Insects as a Sustainable Alternative Source of Animal Proteins in Human Nutrition: Pros and Cons

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Abstract
Considering that the world's population is constantly increasing, there is a growing need to find sustainable alternative sources of animal proteins. In order to expand knowledge in this area and determine the direction of future research, the aim of this review was to provide information based on the currently available scientific literature on the edible insects as a potential sustainable source of animal proteins, both in terms of consumer acceptance, chemical composition, nutritional value, food safety, current legislation, welfare conditions and impact on the environment and ecosystem.
Edible insects and their products are nutritionally valuable and healthy foods (high content of protein, essential fatty acids, fats and polyunsaturated fatty acids, vitamins and minerals) that have a number of beneficial properties for the human organism compared to conventional meat types. Insects do not differ from conventional meat types in terms of microbiological safety and spoilage. Potential consumer health hazards associated with the consumption of edible insects and their products include allergic reactions, pathogenic microorganisms (*Staphylococcus aureus*, *Clostridium* spp., *Bacilus cereus*, *Vibrio* spp. and *Streptococcus* spp.), viruses, parasites (*Dicrocelium dendriticum*, *Entamoeba hystolitica*, *Giardia lamblia* and *Toxoplasm*a spp.), pesticide residues and toxic elements (cadmium, mercury, arsenic and lead). Compared to conventional rearing of farm animals, insect farming has a significantly lower impact on the environment (lower emission of greenhouse gases and ammonia, drastically smaller areas of land for rearing, smaller amounts of water, and easier, cheaper and simpler nutrition). However, there is no adequate legislation regarding insect welfare and safety and quality of edible insects and their products.
Based on the available scientific literature, it can be concluded that edible insects have a great potential as a sustainable source of animal proteins.

Keywords: edible insects, environment, food safety, legislation, nutritive value, welfare

1. Introduction

Considering that world's population is constantly increasing, there is a growing need to find sustainable alternative sources of animal proteins. According to United Nations Department of Economic and Social Affairs world's population will reach 8,2 – 10,5 billion people in 2050 [1]. These projections are very troublesome for food producers and meat industry due to land and soil being more and more limited for farming purposes [1]. In order to achieve maximum production and minimum use of water, soil and other resources, sustainable alternatives to conventional farming practices are being looked into [1].

Very promising sustainable alternative source of animal proteins are edible insects. From 1.4 million species of animals on Earth, one million are insects [2]. *Coleoptera* is the most consumed order of insects on a global level with 31% of total insects consumption. *Lepidoptera* order also takes important part in global insect consumption with 18% [2]. The most important representative of *Coleoptera* order is dung beetle (*Catharsius*

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molossus) [2]. Black soldier fly (*Hermetia illucens*), blue bottle fly (*Calliphora vomitoria*) and house cricket (*Acheta domesticus*) are also consumed globally and are of paramount importance in everyday entomophagy practice [2].
It is estimated that about two billion people worldwide consume insects, while people living in tropical regions regularly consume insects [3]. Insect consumption (entomophagy) is common practice in Africa, Asia, Oceania and Latin America. In recent years, this trend can also be observed in European Union (EU) countries [2]. According to many authors [2, 4-7], edible insects and their products, are nutritionally valuable and healthy foods (high content of proteins, essential fatty acids, fats and polyunsaturated fatty acids, vitamins and minerals) that have a number of beneficial properties for the human organism compared to conventional meat types and, therefore, their consumption is strongly recommended. Nevertheless, consumption of insects requires careful consideration of their sustainability across various dimensions, including environmental sustainability, sustainability of sources, and sustainability of consumption [8]. Compared to conventional rearing of farm animals, insect farming has several advantages as a potential sustainable alternative source of animal proteins: (i) lower emission of greenhouse gases and ammonia, (ii) drastically smaller amounts of land for farming, (iii) small quantities of water used to produce them, and (iv) easier, cheaper and simpler nutrition (efficient feed conversion, and ample food availability) [2, 4–7].
Assessing the lifecycle of farmed insects for obtaining food and feed is crucial for ensuring sustainability [4]. Opting for appropriate insect farming methods not only benefits the environment but also promotes sustainable production [9]. Utilising standardised lifecycle assessment techniques [10,11], the production and processing of farmed insects can be categorised into three main phases: (i) sourcing raw materials; (ii) pretreating harvested insects (including harvesting, sterilisation, drying, defatting and grinding); and (iii) additional food processing [9]. Despite ongoing challenges in industrialising the sustainable production of edible insects, extensive research and the widespread adoption of insect farming and consumption on a global scale suggest their potential for further sustainability and production expansion [12].
Four main factors that influence the pace of growth of edible insect industry are (i) legislation, (ii) marketing, (iii) research and development; and (iv) capital inflow [13]. Legislation will not be an obstacle for achieving large scale production for much longer [13]. Approval of new feedstock and end markets plays vital role for grow of edible insect industry [13]. Marketing plays very important role for edible insect industry because consumer acceptance and promotion of existing insect-based products are crucial for expanding market [13]. In addition, further research studies and development are important factors given that development of new insect-based products is also of great importance for the expansion of edible insect industry [13]. However, capital inflow towards edible insect industry is most influential factor, since all other factors are closely tied to funding and number of investments coming to this sector [13]. Hence, solving the gaps on before-mentioned factors would determine the growth speed of the edible insect industry, which would, in turn, and make possible to reach sustainable large-scale production [13].
Therefore, to expand knowledge in this area and determine the direction of future research, the aim of this review was to provide information based on the currently available scientific literature on the edible insects as an alternative source of animal proteins, in terms of consumer acceptance, chemical composition and nutritional value, biological functions, food safety, current legislation, welfare conditions and impact on the environment and ecosystem.

