rich peptides. Their diverse action mechanisms, broad-spectrum activity, and low risk of resistance make them promising candidates for new antimicrobial drugs and treatments (Nino et al., 2021)

For example, antimicrobial peptides such as cecropin, gloverin, and moricin, produced by the silkworm *Bombyx mori*, have broad-spectrum efficacy against some viruses, fungi, and bacteria (Makwana et al., 2023). The first insect antimicrobial peptide discovered in *Hyalophora cecropia* pupae, cecropin, has demonstrated efficacy in preventing the growth of parasites and viruses linked to malaria. Edible insects have a wide range of chemicals, which highlights their potential as a source of bioactive compounds with important health advantages in addition to being a nutritional resource (Brady et al., 2019)

3. Health Benefits of Consuming Edible Insects

3.1. Potential Health Benefits

Edible insects are increasingly recognized for their various health benefits, ranging from antioxidant and anti-inflammatory properties to anti-cancer and anti-obesity effects as shown in figure 2. This diverse array of bioactivities makes edible insects a promising source of functional ingredients for human health.

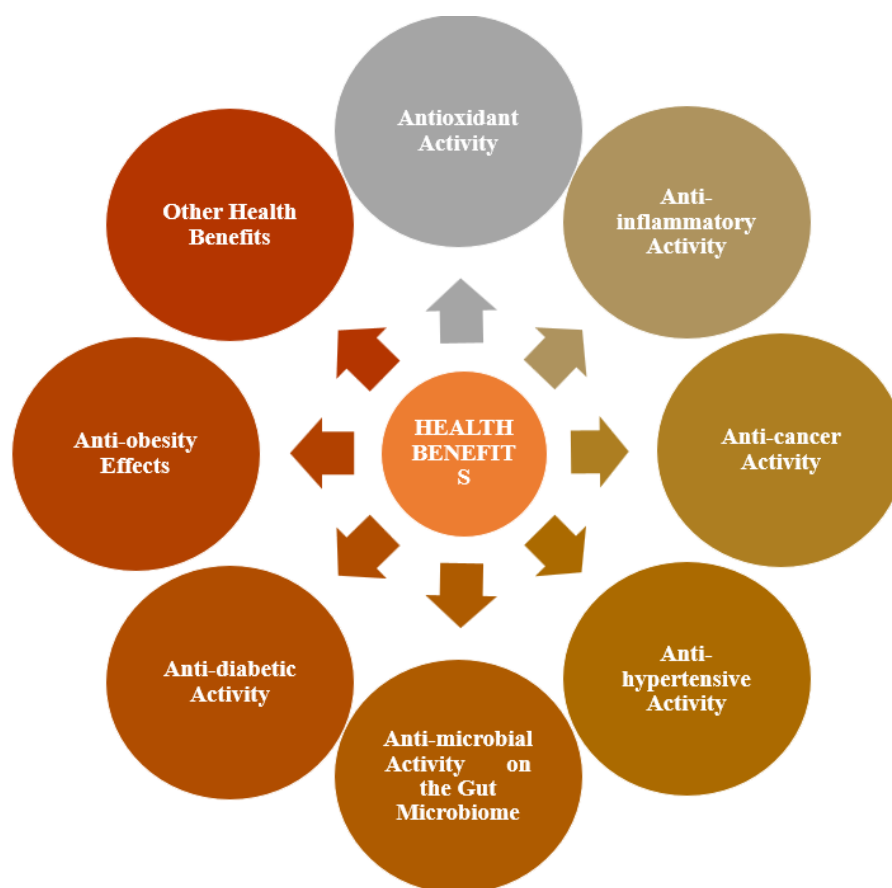


Figure 2: Health Benefits of Consuming Edible Insects

3.1.1. Antioxidant Activity

Edible insects are proving to be an excellent source of antioxidants, with beneficial characteristics originating from a variety of components including hydrolysates, peptides, and chitosan. Protein isolates from *Bombyx mori* (silkworm) larvae (Makwana et al., 2023), when treated with gastrointestinal enzymes, show strong radical scavenging and ferrous ion chelating properties. These extracts possess antioxidant properties on par with, if not higher than, those of conventional functional foods like olive oil and orange juice. Similar to this, amino acids including Glu, Asp, Arg, and Lys are abundant in hydrolysates from *Musca domestica* (housefly) (Zhang et al., 2016), which supports their potent antioxidant properties. Interestingly, chitosan derived from housefly larvae exhibits more antioxidant activity than the widely used reference standard, ascorbic acid.

