Heliyon 10 (2024) e24045

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

Bioactive compounds and biological activity in edible insects: A review

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A R T I C L E I N F O

Keywords:
Edible insects
Biological activities
Nutritional aspects
Anti-nutritional aspects

A B S T R A C T

New strategies to combat hunger are a current and urgent demand. The increase in population has generated a high demand for products and services that affect food production, cultivation areas, and climate. Viable and sustainable alternative sources have been sought to meet food quality requirements. In this context, edible insects are a good source of macro-nutrients, and bioactive compounds confer biological properties that improve their nutritional aspects and benefit human health. This review aims to present the benefits and contributions of edible insects from the point of view of the biological contribution of macronutrients, and bioactive compounds, as well as consider some anti-nutritional aspects reported in edible insects. It was found that insects possess most of the macronutrients necessary for human life and are rich in bioactive compounds commonly found in plants. These bioactive compounds can vary significantly depending on the developmental stage, diet, and species of edible insects. However, they also contain phytochemicals in which anti-nutrients predominate, which can adversely affect humans with allergenic reactions or reduced nutrient viability when consumed in high amounts or for prolonged periods. Hydrocyanide, oxalates, soluble oxalate, and phytate are the most studied anti-nutrients. However, the doses at which they occur are far below the limits in foods. In addition, anti-nutrient levels decrease significantly in processing, such as oven-drying and defatting methods. However, there are few studies, so more trials are needed to avoid generalizing. Therefore, edible insects can be considered complete food.

1. Introduction

Throughout history, humans have fed on different protein sources, including insects. The consumption of these organisms, called entomophagy, not only contributes to diet but also plays a cultural, traditional, religious, and ecological role [1]. FAO has considered the consumption of insects as a viable and sustainable strategy to combat hunger in developing countries and as a high-protein quality food alternative for the increase of population predicted for 2050 [2]. About 2000 of the approximately one million known insect species are edible (also considering their developmental stage), which are an excellent source of protein, amino acids, lipids, minerals, and vitamins [3,4]. The protein content of edible insects ranges from 50 to 70 % DW [3,5]and lipids from 10 to 50 % DW. Additionally,

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https://doi.org/10.1016/j.heliyon.2024.e24045
Received 26 October 2023; Received in revised form 9 December 2023; Accepted 2 January 2024
Available online 5 January 2024
2405-8440/

insect bioactive compounds are also of interest since therapeutic purposes have been documented due to the health-promoting properties of these components [6,7].

Polyphenols are the most abundant and studied bioactive compounds. These compounds are subclassified into phenols, including phenolic acids, coumarins, lignin, and tannins; and flavonoids, which include flavones, chalcones, isoflavones, aurones, anthocyanins, and flavanols [8–11]. Disease prevention by consuming polyphenolic compounds in the diet has been documented in epidemiological studies [12–14]. Polyphenols are natural antioxidants that help decrease oxidative stress generated by free radicals, protecting against heart diseases, cancer, autoimmune diseases, inflammation, and obesity [14–17]. Insects cannot synthesize polyphenolic compounds; however, these organisms can accumulate them during their larval stage through diet [18]. In the specific case of flavonoids, their presence in insects has been related to their chemical defense, mating, intraspecific visual communication, and pigmentation [19–21]. Furthermore, insect proteins are hydrolyzed, forming small peptides of up to 20 amino acids and a weight of no more than 60 kDa, known as biopeptides, linked to beneficial health properties [7]. Dietary fiber, represented mainly by chitin from the insect exoskeleton, also provides an important biological activity [22]. Similarly, vitamins and minerals present in insects benefit human health [5]. Because there have been few reviews on bioactive compounds in edible insects, this review will address the biological activities of bioactive compounds in edible insects, considering also the antinutritional aspects, information not covered in other reviews [23,24]. In addition, this review aims to protect the bioactive compounds of the whole insect and its macronutrient fractions.