2. Consumer acceptance of insects as a food

In the past few years, the focus of private food sector is on edible insects as novelty food [7]. In the same manner, scientific community is being more interested in edible insects as a potential sustainable alternative food source [7]. This has caused significant growth of edible insect market and numerous entrepreneurs and companies have become active in their production [7].
However, everything depends on overall acceptability of insects as food by the consumers [14]. The consumer acceptance is one of the largest barriers to adopting insects as food in Western countries which are characterised by a strong socio-culturally defined public bias towards

insects and clearly established neophobia towards insect as a food [14]. Despite the fact that, nowadays, edible insects and their products are available in grocery shops and restaurants in some European countries, consumers often do not want to consume them due to fear of disease and social and cultural norms [14]. Most important impact on consumer acceptability of insects as food lies within information about taste, nutritional value, environmental impact and health benefits [14].

In the study recently conducted in Serbia regarding the consumer acceptability of insects as food, women show more willingness to consume and higher acceptability of insects as food than men [14]. According to this research, 85.3% of respondents were familiar with entomophagy either by media or internet. However, only 12.5% of respondents consumed edible insects and/or their products [14]. Respondents also stated that their willingness to try and consume insects is mostly based on visualisation of insects in the food they are going to consume [14]. Almost half of respondents (49.4%) indicated that they would consume food products in which edible insects are unrecognizable incorporated [14]. Furthermore, 45.6% of respondents answered that they would buy insect-based products if their price would be the similar as for other conventional meat products [14]. According to respondents, the main reasons for consumption of edible insects are some kind of crises, curiosity and high nutritional value [14]. On the other hand, main reasons for not consuming and buying insect-based products are disgust and concerns regarding health [14].

3. Chemical composition and nutritional characteristics of edible insects

Chemical composition and nutritional characteristics are very variable and mostly depend on developmental stage of insects, insects' diets during farming and processing methods of food products obtained from edible insects [2].

The nutritional value of insects is extremely high, and the main nutrients include proteins, oils, vitamins, minerals and sugars, all of which are essential for human growth and development [4]. In comparison with conventional meat types, insects have higher energy, protein, fat, polyunsaturated fatty acids and cholesterol as well as higher content and variety of micronutrients [4].

Edible insects have more diverse nutritional composition than conventional meat, which makes them healthier food [4]. In case of malnutrition, edible insects can be great source of supplementary nutrients, while for overnourished and overweighed persons consumption of edible insects can make condition worse and, thus, are not recommended [4].

Protein content largely depends on the order of edible insects [4]. Amount of protein, amino acid and micronutrients in edible insects is sufficient to satisfy dietary needs of humans [4]. The average protein content by order of edible insects is shown in Table 1.