Another well-known product made from insects is cricket powder, which is rich in bioactive peptides with antioxidant and antibacterial properties. Studies demonstrate how these peptides can enhance immunological response and gastrointestinal health in animals, with possible advantages for human health as well. Insect heat treatment also promotes the synthesis of these bioactive peptides, strengthening their antioxidant capabilities. According to studies, water-soluble extracts from crickets, silkworms, and grasshoppers can have antioxidant properties up to five times higher than those of fresh orange juice (Kosečková et al., 2022). Furthermore, the enzymatic hydrolysis of cricket proteins can lessen their allergenicity, giving customers a safer and easier-to-access option.

Oecophylla smaragdina hydrolysates produced via gastrointestinal digestion were used to isolate and purify antioxidant peptides by (Chakravorty et al., 2016). These techniques included size-exclusion chromatography, RP-HPLC, LC-MS/MS, and ultrafiltration. The CTKKHKPNC peptide was ultimately isolated, and it demonstrated outstanding antioxidant activity (IC₅₀ values: 48.2 μM for the DPPH assay and 38.4 μM for the ABTS assay) (Pattarayingsakul et al., 2017). Overall, the chemicals obtained from insects have antioxidant properties that point to a promising possibility for treating chronic diseases including diabetes, cancer, and cardiovascular disease that are brought on by oxidative stress and inflammation. Research on antioxidant activity is mostly focused on edible insects, particularly on species like house crickets and yellow mealworms. As a result, edible insects are becoming recognised as an important dietary supplement for improving health and preventing disease (Di Mattia et al., 2019).

3.1.2. Anti-Inflammatory

Edible insects, especially crickets, have anti-inflammatory properties that are gaining attention due to their potential health benefits. Studies have indicated that the polysaccharide glycosaminoglycan, which is found in crickets, plays a major role in the prevention of inflammation. Glycosaminoglycan from the cricket species *Gryllus bimaculatus* has been found in studies by Ahn and colleagues to have significant anti-inflammatory properties. According to Ahn et al. (2014), this substance successfully decreased the symptoms of chronic arthritis in mouse models by decreasing a number of inflammatory indicators and blocking rheumatoid factor and C-reactive protein (CRP). Further research found that combining glycosaminoglycan with indomethacin, a nonsteroidal anti-inflammatory medication, resulted in a greater decrease of paw oedema than either treatment alone. This combined therapy showed more efficacy in decreasing inflammation.

Furthermore, glycosaminoglycan markedly decreased CRP levels and decreased the amount of fat in the abdomen and epididym in rats given a high-fat diet. Additionally, it raised a number of biochemical markers that may be useful in preventing diseases like hyperlipidaemia and fatty liver, including glucose, phospholipid levels, aspartate transaminase (AST), alanine transaminase (ALT), and total cholesterol. Furthermore, supplementing diabetic mice with glycosaminoglycan resulted in decreased levels of blood glucose and LDL cholesterol as well as increased activity of antioxidant enzymes such as glutathione peroxidase, catalase, and superoxide dismutase (Ahn et al., 2014). These findings underscore glycosaminoglycan's potential in lowering the risk of diabetes and chronic inflammatory diseases. Collectively, these studies suggest that the anti-inflammatory properties of cricket-derived glycosaminoglycan could be a valuable addition to dietary strategies aimed at managing and preventing chronic inflammation and related health conditions.