2. Search strategy

The qualitative systematic review presents the most relevant articles that matched the characteristics of edible insects that provide biological and antinutrient activity available in electronic resources such as Science Direct, Google Scholar, and PubMed. The strategy to search articles was the words such as bioactive compounds, edible insects, secondary metabolites, antinutrients, biological activity, as well as specific molecules included in the above, for example, proteins, lipids, carbohydrates, minerals, antioxidant molecules, or the main antinutrients studied such as oxalates, phytic acid, cyanogenic glycosides, and saponins. This review focuses on the state of the art of the last five years. Although not excluded, some studies between 2000 and 2018 were very few, especially on the anti-nutritional aspects.

3. Biological activity of nutritional components of edible insects

The use of synthetic substances for human food production is restricted because they have been linked to biochemical processes that damage human health; therefore, the search for natural compounds with beneficial biological activities has increased [25]. Edible insects are a good source of compounds with diverse biological activities, for example, antioxidant activity. In this line, free radicals generated in natural biological processes can induce oxidative stress, affecting lipids, proteins, ribonucleic acid (RNA), and deoxyribonucleic acid (DNA), triggering aging processes and chronic diseases [26]. Several insect species contain high amounts of bioactive compounds that have been found helpful in treating wounds, microbial infections, bleeding, respiratory disorders, rheumatism, cough, cancer, and diarrhea [27–29]. The chemical composition of insects varies depending on developmental stage, diet, habitat, and species [30].

4. Protein

Protein represents the highest percentage of macronutrients in edible insects; therefore, their amino acid profile has been extensively studied regarding functional importance and biological value [31]. In this sense, the protein concentrates and hydrolysates research in these organisms offers diverse applications due to their better solubility, palatability, and digestibility [32]. The variability of amino acids is vast as it depends on the species and stage of development (i.e., larva, egg, adult). For example [33], found that glutamic acid was the predominant amino acid of the 17 identified in *Allomyrina dichotoma*, *Protaetia brevitarsis*, *Tenebrio molitor*, *Teleogryllus emma*, and *Gryllus bimaculatus*. Within these 17 amino acids, eight essential and one conditionally essential were found. Of the essentials, lutein was predominant in the five insects, followed by valine, except for *P. brevitarsis*, where valine was more abundant than leucine. In addition, Chakravorty et al. reported 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) and low concentrations of methionine (0.5 %) [33]. Finally [34], who analyzed the edible insect species in Mexico *Ascra cordifera* and *Brachygastra melifica*, which presented an amount of methionine (sulfur amino acid) of 18–21 mg/g, similar to the recommended for adults (22 mg/g) by Ref. [35].

Another area that has generated interest derived from edible insect protein hydrolysates is the production of bioactive peptides or biopeptides. They participate in peptide-enzyme interactions that alter the enzyme conformation and inhibit the enzyme's metabolic activity [36], a viable and promising mechanism given the potential effects on the reduction of hypertension, inflammation, type 2 diabetes, microbial infections, immune disorders, and oxidative stress [37]. Such biopeptides have demonstrated antimicrobial [38] and antidiabetic properties by inhibiting alpha-glucosidase and dipeptidyl peptidase IV, reducing blood glucose [39,40]. Similarly, inhibition of the angiotensin-converting enzyme and antihypertensive activity has been demonstrated [3]. Moreover, the biological activity (i.e., the amount of protein the organism can utilize is a relevant characteristic of the protein quality. In this sense [5], indicates that some edible insects, such as termites, crickets, grasshoppers, and moths, have a higher biological value and, therefore, higher protein quality than some other ingredients, such as casein; additionally, they also explain that their availability can be affected by the heat treatment to which these amino acids are exposed.

Further, different mechanisms for free radical scavenging and the activation of the endogenous antioxidant enzyme system have been attributed to edible insect biopeptides, contributing to the balance of the oxidative stage [1]. However, a deeper understanding of these biological activities must be addressed and studied further. Examples of more biological activities identified by the proteins of edible insects are mentioned in Table 1.