Table 1. Average protein content by order of edible insects [4]

Order of Insects	Protein content
Blattodea	68.33%
Coleoptera	41.75%
Diptera	48.88%
Hemipera	48.83%
Hymenoptera	51.43%
Lepidoptera	65.25%
Orthoptera	59.17%

Edible insects are also important source of fats. They have very high content of polyunsaturated fatty acids [2]. For example, african palm weevil (*Rhynhcophrus phoenicis*) had a fat content of 54% with 38% palmitoleic acid (monounsaturated fatty acids) and 45% linoleic acid (polyunsaturated fatty acids) [2]. Hence, in countries with low per capita fish consumption, edible insects may be a great alternative source of polyunsaturated fatty acids in human diet [2].

Furthermore, insects are important replacement for cereals due to amino acid composition and content [2]. Amino acids such as lysine, tryptophan and threonine are present in high amount in some species of edible insects. For example, caterpillars have more than 100 mg of amino acid per 100 g of proteins [2]. The approximate amino acid composition for certain edible insect species is shown in Table 2. Content of vitamins and minerals in edible insects is very variable and largely depend on insect order and species [4]. Edible insects are good source of vitamins such as riboflavin, pantothenic acid, niacin, pyridoxine and biotin [4].

Table 2. The approximate amino acid composition for certain edible insect species [5]

Amino acid	*H. illucens*	*C. vomitoria*	*A. domesticus*
Lysine	3.88	5.83	5.78
Valine	3.19	2.64	2.52
Methionine	26.26	7.83	7.83
Tyrosine	9.69	9.69	9.72
Isoleucine	19.01	19.01	19.23
Leucine	24.01	22.03	22.03
Arginine	5.61	6.16	6.12
Glutamine	6.04	5.06	4.99
Serine	3.53	3.87	3.78

** g/100 g crude protein*

Mealworm larvae (*Tenebrio molitor*) and house cricket have high content of vitamin B_{12}. However, the most edible insects have very low levels of vitamin B_{12} [2]. Majority of edible insects species have higher content of iron than beef. For instance, locusts (*Acrididae spp.)* (8-20 mg/100 g) and mopane caterpillar (*Gonimbrasia belina*) (31-77 mg/100 g) have much higher iron content compared to beef (6 mg/100 g) [2]. Also, edible insects are good sources of zinc. Palm weevil (*Rhynchophorus ferrugineus*) larvae (26.5 mg/100 g dry weight) has higher zinc content than beef (12.5 g/100 g dry weight) [2].

4. Biological functions of active compounds of edible insects

Active compounds found in edible insects have numerous functional effects that can be beneficial to human health [4]. In general, biological functions of insect active compunds can be divided as follows: (i) antibacterial, (ii) anti-inflammatory, (iii) antiviral, (iv) antioxidative, (v) immunomodulatory, (vi) anticancer, (vii) blood glucose and lipid regulation, (viii) regulation of intestinal flora, (ix) hypotensive, (x) hepatoprotective, (xi) anti-atherosclerotic, (xii) anti-angiogenesis, (xiii) anti-apoptotic and (xiv) anti-allergy [4]. Furthermore, active compounds found in edible insects have the therapeutic effects on several common human diseases including Alzheimer's disease, Parkinson's disease, gastric ulcers, human immunodeficiency virus (HIV), atherosclerosis, liver diseases and external trauma (wounds, burns and ulcers) [4].

Insects have a vast number of substances with antibacterial activity including oil, peptides, chitin and chitosan [4]. Most important compounds are antibacterial peptides, which are thermostable, have no drug sensitivity nor effect on eukaryotic cells [15]. Peptides purified from the plasma of silkworm (*Bombyx mori*) larvae have shown a strong inhibitory effect against Gram-negative bacteria [16].

For instance, chitin and chitosan from silkworms have exhibited antibacterial effects *in vitro* towards *Bacillus cereus, Staphylococcus aureus, Escherichia coli* and *Klebsiella pneumonia* [17]. The antimicrobial activity, advantages and benefits of active compounds found in edible insects are shown in Figure 1.

Compounds with anti-inflammatory effects found in insects are usually protein-based [4]. The peptides from mealworm larvae, desert locust (*Schistocerca gregaria*) and tropical house cricket (*Gryllodes sigillatus*) have shown inhibitory effects on activity of lipoxygenase (LOX) and cyclooxygenase-2 (COX-2) [18]. *In vivo* studies have also proven that sugars and peptides from edible insects have anti-inflammatory effects [4]. Protein enriched fraction/extracts from housefly (*Musca domestica*) have shown anti-inflammatory effects in male inbred mice [19], whereas glycosaminoglycan from southern field cricket (*Gryllus bimaculatus*) exhibited anti-inflammatory effects during *in vivo* testing on chronic arthritic rat model [20].