Edible insects have strong anti-inflammatory properties. It has been demonstrated that hydrolysates derived from insects like *G. sigillatus*, *T. molitor*, and *S. gregaria* suppress important inflammatory enzymes including lipoxygenase (LOX) and cyclooxygenase-2 (COX-2), which are linked to the synthesis of prostaglandins and leukotrienes. According to these results, eating insects may help control inflammatory conditions and prevent diseases linked to them (Zielińska et al., 2017)

3.1.3. Anti-Hypertensive Activity

Angiotensin-converting enzyme (ACE) inhibitors can help control hypertension, a significant risk factor for cardiovascular diseases (Prasad, Younis, et al., 2024). Studies revealing the ACE inhibitory activity of hydrolysates and peptides from a variety of species have demonstrated the promise that edible insects have exhibited in this area (Prasad & Qidwai, 2023). For example, *B. mori* larvae enzymatic hydrolysates greatly boosted ACE inhibitory action, and following gastrointestinal digestion, IC₅₀ values significantly decreased. In a similar manner, it has been discovered that hydrolysates from cotton leafworm larvae of *Spodoptera littoralis* have strong ACE inhibitory characteristics (Vercruysse et al., 2009)

Furthermore, major ACE inhibitory effects have been demonstrated by peptides isolated from *Tenebrio molitor* (mealworm) larvae and other insects, such as *Gryllodessigillatus* and *Oecophylla smaragdina* (Ferrazzano et al., 2023). These findings suggest that edible insects could be developed into natural ACE inhibitors, potentially offering a natural means to manage hypertension.

3.1.4. Anti-Microbial Activity and Effects on the Gut Microbiome

Edible insects are emerging as a prospective source of health benefits, notably due to their antimicrobial activity and beneficial effects on the gut microbiome. Anti-microbial peptides (AMPs) from insects, such as those isolated from *Galleria mellonella* (greater wax moth) larvae, have been demonstrated in studies to have strong antimicrobial activity. These peptides affect the gut microbiome, promoting a healthy balance of bacteria and perhaps preventing disorders associated with microbial imbalances (Cytryńska et al., 2007)

One study investigated the effects of cricket-derived glycosaminoglycan on gut health. Consuming 25 grams of dried, roasted cricket powder everyday for 14 days enhanced the abundance of the probiotic bacterium *Bifidobacterium animalis* and lowered plasma levels of tumour necrosis factor (TNF)- α , a proinflammatory cytokine. This shows that cricket powder not only supports good gut flora but also has an anti-inflammatory impact (Stull et al., 2018)

Similarly, feeding black soldier fly larvae to rainbow trout increased gut microbial diversity and improved disease resistance (Sayramoğlu et al., 2023). This effect was also demonstrated in fowl, where dry mealworm and super mealworm larvae decreased infections from *E. coli* and *Salmonella*. Insects' exoskeletons include chitin, a polymer that contributes to their antibacterial properties. Chitin and its derivative, chitosan, are known to have antibacterial, antioxidant, anti-inflammatory, and immunostimulatory properties.

Additionally, eating insects has been associated to higher levels of short-chain fatty acids (SCFAs) in the intestines. In hens, chitin from insect meals led to greater levels of SCFAs such as propionate and butyrate, which are related with decreased food consumption, lower cholesterol and triglyceride levels, and increased energy. These SCFAs also promote the release of satiety hormones, contributing to better metabolic health (Borrelli et al., 2017).

Chito-oligosaccharides produced from chitin and chitosan have been found to reduce pro-inflammatory cytokines including TNF- α and interleukin (IL)-1 β in aged people. Supplementing fish with chitin and chitosan increased immunological function by boosting white blood cells, haemoglobin, and red blood cells. Supplementing hens with black soldier fly larvae lowers triglycerides and cholesterol while boosting blood calcium levels, most likely due to chitin's propensity to bind to free fatty acids and bile acids (Aprianto et al., 2023). Overall, including insect-based items in the diet appears to benefit gut microbiota health, immunological response, and inflammation. These findings highlight insects' potential as a functional and sustainable food source with positive benefits on human health.

3.1.5. Anti-Cancer Activity

Various research has investigated edible insects have anti-cancer properties. For example, ethanol extracts from fermented *B. mori* inhibited HepG2 hepatocellular carcinoma development more effectively than unfermented extracts. The fermented extracts boosted the expression of pro-apoptotic proteins while inhibited anti-apoptotic proteins, causing apoptosis in cancer cells (Cho et al., 2019).

