Bioactive Compounds, Nutritional Value And Health Benefits Of Edible Insects- A comprehensive Analysis

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Abstract:
The practice of entomophagy has been a significant source of nutrition for various cultures worldwide for centuries. As global populations increase, and the demand for sustainable protein sources rises, edible insects have gained attention due to their nutritional and environmental benefits. This paper explores the bioactive compounds, nutritional profile, and health benefits of edible insects. Insects are rich in proteins, fats, vitamins, and minerals, providing essential nutrients often lacking in the diets of many developing regions. Additionally, bioactive compounds such as antibacterial peptides and phenolics found in insects may have potential health benefits, including immune system enhancement and cancer prevention. The environmental advantages of insect farming, such as lower greenhouse gas emissions and minimal land usage compared to traditional livestock farming, further highlight the viability of insects as an alternative protein source. This study provides an overview of the nutritional and functional properties of edible insects and health benefits.

Keywords: Edible insects, entomophagy, bioactive compounds, nutritional value, protein, fats, vitamins, minerals, health benefits, sustainable food sources, environmental impact

Introduction
Nearly 2.5 billion people in the world currently supplement their diet with insects **(Van Huis, 2016**). Entomophagy, the practice of insect consumption is not a new habit as it has been practiced for years by many cultures worldwide as a means of providing unique, delicious and nutritious food to the consuming
populations **(Ramos and Elorduy 2009**). According to Food and Agriculture Organization, 2100 species has been identified as diet among 3071 cultural groups in 130 countries throughout the world **(Deka et al. 2021).** It is believed that the population of the world will hit around 9 billion by 2025 which could have an adverse effect on satisfying the world's nourishment and nutrition challenges **(Liceaga and Andrea 2021).**To meet these growing demands, global food production has to increase by as much as 70 percent by 2050 **(FAO 2009).**
According to **(Yen 2009)** rearing edible insects compared to rearing livestock has been shown to have an insignificant environmental footprint making it a better choice for caring of the environment while providing the nutritional benefits. Essential proteins, vitamins and minerals are often lacking in the traditional diets of developing areas which are necessary for infants and children. The nutritional composition of edible insects between and within species is highly variable, depending upon metamorphic stage, habitat and diet of the insect **(Rumpold and Schlüter, 2013).**Generally, edible insects are rich in proteins (amino acids such as methionine, cysteine, lysine and threonine), carbohydrate, fats, some minerals (calcium, iron, zinc, phosphorous), essential vitamins –vitamin A, B complex, C **(Pal and Roy, 2014).**Besides their nutritional benefits, edible insects are also promoted by various organizations and governments as one way of taming climate change, conferring an environmental benefit of reduced greenhouse gas emissions **(Oonincx et al.2010)** as they have been associated with feeding on waste organic matter **(FAO et al. 2013)** . As an alternative source of protein compared to domestic animals-based foods, edible insects have additionalbenefits that include use of less rearing land, a high rate of reproduction and high feed conversion efficiency **(Klunder et al . 2012)**. The present study discusses about the bioactive compounds, nutritional values and health benefits of edible insects.

Bioactive compounds of edible insects
Bioactive compounds are extra-nutritional constituents that typically occur in small quantities in foods **(Kris-Etherton *et al*, 2002).** Many studies have found bioactive compounds in insects with characteristics that could have the potential to reduce health risks and strengthen the immune system **(Roos and Huis, 2017).**
Bioactive peptides are naturally produced by dietary proteins during the gastrointestinal process that may contain 2–20 amino acids **(Najafian & Babji, 2012).**Moricin, an antibacterial peptide consisting of 42 amino acids shows antibacterial activity against *Staphylococcus aureus* was isolated from the hemolymph of the silkworm, *Bombyx mori.* The effects of the peptide on bacterial and liposomal membranes showed that a target of the peptide is the bacterial cytoplasmic membrane **(Seiichi Hara and Minoru Yamakawa 1995). (Guangqiang Ma et al., 2019)** also reported theextractives of the shell of*Cryptotympanapustulata Fabricius* and the body of *Mole cricket* has significant antibacterial activity on *Staphylococcus aureus* and *Mycobacterium tuberculosis*; the different organic solvents components of *C. Fabricius* and *M.cricket* also have inhibit effects on *S.aureus* and *M.tuberculosis*.
(Sarmah et al., 2022) reported *Cybister sp.* have high phenolics (363.80 mg catechol equivalent/100 g) and flavonoid (50.82 mg quercetin equivalent/100 g) and Ranatra sp. showed high DPPH inhibition (91.47%). **(Kouˇrimská &**

Adámková, 2016) detected *β*-carotene in some butterfly caterpillars of the species *I. oyemensis*, *N. oyemensis*, *I. truncata*, and *I. epimethea* in values between 6.8 and 8.2 *μ*g of *β*-carotene per 100 g of dry matter. Recently, study on the content of phenolic compounds in *A. domesticus* identified 4-hydroxybenzoic acid, p-coumaric acid, ferulic acid, and syringic acid as the major phenolic compounds present **(Nino et al., 2021). (Finke 2009)** repoted that the dry matter chitin of *Tenebrio molitor* can reach 137.2 mg/kg and large amounts of chitin can be used to produce bioactive chitosan **(Hahn et al., 2020).(Wu et al., 2011)** also reported thathydrolysates of silkworm larvae prepared by gastrointestinal enzymes showed strong ACE inhibition in vitro with an IC50 of 8.3 g/mL.