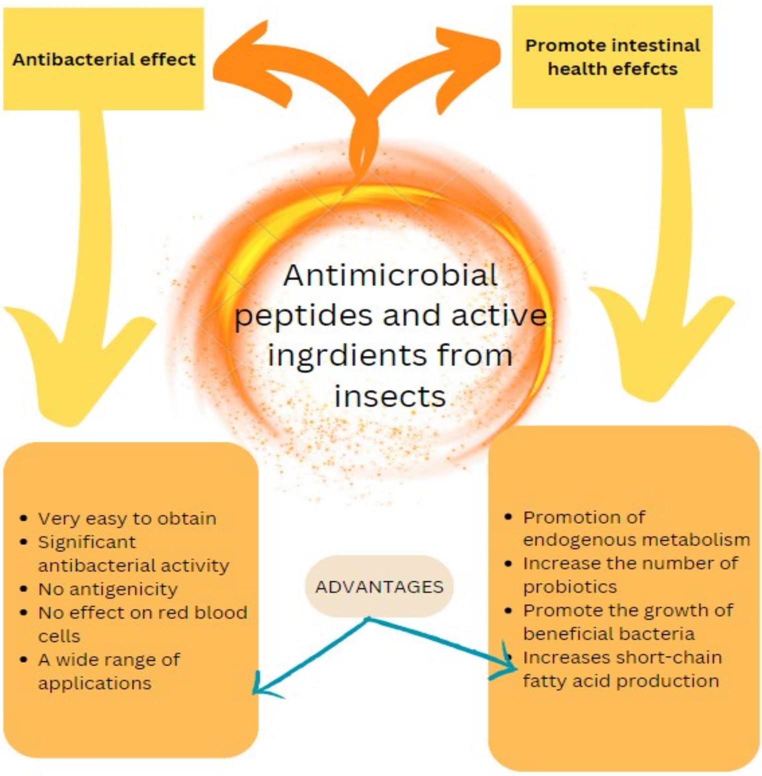

Figure 1. Antimicrobial activity and advantages of active substances found in edible insects [4]

Compound with pronounced antiviral effect is alloferon found in blue blowfly (*Calliphora vicina*) [4]. This active compound stimulates natural killer cells which also causes production of interferons [21]. This has been confirmed *in vivo* on the model of mice with lethal pulmonary infection with human influenza viruses A and B [21].

Antioxidative effect is also found in many functional compounds of edible insects [4]. Polyphenols from silkworms have strong capacity for scavenging reactive oxygen species (ROS) [22]. Protein hydrolysates from silkworms exhibit strong reduction effect on ROS [4]. In addition, water-soluble chitosan from soybean hawkmoth (*Clanis bilineata*) boost activity of superoxide dismutase demonstrating strong scavenging ability against superoxide anions [4].

The strongest immunomodulatory effects are exhibited by bee venom found in honeybees (*Apis melifera*) and by polysaccharides and peptides found in silkworms [4]. Active peptides from edible insects stimulate expression of immune-related factors [4]. Likewise, bee venom induces primary type 2 response and confers protective immunity [23]. Moreover, immunomodulatory activity of bee venom is confirmed *in vivo* on BALB/c and C57BL/6 mice [23].

Anticancer effect is one of the most important effects of active compounds found in edible insects [4]. Active proteins, active peptides, vitamins and chitosan from edible insects exhibit anti-cancer functions and activities [4]. Among many active compounds with anti-cancer effect, protein-based substances are dominant [4]. The silkworm pupae proteins have a strong anti-cancer effect [24]. It has been proven that selenium-rich amino acid from silkworm pupae could inhibit cancerous cell proliferation of human hepatoma [25]. Also, oils from mealworm larvae exhibit anti-cancer effect specifically against human hepatocellular carcinoma [26]. Anticancer effect of glycosaminoglycan from dung beetle (*Catharsius molossus*) has been confirmed *in vivo* on melanoma mice induced by B16F10 cells [27]. Likewise, bee venom has shown anticancer effects *in vitro* on human lung cancer cell lines A549 and NCI-H460 [28]. Also, 72-kDa anticancer protein (EPS72) from Chinese medicinal cockroach (*Eupolyphaga sinensis*) exhibited anticancer effects *in vitro* on human lung cancer A549 cell line [29].