5. Lipids

Lipids are the second most significant macronutrient fraction in edible insects, where unsaturated fatty acids (UFAs) are in higher percentages than saturated fatty acids (SFAs) [74]. However, this proportion varies according to the species, developmental stage, diet, environmental factors, and whether the insects are wild or cultivated [75]. In this regard [76], reports a high oleic and palmitic acid content in *Tenebrio molitor* and *Acheta domesticus*. In comparison, *Hermetia illucens* is characterized by a high lauric acid content and a medium-SFA [77]. Additionally, the ratio of UFAs to SFAs influences some biological activities, as suggested by Ref. [78], which indicates that a polyunsaturated fatty acid (PUFAs)/SFAs ratio of 0.45 or higher may contribute to cancer prevention and that such composition more closely resembles the characteristics of vegetable oil than those of animal fat [79]. Moreover [80], describes that edible insects contain more PUFAs, suggesting lower cholesterol content. Lipid compounds such as carotenoids, phytosterols, and tocols are related to anti-inflammatory, antioxidant, and hypercholesterolemic properties [79,81]. Finally, insects are also a source of saturated fatty acids omega 6 and 9. Compounds that play a significant role in human health and nutrition, reducing hypertension and autoimmune disorders and helping as anti-inflammatory and in some neurological processes [82]. Examples of more biological activities identified in the lipids of edible insects are mentioned in Table 1.

Table 1
Examples of biological activity of edible insect compounds.

Insect name	Developmental stage	Biological activity	Bioactive compounds	Reference
Tenebrio molitor (Mealworm)		Antioxidant	Phenolic compounds, Tocopherols, Chitosan	[41,42]
	Larvae	Anti-inflammatory	Proteins	[43]
		Antidiabetic	Crude protein, Protein hydrolysates	[44]
		Antihypertensive	Crude protein,	[44,45]
		Anti-obesity	Protein hydrolysates Protein, chitin, UFAs and PUFAs	[46,47]
Hermetia illucens (Soldier fly)		Antioxidant	Protein concentrate, Protein hydrolysates, Oil rich in n-3 HUFA	[48–50]
	Larvae	Anti-inflammatory	Oil rich in n-3 HUFA, Oil	[49,51]
		Antilipidemic	Oil rich in n-3 HUFA	[49]
Musca domestica (House fly)		Antioxidant	Protein hydrolysates Polypeptide Chitosan	[25, 52–54]
	Larvae	Anti-inflammatory	Cecropin-A2 (4301 Da) Serine protease inhibitor MDSPI16	[54,55]
		Antidiabetic	Amino Acids DPP-IV	[56]
		Antihypertensive	Protein isolates	[57]
		Antilipidemic	Protein-enriched extract	[58,59]
Acheta Domesticus (Cricket)	Adult	Antioxidant	Oil, Protein hydrolysate	[46,60,61]
Gryllodes sigillatus (Cricket)		Antioxidant	Peptide fractions Protein hydrolysates	[62–64]
		Anti-inflammatory	Peptide fractions	[63–65]
	Adult	Antidiabetic	Protein isolate Peptide hydrolysates Peptide fractions	[62,65,66]
		Antihypertensive	Protein hydrolysates Peptide fractions	[62,65]
Alphitobius diaperinus (Lesser mealworm)		Antioxidant	Peptide hydrolysates	[67]
	Larvae	Antihypertensive	Peptide hydrolysates	[67]
Tessaratoma papillosa (Stink Bugs)	Nymph and Adult	Antioxidant Anticarcinogenic	Phenolic acid Flavonids Tocopherols Amino acid	[68]
Sphenarium purpurascens (Grasshopper)	Nymph and Adult	Antioxidant Antimicrobial activity	Protein hydrolysates Phenolic compounds Chitin	[69]
Protaetia brevitarsis (White-spotted flower chafer)	Larvae	Antioxidant Anti-apoptosis Anti-inflammatory Antibacterial	Protein extracts Ethanolic, and methanolic extracts Peptide fractions	[70–73]

HUFA, highly unsaturated fatty acids; UFAs, unsaturated fatty acids, and PUFAs polyunsaturated fatty acids.