In addition to their anti-cancer potential, (Sinha & Choudhury, 2024) investigate emerging information supporting the use of edible insects in cancer therapy. They emphasize that edible insects contain a high concentration of beneficial substances such as proteins, peptides, and antioxidants, all of which have been linked to cancer prevention. Studies have shown that these chemicals can cause cancer cells to die and prevent tumor growth. The review also highlights the historical use of insects in traditional medicine to treat cancer, implying that old traditions may inform modern treatments. Furthermore, the review investigates the mechanisms by which insect-derived chemicals exert anti-cancer activity, such as regulation of important signaling pathways involved in cell growth and death. Additionally, the potential of edible insects as drug delivery systems is discussed, with their natural composition offering novel methods for targeting cancer cells more precisely. The review concludes with a call for further research to validate these findings and to explore the full potential of insects in cancer therapeutics and drug delivery systems.

3.1.6. Anti-Obesity and Anti-Diabetic Activity

Edible insect research has also focused on obesity and diabetes, two common metabolic illnesses. Ethanol extracts of *Allomyrinadichotoma* (Korean horn beetle) have been found in studies to suppress lipid accumulation and the expression of adipogenesis and lipogenesis genes in adipocytes (Chung et al., 2014). Furthermore, *T. molitor* larvae have been shown to exhibit anti-obesity properties by preventing adipogenesis and lowering body weight gain in high-fat diet models (Park et al., 2021).

Furthermore, many edible insects, such as *M. domestica* (H. Li et al., 2017) and *Alphitobius diaperinus* (lesser mealworm), have shown anti-diabetic effect by inhibiting dipeptidyl peptidase-IV (DPP-IV), an enzyme involved in blood glucose regulation (Lacroix et al., 2019). These findings indicate that edible insects may provide natural solutions for addressing obesity and diabetes.

3.1.7. Other Health Benefits

Aside from the antioxidant and anti-inflammatory effects, edible insects provide a wide range of health benefits. Key nutritional components found in insects, including as medium-chain fatty acids, globulin and albumin proteins, as well as critical vitamins and minerals, have been demonstrated to improve health and prevent disease. One significant component is lauric acid, a medium-chain fatty acid found in black soldier flies. Sprangers et al. found that lauric acid successfully combats bacterial infections and regulates gram-positive bacteria in piglets' intestines. The antimicrobial effects of lauric acid are greatly boosted when mixed with lipase in piglet feed, highlighting its potential to improve animal health (Sprangers et al., 2018).

Insect proteins have a positive impact on animal health at both the globulin and albumin levels. Studies have demonstrated that replacing soybean meal with insect meal in the diets of broiler chickens and early-weaned piglets increases globulin levels while decreasing albumin levels (Marono et al., 2017). This dietary adjustment has been associated with enhanced disease resistance and immunological response in these animals. For example, pigs given insect meal had a lower frequency of diarrhoea, which did not impair their growth. These findings indicate that similar benefits could be realized in humans, improving total immune function.

The high vitamin and mineral content of edible insects enhances their health advantages. Crickets, in particular, are abundant in vitamin B12, which helps to avoid pernicious anaemia, cognitive loss, and bone fractures, particularly in the elderly. Vitamin B12 also lowers total homocysteine levels in the blood, which reduces the risk of cardiovascular disease. Crickets are also a good source of calcium, which can help enhance bone mineral density and reduce the risk of fractures in older persons.

Furthermore, the iron and zinc content of crickets and other edible insects may help avoid anaemia while also supporting cognitive function, immunological health, and gastrointestinal well-being in humans. Incorporating edible insects into the diet could thus offer a holistic approach to improving health and preventing nutrient deficiencies (Fan et al., 2023). In summary, the integration of edible insects into diets presents a promising opportunity for enhancing human health through their unique blend of fatty acids, proteins, vitamins, and minerals, potentially offering protection against a range of health issues and contributing to overall well-being.

4. Cultural and Societal Acceptance

The acceptance of edible insects as food varies greatly amongst cultures. In Asia, Africa, and Latin America, insects have long been a part of traditional diets and are culturally recognized as a valuable food source. However, in Western nations, the concept of eating insects is frequently received with scepticism and discomfort, owing to cultural norms and preconceptions. The authors emphasize the importance of overcoming cultural hurdles in supporting the widespread adoption of insects as a sustainable food source. Education, marketing efforts, and incorporating insects into known food products are advocated as methods for increasing societal acceptability (Melgar-Lalanne et al., 2019a).