Blood glucose and lipids are very important health indicators [4]. High or low levels of blood glucose and/or lipids can directly affect metabolism, and cause development of various diseases such as diabetes and/or obesity [30]. For example, ethanol extract from mealworm larvae reduce lipid accumulation and triglyceride levels in mature adipocytes [31]. Additionaly, oil from silkworms increased fat metabolism during *in vivo* testing on Sprague–Dawley rats which decreased blood lipid levels [32].

Hypotensive effect of hydrolysates from silkworm larvae has been confirmed *in vivo* in rats [4]. It has also been confirmed that protein hydrolysates from silkworms have inhibiting effects on angiotensin I-converting enzyme [33].

Anti-HIV effect of bee venom has been proven *in vitro* [34]. HIV infected cells that absorb bee venom exhibited decreased HIV gene expression and replication [34].

Treatment of Parkinson's disease by bee venom has been tested *in vivo* on mouse models [4]. Furthermore, bee venom offers long lasting protection in laboratory animal models with chronic degenerative process of Parkinson's disease [4].

Alcohol detoxification effects of extracts from silkworms are confirmed *in vivo* on ICR mice [35], whereas silkworm pupae vaccine has shown anti-Alzheimer's disease effect in mice by enhancing memory and cognitive functions [4]. Additionally, oil extracts from silkworms have exhibited hepatoprotective effects by reducing acute liver damage caused by oxidative stress [4].

Fermented cricket powder promotes hair growth by controlling the expression of growth factors, which is confirmed *in vivo* on male C57BL/6 mice [36].

Oil from silkworm pupae can be used for treatment of gastric ulcers by shrinking the alterations and lessens the inflammatory response [37]. This is confirmed *in vivo* on hydrochloric acid/ethanol induced gastric ulcers in Kunming mice model [37].

Despite the fact that insects have a numerious active coumpunds that can affect human health positively, describing the therapeutic advantages and mechanisms of edible insects, along with their active constituents, requires greater elaboration. Additionally, conducting experiments on humans to investigate if the diverse functional effects of these insects have similar impacts is essential [4].

5. Edible insects as ingredients in food products

Considering their high nutritional value, the edible insect industry is gradually growing and coming into people's lives, and, thus, they can be found in many different types of food products, such as pastas, snacks, bakery products, fermented foods and meat products [4]. Applications of edible insects in different foods are shown in Figure 2.

The addition of grasshopper flour (200 g/kg) and defatted grasshopper flour to bread positively affects its rheological properties (better texture) and nutritional value (increased protein content up to 60%) [38]. Likewise, the inclusion of 10% cricket powder to wheat flour increases bread nutritional characteristics (high protein content and amino acid and fatty acid profile) and consumer acceptability [39], while adding cricket flour in the gluten-free bread positively influence product technological properties, nutritional value and antioxidant activity [40, 41]. Further, the addition of silkworm flour to soba noodles increases protein content, reduces preparation time and, the most important, conceals undesirable taste of soba [42].

Similar to bakery and pasta products, the inclusion of edible insects' flour to meat products can be beneficial for their physicochemical properties and nutritional value [4]. Incorporating edible silkworm pupae into beef batter can enhance its physicochemical properties, such as pH, viscosity, hardness and chewiness [43]. Additionally, the inclusion of cricket powder in emulsified meat products can increase the content of protein and minerals within the emulsion [44]. Both mealworm larvae and silkworm pupae can be used as valuable protein sources in emulsified sausages [45]. Moreover, edible insects are increasingly being used in a range of snack foods, such as biscuits, chocolates, tortilla chips, etc. where they affect the texture (crispness) and chemical composition of the products [46, 47]. Adding edible insects to fermented foods can result in products with increased nutritional value, along with antibacterial and medicinal properties. [4, 48].