6. Carbohydrates

Chitin, a polysaccharide considered dietary fiber, forms the cuticle and the supporting exoskeleton, and represents up to 50 % of carbohydrates in insects [3]. This compound stimulates the immune system [83], provides protection against possible parasitic and allergic infections [84], modulates the intestinal microbiota [85,86], and has antimicrobial, antioxidant, antifungal, and anti-inflammatory properties [26,87]. Although this compound is considered a source of fiber for humans, its elimination improves protein digestibility [88]. Additionally, it is known that in some cases, chitin triggers tissue inflammation by activating the expression of host chitinases, generating an allergic reaction in people susceptible to this compound [89]. There is no description of other types of carbohydrates in edible insects [90]. In addition, a recent study shows how chitin has fat-binding capacity in insects such as *Gryllus bimaculatus* and *Acheta domesticus*, showing higher values in fat absorption capacity [91].

7. Minerals, vitamins, and bioactive compounds

Edible insects are also a source of minerals (e.g., copper, iron, magnesium, manganese, phosphorus, selenium, and zinc), vitamins (e.g., riboflavin, pantothenic acid, biotin, and folic acid), and other bioactive compounds [92,93] that are generally obtained from plants (e.g., phenolic compounds, terpenoids, steroids, glycosides, organic acids, carotenoids, and sulfur compounds) (Table 2) [26,94]. These micronutrients can vary in concentration and presence from species to species, growth conditions, diet, and developmental stage [95,96]. Insects contain more calcium and iron than beef, chicken, or pork. However, more research is required to describe the most predominant minerals in insects, whose proportion varies depending on the species, insect feed, and place of origin [3,97]. Studies on the content of vitamins in insects are scarce. Still, some studies have demonstrated they contain carotene, vitamins B1, B2, B6, C, D, E, and K. Species such as Orthoptera and Coleoptera contain folic acid, but further studies are needed [6,98].

8. Anti-nutrients

The composition of edible insects is diverse. This diversity includes substances or phytochemicals that protect insects against predators, contribute to mate attraction during the reproductive process and help them hunt and feed [6]. However, some of these phytochemicals are called anti-nutrients as they negatively affect humans, such as allergenic reactions and reduced nutrient viability

Table 2
Examples of minerals, vitamins, and bioactive compounds identified in edible insects.

Insect name	Developmental stage	Identified Compounds	Reference
Patanga succincta L. (Bombay locust)	Adult	[a]Potassium (349.80), Phosphorus (266.90), Calcium (65.60), Magnesium (39.40), Sodium (515.90).	[99]
Bombyx mori (Silkworm)	Adult	[a]Potassium (492.90), Phosphorus (392.20), Sodium (128.40), Magnesium (157.70), Calcium (92.20).	[99]
Acheta domesticus (Cricket)	Adult	[a]Sodium (998.50), Potassium (457.70), Phosphorus (424.30), Calcium (88.70), Magnesium (63.80).	[99]
Oryctes rhinoceros (Rhinoceros beetle)	Larvae	[a]Calcium (368.0), Sodium (931.50), Iron (1.20), Magnesium (145.2), Vit B1 (5.90), B12 (70.43), B2 (27.19), Vit E (24.09), Vit K (7.43).	[100]
Brachystola magna (Grasshopper)	Egg	[a]Vit C (19.860), Vit E (21.93), Vit D (2.710), B6 (0.430), B3 (0.540), B1 (0.075), B9 (0.020), Vit A (0.150).	[101]
Brachystola magna (Grasshopper)	Adult	[a]Vit C (34.55), Vit E (145.36), Vit D (5.25), B6 (0.580), B3 (0.670), B1 (0.090), B9 (0.023), Vit A (0.390).	[101]
Liometupum apiculatum (Escamoles ant)	Egg	[a]Vit E (2.22), Vit D (0.0036).	[102]
Acheta domesticus (Cricket)	Adult	[a]Vit E (33.13).	[103]
Ruspolia differens (Grasshopper)	Adult	[a]Vit B3 (3.01–3.22), B2 (0.84–0.96), Folic acid (0.34–0.35), Vit A (0.106–0.221).	[104]
Chlosyne lacinia (Patch butterfly)	Larvae	[b]Isorhamnetin 3-O-hexaside, Hispidulin 4′-O-hexoside, Hispidulin (Flavonoid).	[105]
Bombyx mori L (Silkworm)	Cocoons	[b]Quercetin, Isoquercetin, Quercetin 3-O-rutinoside, Kaempferol, Alcaloids, Terpenes and Lignans.	[106]
Antheraea pernyi (Chinese oak silkworm)	Larvae	[b] Flavones, Flavonols, Flavonoids, Flavanones, Polyphenols, Isoflavones, Anthocyanins, Proanthocyanidins.	[19]
Pieris brassicae (Large white butterfly)	Larvae and adults	[b]Flavonols: Kaempferol-3-O-sophoroside-7-O-glucoside, Kaempferol-3-O-sophoriside; phenolic acids: ferulic acid and sinapinic acid.	[107,108]
Rondatia menciana (Mulberry white caterpillar)	Cocoon	[b]Quercetin 3-O-galactosyl-galactoside, Kuercetin-3-O-galactoside, Kaempferol 3-O-galactosyl-galactoside, Kaempferol 3-O-galactoside, Quercetin 3-O-β-D-galactopyranosyl-(1 → 3)-β-D-galactopyranoside, Kaempferol 3-O-β-D-galactopyranosyl-(1 → 3)-β-D-galactopyranoside (Flavonols).	[109]
Holotrichia parallela (Large black chafer)	Adults	[b]Gallic acid, Protocatechuic acid, Catechin, Epicatechin, Protocatechualdehyde, 4-hydroxyacetophenone, Ferulic acid, Resveratrol, Quercetin.	[110]