Nutritional values of edible insects

Proteins

Edible insects have high nutritional value and low environmental costs in terms of protein production ***(Oonincx and de Boer, 2012).***On average, the protein content of edible insects ranges 35–60% dry weight or 10–25% fresh weight **(Melo et al., 2011)**, which are higher than plant protein sources, including cereal, soybeans, and lentils **(Bukkens, 1997). (Orkusz 2021)** reported that adults of *T. molitor* (24.13 g/100 g) and larvae of *B. mori* (23.1 g/100 g), *G. belina* (35.2 g/100 g) and *T. molitor* (25.0 g/100 g) contain a higher protein content than poultry breast muscle, beef sirloin, and horse meat.

A study showed thatthe crude protein contents of the caterpillars of the pillar emperor moths (*Cirina forda*)and spiny emperor moth (*Bunaea alcinoe*) were significantly highest followed by termite (*Macrotermes natelensis*) and cricket (*Brachytrupes membranaceous*) **(Agbidye et al., 2009**) in Africa in comparison to meat or fish**.(Sailo S et al., 2020)** reported high values of crude protein in different species of insect in Assam, India among which the highest protein content was recorded in species muga silkworm (*Antheraea assamensis*) (52.35%) and the lowest in winged termite (*Odontotermesobesus*) (23.31%). On the other hand **(Chakravorty et al.,2014)** alsoreported the nutritional composition of pink Chondacris and eastern Brachytrupes, two insects consumed by Indian tribes, with 65–69 % of protein, composed of 18 amino acids, highlighting a high amount of leucine and valine (8 and 7 % respectively).

Studies done on five edible aquatic insects of Assam- water bug(*Diplonychus rusticus*); giant water bug (*Lethocerus indicus Lepeletier* and *Serville)* ; water scorpion (*Laccotrephes sp*.) , water stick (*Ranatra sp.)* ; diving beetle (*Cybister sp.)* revealed that the selected aquatic insect species have high nutritive value and are rich sources of protein (50.03 to 57.67%) **(Sarmah et al., 2022). (Kinyuru et al., 2021)** reported that the longhorn grasshopper (*Ruspolia differens)*being a major part of the food in East Africa were found to contain a protein content of 37.1 and 35.3%, respectively.

Fats

The second largest component of insect nutrient composition is fat. The larvae and pupae have more fat than adult insect **(Mlcek et al., 2014).(Rumpold and Schluter 2013)** reported that on average, across all edible insects types, the fat content ranges from 13 to 33% for Orthoptera (e.g. crickets and grasshoppers) and Coleoptera (e.g. beetles and grubs (insect larvae) respectively. Most edible insects usually have low SFA contents **(DeFoliart 1991)** and high content of good fat like MUFA and PUFA **(Kouřimská & Adámková 2016**). **(Sales-Campos et al. 2013)** reported that oleic acid, a common monounsaturated fatty acid found in insects helps to reduce blood pressure for human-being and has great potential in curing inflammatory, immune and cardiovascular diseases.

Fat is present in several forms in the insect. Triacylglycerols constitute about 80% of fat which serve as an energy reserve for periods of high energy intensity, such as longer flights **(Tzompa-Sosa et al., 2014)**including phospholipids which are second most abundant group in insect fat with content less than 20%.**(Ferdousi L et al)** reported that edible oil extracted from desilked silkworm pupae (*Bombyx mori*) contain low peroxide and acid value of 4.82 meq/kg and 1.35 mg KOH/g oil, respectively, and comprised of different fatty acids, in which palmitic acid (32.04%) and oleic acid (34.62%) were in large portions among the total fatty acids including linoleic, α-linolenic, and dihomo-gamma-linolenic acid which have health benefits. Linolenic acid and α-Linolenic acid are essential for human-being as they cannot be produced by us. Orthoptera is the best source of linoleic acid compared with other orders of insects and Lepidotera with high amounts of PUFAs, is especially rich in α-Linolenic acid **(Blondeau et al. 2015).(Igwe et al., 2011)** reported termite, *Microtermes nigeriensis* to be rich inare linoleic acid, oleic acid and palmitic acid but poor in myristic acid, lauric acid and palmitoleic acid.

Carbohydrates

Carbohydrates represent the primary source of energy in most human diets. Carbohydrates in insects mainly exist in two forms of chitin and glycogen. The averaged carbohydrate content of edible insects ranges from 6.71% (stink bug) to 15.98% (cicada**) (Mlcek et al., 2014).** Chitin is a type of carbohydrate polymer that forms the exoskeleton of most arthropods including insects and is reportedto improve gastrointestinal health due to its prebiotic potential **(Selenius et al., 2018)**.