4.1 Traditional Consumption of Insects

Insect ingestion has long been a part of many societies' cultural practices around the world. For generations, insects have been used not just as food, but also for their nutritional and therapeutic properties. The research recounts how diverse civilizations have historically harvested, cooked, and consumed numerous insect species, frequently using indigenous knowledge passed down through generations. This tradition emphasizes the relevance of insects in local diets and the need to preserve traditional practices while incorporating them into modern food systems. (Melgar-Lalanne et al., 2019b)

(Raheem et al., 2019) provide a thorough analysis of the traditional consumption and rearing of edible insects throughout Africa, Asia, and Europe. In Africa and Asia, insect consumption is firmly ingrained in cultural practices, with species such as mopane worms and locusts in Africa and fried crickets and silkworms in Asia being both culturally important and nutritious. These insects are frequently collected from the wild and used in communal meals and ceremonies. While traditional consumption is declining in Europe, edible insects are becoming more popular due to their environmental and nutritional benefits. The research discusses the possibility for expanding insect cultivation and consumption in Western nations, considering cultural acceptance as well as regulatory constraints. Overall, it emphasizes the value of edible insects as a culturally significant, nutritious, and sustainable food resource.

(Krongdang et al., 2023) highlights the diverse range of insect species consumed in Thailand and their nutritional benefits, such as high protein content and essential vitamins. The study examines various processing methods, including drying and frying, and their impact on flavor and texture. Additionally, it discusses the role of edible insects in the Thai food industry, focusing on their cultural significance and potential for sustainable food production highlighted in the Figure 3. The authors call for further research and innovation to enhance the integration of edible insects into mainstream food systems.

Hlongwane et al., 2020 investigate the traditional practices and knowledge systems surrounding the use of edible insects in South Africa. It emphasizes the important role that indigenous societies have played in incorporating specific bug species into their meals, which not only provides nutritional benefits but also helps to shape cultural identity. The research contends that traditional knowledge of edible insects is critical for encouraging sustainable eating practices and protecting biodiversity. (Alhujaili et al., 2023) The authors advocate for greater research into the comprehensive integration of edible insects into current food systems, considering both the potential benefits and limitations. This study emphasizes the necessity of retaining indigenous knowledge while simultaneously investigating the benefits and drawbacks of increasing the consumption of edible insects outside traditional settings. (Aung et al., 2023; Hlongwane et al., 2020)



a) *Gryllus bimaculatus* (Crickets) and the *Caelifera Siamese* (Grasshopper)



b) *Bombyx mori* (Silkworm pupae)

Figure 3: Examples of fresh and cooked edible insects traditionally consumed as food resources in Thailand. (a) fried Crickets and Grasshoppers b) fried silkworm pupae.

4.2 Barriers to Adoption in Western Diets

In Western nations, entomophagy is frequently regarded as disgusting or a sign of primitiveness and poverty, in contrast to the ability to purchase beef, which is regarded as a symbol of social and economic progress. This perspective mirrors a larger tendency in which economic success is measured by availability to specific meals, separating wealthier folks from those in economically disadvantaged situations. Furthermore, food neophobia—the inclination to reject new or unfamiliar foods—is particularly prevalent when it comes to edible insects. (Poortvliet et al., 2019)

Megido et al. (2016) identify four major challenges to the acceptance of insect-based meat alternatives in Western diets. Cultural attitudes are important, as insects are sometimes regarded as unpleasant or "dirty" in Western nations due to longstanding dietary taboos and unfamiliarity with entomophagy. This bad perception is exacerbated by aesthetic concerns, since many consumers find the physical appearance of insects repulsive. Furthermore, there is a lack of familiarity with insect-based diets, which causes hesitation to test these items. Effective marketing and educational activities are required to dispel myths and promote the advantages of insect-based solutions. Regulatory problems present further challenges, since fluctuating food safety standards and laws cause uncertainty for both producers and consumers. Overcoming these barriers requires a multifaceted approach, including cultural shifts, better consumer education, and clear regulatory frameworks. (Caparros Megido et al., 2016)