[a] Essential mineral and vitamin content per 100g of insect samples (mg/100g).
[b] Bioactive compounds identified in edible insects.

when consumed in high quantities or for long periods [5]. Table 3 shows some anti-nutrients in edible insects and their effects on humans.

The main anti-nutrient compounds detected in edible insects are oxalates, phytic acid, cyanogenic glycosides, and saponins. These anti-nutrients have been linked to the chelation of minerals and proteins, decreasing their absorption and lowering availability. Samuel and Humtap [117] propose that anti-nutrients bind to digestive enzymes, creating a blockage in feed degradation and preventing absorption [113]. Oxalates chelate calcium and magnesium that are released in the digestive system, decreasing, or preventing their absorption. The low availability of calcium affects bone formation, hormonal and enzymatic functions, and osmotic and nerve impulse mechanisms [100]. Additionally, prolonged ingestion of oxalates can induce kidney stone formation, as they are filtered through this organ for excretion [118]. The presence of phytic acid decreases the absorption of calcium, iron, magnesium, and zinc, minerals linked to various processes such as growth, reproduction, mental capacity, blood oxygenation, and proper functioning of the cardiac system. Cyanogenic glycosides (HCN) disrupt the transfer of electrons to oxygen molecules by combining with the catalytic ion of the enzyme cytochrome oxidase, inducing the inhibition of cellular oxidation [119]. Finally, saponins can eventually generate complexes with zinc and iron, decreasing their availability [120]. On the other hand, the study by Gachini et al. shows that anti-nutrient levels decreased significantly on processing such as oven and sun drying or defatted sun-dried and defatting oven drying methods by 2%–70 %, with oxalates and phytates having decreased in the edible insects [116].

9. Conclusion

Insect biomass has recently increased interest in using fractions, e.g., protein, lipid, and chitin, as food and feed ingredients. These fractions could be a suitable alternative to industrial applications because they are an essential source of macronutrients, micronutrients, and bioactive compounds that provide them with biological properties that positively impact human health; however, they

Table 3
Anti-nutrients in edible insects.