Minerals and vitamins

Edible insects are rich in minerals, including phosphorus,calcium, potassium, sodium, iron, zinc, magnesium, copper, and manganese**(Kouřimská & Adámková, 2016).(Oonincx et al., 2010)** reported that the large caterpillar of the moth *Gonimbrasia belina* has a high iron content (31–77 mg per 100 g of dry matter) and so does the grasshopper *L.migratoria* (8–20 mg per 100 g of drymatter).

(Adeduntan, 2005) reported the amount of calcium in aquatic insects (24.3–96 mg/100 g) is much higher than in different terrestrial insects (0.0012–0.126 mg/100 g)**).** *Bombyx mori* has high calcium content almost comparable to semi-skimmed cow's milk **(Adámková et al., 2014).** A high content of magnesium (7.54-8.21g/100g) has been found in grasshoppers and weevils **(Banjo *et al*., 2006).** Eggs, larvae and pupae of honeybees have a high amount of vitamins A, B2 and C to the extent of 12.44mg/100g, 3.24mg/100g and 10.25mg/100g, respectively **(Bukkens, 2005). (Sarmah et al., 2022**) reported *D. rusticus* have content of Na (28.62 mg/100 g) and Mg (45.20 mg/100 g) and *Cybister sp*. Have high P (153.32 mg/100 g) and K (34.60 mg/100 g). Red palm weevil (Rhynchophorus ferrugineus) is a good source of vitamin E **(Bukkens & Paoletti 2005).(Kouřimská & Adámková 2016)** reported that*A. domesticus* have significant B12 vitamin content: from 5.4 µg per 100 g in adults to 8.7 µg per 100 g in nymphswhereasdried insects, especially coleopteran like *T. molitor* and *Z. morio,* are rich in riboflavin, pantothenic acid, and biotin, while insects like grasshoppers, crickets, locusts, and beetles are also rich in folic acid **(Rumpold & Schlüter 2013).**

Health benefits

Consumption of edible insects provides various beneficial benefits to our body. As reported, one of the most important effects of functional substances in insects is the anti-cancer effect **(Qian et al., 2022).**According to studies done invivo and in vitro, the active ingredients in the insects have inhibited cancers of the liver and stomach **(Hu et al., 2005). (Li et al.,2018)** reported that the silkworm pupae protein hydrolysate could specifically inhibit the proliferation of human gastric cancer cells SGC-7901, induce apoptosis and block the cell cycle in the S phase.

Study on 12 commercial edible insects showed that the water-soluble extracts from grasshoppers, silkworms, and crickets were found to have the highest antioxidant activity, five times that of fresh orange juice, while the fat-soluble extracts from the silkworm, evening cicada, and African caterpillars had the highest antioxidant activity, up to twice that of olive oil **(Di Mattia et al., 2019). (Zhang et al., 2022)** reportedinsect teas are rich in phytochemicals and could be used as a promising source of natural antioxidants involving 33 flavonoids and 14 phenolic acids. **(Kim et al., 2010)**alsoreportedthatpapain peptides isolated from swallowtail butterflies (*Papilio xuthus*) have broad activity against fungal, gram-positive and gram-negative bacteria.

Honey has long been used as a healing remedy for wounds, burns, and ulcers **(Majtan and Majtan 2010).** According to **(Hwang and Hwang 2022**)fermented cricket powder has been found to promote hair growth. (**Narzary and Sarmah, 2015)** reported *Gryllotalpa Africana* is used to treat childhood diseases, and Nephila spiders are used in preparations for folk medicines. The pupae and larvae of Mulberry silkworm (*Bombyx mori*) and Muga silkworm (*A. assama*) is used to treat constant itching and soreness of the throat whereas the pupae and larvae of Eri silkworm (*Samia cynthia ricini*) for curing "dudmur" or infection of mouth and tongue in small children (**Dutta et al., 2016). (Yan et al., 2021)**reported the American cockroach, *Periplaneta Americana* is used for wound healing and antiangiogenesis for cancer, ulcers, and wounds treatment.

Conclusion:

Edible insects represent a promising alternative to traditional animal-based proteins, offering a rich source of essential nutrients such as proteins, fats, vitamins, and minerals. The bioactive compounds in insects, including antibacterial peptides, phenolics, and antioxidants, contribute to their potential health benefits, such as enhancing immunity, reducing cancer risks, and promoting general well-being. Furthermore, insect farming is environmentally sustainable, requiring less land, water, and producing fewer greenhouse gases compared to livestock farming. Given their nutritional value and environmental benefits, edible insects have the potential to play a significant role in addressing the nutritional needs of a growing global population while contributing to a more sustainable food system. Future research should continue to explore the full potential of edible insects in both nutrition and health.

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