Meyer-Rochow and Kejonen (2020) look into how idioms and expressions with negative connotations about insects, spiders, and other invertebrates influence Western attitudes towards edible insects. According to the study, many Western languages have idiomatic terms that portray insects and other similar critters negatively, which may create and sustain societal aversions to consuming these organisms. These idioms frequently communicate disgust or unpleasantness, which may contribute to a greater cultural aversion to consume insects as sustenance. The study implies that addressing these linguistic biases and changing views through positive framing and education could help shift attitudes and boost acceptance of edible insects in Western diets. (Meyer-Rochow & Kejonen, 2020)

Yen (2009) investigates the contrast between traditional knowledge and Western dread of edible insects. The study investigates how traditional civilizations see insects as a significant food source, revealing deeply ingrained knowledge and habits passed down through generations. In contrast, Western nations frequently demonstrate fear and reluctance to consume insects, which is impacted by cultural prejudices and a lack of familiarity. According to Yen, overcoming Western antipathy to edible insects demands a greater appreciation for traditional traditions as well as acknowledgement of their nutritional and environmental benefits. The study emphasizes the importance of educational initiatives to close the gap between traditional entomophagy and Western food habits. (YEN, 2009)

Kroger et al. (2021) conduct a systematic evaluation of the adoption of insect-based foods in Western civilizations. According to the review, while there is increased interest in the potential benefits of insect-based foods, such as nutritional

content and environmental sustainability, acceptability remains low in Western countries. Cultural opposition, unfamiliarity with insects as food, and aesthetic issues all have an impact on acceptability. The paper emphasizes that overcoming these hurdles necessitates focused training initiatives, enhanced product presentation, and regulatory compliance. Furthermore, the analysis emphasizes the necessity of understanding consumer attitudes and devising strategies for more effectively incorporating insect-based products into Western diets. (Kröger et al., 2022)

4.3 Strategies to Increase Acceptance

(Onwezen et al., 2019) investigate how emotional responses and cultural influences affect consumer acceptability of insects as food and feed. It discovers that acceptance is greatly influenced by emotions such as disgust or curiosity, with good sensations increasing acceptance and negative ones acting as obstacles. Cultural background also influences these emotional responses, since nations less accustomed with entomophagy frequently have stronger aversions. According to the study, emphasizing insects' environmental and nutritional benefits, combined with focused educational activities to address emotional and cultural barriers, is critical to increasing consumer acceptance and incorporating insect-based products into mainstream diets.

(Verbeke, 2015) examines Western customers that are willing to using insects as a meat substitute. The study highlights specific consumer segments that are more inclined to accept insect-based products, such as those motivated by environmental concerns, health benefits, and a desire to try new meals. Awareness of the environmental impact of traditional meat production, as well as positive attitudes towards alternative proteins, are important elements that influence readiness. The study concludes that, while a small group of people are enthused about insect-based meat, widespread acceptance will need overcoming cultural hurdles and improving product appeal to reach mainstream customers.

5. Conclusion

Edible insects are a viable alternative source of nutrition, with a diversified and healthy nutritional profile. They are high in essential protein, fatty acids, vitamins, and minerals, making them an important part of a healthy diet. Edible insects' protein composition frequently approaches or exceeds that of traditional animal proteins, and their fatty acid profiles are beneficial, with many species containing important omega-3 and omega-6 fatty acids. Furthermore, they are high in vitamins and minerals such as B vitamins, iron, and zinc, all of which are essential for overall health and wellness. Despite these benefits, eating edible insects presents certain obstacles.

Potential health benefits include increased nutrient intake and dietary diversity, although allergies and antinutritional factors must also be addressed. The safety of edible insects as food is critical, needing stringent food safety protocols to avoid contamination and protect consumer health. Cultural and social factors influence the adoption of edible insects. Traditional consuming traditions in numerous cultures illustrate the possibility for incorporating insects into diets; yet, impediments to acceptability in Western diets persist. These limitations include cultural biases, sensory aversions, and a lack of familiarity with insects as a dietary source. Addressing these challenges through education, creative food products, and successful marketing methods might assist to boost acceptance and promote wider adoption.

Overall, edible insects have a significant potential to improve global food security and nutritional needs. Continued investigation, combined with cultural sensitivity and effective communication, will be critical to overcoming obstacles and reaping the benefits of this sustainable food source. Edible insects can play an important part in future dietary patterns by addressing health hazards, increasing food safety, and creating favorable impressions, as well as meeting the growing need for healthy and sustainable food alternatives.

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