Insects Name	Developmental stage	Anti-nutrient	Effect	Reference
Anaphe spp. (African silk)	Pupae	Heat resistant thiaminase	Seasonal ataxic syndrome	[111]
Gymnogryllus lucens (Cricket)	Adult	Hydrocyanide (2.187 mg/kg) Oxalates (13.20 mg/kg) Soluble Oxalate (8.80 mg/kg) Phytate (0.283 mg/kg) Tannin (0.329 mg/kg)	HCN Limit the availability of some minerals	[112]
Heteroligus meles (Yam beetle)	Adult	Hydrocyanide (2.734 mg/kg) Oxalates (28.40 mg/kg) Soluble Oxalate (22.0 mg/kg) Phytate (0.28 mg/kg) Tannin (0.379 mg/kg)	HCN Limit the availability of some minerals	[112]
Henicus whellani		Oxalates (9.3 g/100 g), Alkaloids (52.3 g/100 g) and saponins (53.3 g/100 g)	Limit the availability of some minerals and proteins	[113]
Macotermes facilger (Termite)	Adult	Oxalates (14.08 g/100 g), Saponins (57.0 g/100 g)	Limit the availability of some minerals and proteins	[113]
Rhynchophorus Phoenicis (Palm weevil)	Adult	Hydrocyanide (2.422 mg/kg) Oxalates (17.60 mg/kg) Soluble Oxalate (13.2 mg/kg) Phytate (0.289 mg/kg) Tannin (0.405 mg/kg)	HCN Limit the availability of some minerals	[112]
Zonocerus variegatus (Grass-hopper)	Adult	Hydrocyanide (3.202 mg/kg) Oxalates (26.40 mg/kg) Soluble Oxalate (8.80 mg/kg) Phytate (0.281 mg/kg) Tannin (0.430 mg/kg)	HCN Limit the availability of some minerals.	[112]
Cirina forda (Westwood)	Larvae	Oxalates (4.11 mg/100g) Phytic acid (1.02 mg/100g)	Limit the availability of some minerals	[114]
Oecophylla smaragdina (Ant)	Adult	Phytic acid (171.0 mg/100g) Tannin (496.67 mg/100g)	limits the availability of some minerals and reduce the absorption of proteins	[115]
Odontotermes sp. (Termite)	Adult	Phytic acid (141.23 mg/100g) Tannin (615.0 mg/100g)	limits the availability of some minerals and reduce the absorption of proteins	[115]
Ruspolia differens (Grasshopper)	Adult	Oxalates (14.03 mg/100g) Phytates (0.41 mg/100g) Tannins (0.93 mg/100g)	Limit the availability of some minerals and proteins	[116]
Nasutitermes spp. (Winged termites)	Adult	Oxalates (7.88 mg/100g) Phytates (0.67 mg/100g) Tannins (1.69 mg/100g)	Limit the availability of some minerals and proteins	[116]

HCN: High hydrocyanide levels have been implicated in cerebral damage and lethargy in humans and animals. A lethal dose of HCN is 35 mg. Permissible levels of Oxalate in the human body are 250 mg/100g; a maximum concentration range of 250–500 mg/100 g of phytic acid, and 150–200 mg/100g of tannins in food samples.

also have anti-nutritional compounds with adverse effects. Studies reported in this review found that the antinutrients of the edible insects found are within the permitted limits at non-toxic levels, so they cannot threaten their use as food sources in humans. However, there are few studies, so more trials are needed to avoid generalizing. On the other hand, edible insects provide various bioactive compounds such as amino acids, fatty acids, vitamins, minerals, and antioxidant compounds, which have outstanding biological activity as anti-inflammatory, antidiabetic, antihypertensive, antilipidemic, to mention a few. The results reviewed in this work justify that edible insects are a potential, complete, and safe product for human consumption with biological activity. They are not discarded as a natural alternative for treating various chronic diseases and thus contribute to the benefit of human health. In addition, Insects are a viable and feasible strategy to combat hunger and thus contribute to the goal set by the United Nations in the 2030 Agenda for Sustainable Development.

Author contributions

Ana Angelica Feregrino-Perez: Writing – review & editing, Project administration, Conceptualization. Humberto Aguirre-Becerra: Supervision, Investigation. María de la Luz Sánchez-Estrada: Writing – original draft, Investigation, Formal analysis

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors want to thank the Consejo Nacional de Humanidades, Ciencias y Tecnologías (CONAHCyT) of México for its scholarship support and the Engineering Faculty for their support FIN 202107 and FOPER-2022-FIN02840.

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