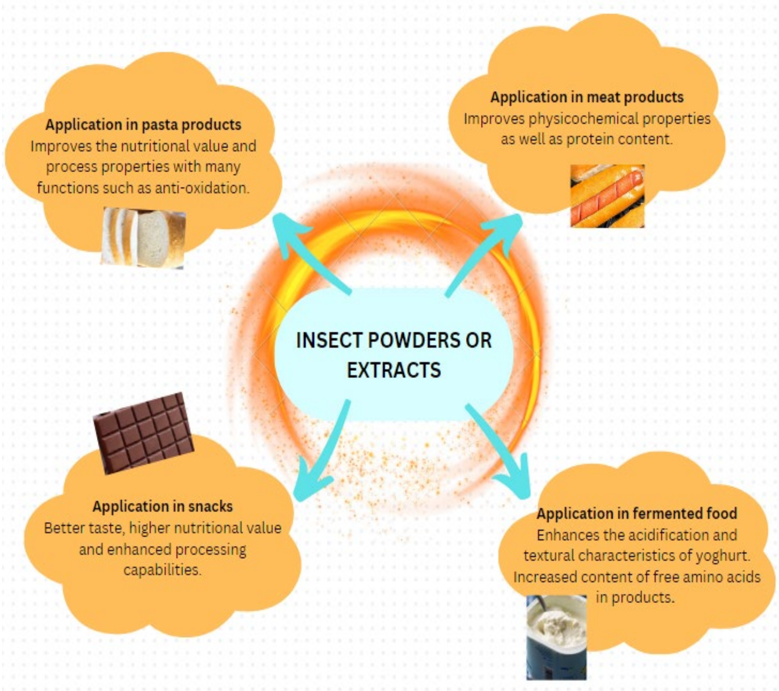

Figure 2. Application of edible insects in food products [4]

Fermented products of edible insects can be used to produce a number of food products including pastas, meals, sauces and powders [48]. For example, the incorporation of silkworm pupae peptides in fermented dairy products improved yogurt textural and physicochemical traits [49], whereas the addition of yellow mealworm larvae in fermentation of soya sauce significantly increased amount of free amino acids and their derivates, such as glutamic acids, alanine, aspartic acid, serine, isoleucine, lysine, phenylalanine and valine [50].

6. Food safety and edible insects

The expanding market for edible insects presents a significant challenge regarding their quality and safety control [4]. Potential safety concerns related to edible insects encompass (i) allergic reactions, (ii) pathogenic microorganisms, (iii) pesticide residues, (iv) heavy metals, (v) parasites and (vi) toxins [3, 4].

Recently, European Food Safety Authority (EFSA) has published first study regarding edible insects as food for humans and animals [7]. It addressed considerations regarding potential allergenic and environmental risks, along with chemical and biological hazards associated with external factors such as production methods, feeding substrates, and the stage of the lifecycle at which they are harvested [7]. EFSA made decision to ban feeding substrates for farmed insects that contain manure due to risk of residues and parasites [7]. Accordingly, this implies that edible insects can only be safely raised on plant-based feeding substrates or specific permitted animal-origin materials, thereby excluding the use of substrates containing manure and other waste materials [7].

Allergic reactions are the most important safety issues for insect consumers [4]. Based on the statistics of World Health Organization, 239 potential allergens were detected in arthropods [4]. Most allergens from edible insects are proteins such as hyaluronidase, microtubulin, phospholipase A, arginine kinase and protomyosin [4]. The main symptoms of insect allergies are breathing difficulties, asthma, itching, redness, digestive disorders, tachycardia, hives and, in severe cases, fainting [4]. Some research studies suggest that insect consumption can trigger allergic reactions similar to those observed with seafood [4]. However, it is reassuring that allergens in edible insects can be mitigated using various methods to reduce their allergenicity, including heat treatment, fermentation and hydrolysis [51, 52].

Despite the fact that most of microorganisms that are specific to edible insects may not pose direct safety concerns for humans, they can still transmit diseases that are potentially harmful [4]. Viruses can be important safety issues for consumers with over 70 viruses detected in edible insects, 36 of which can cause infections in humans (including novel zoonotic coronavirus SARS) [3, 53]. Additionally, edible insects harbor numerous pathogenic bacteria that can impact human health, whereby the most important are *Staphylococcus aureus, Clostridium* spp.*, Bacillus cereus, Vibrio* spp. and *Streptococcus* spp. [3, 4]. *Vibrio, Streptococcus, Staphylococcus* and *Clostridium* were detected in edible insects in EU [4].

Pesticide residues do not pose a potential threat to safety of farmed edible insect. Contrairily, wild-caught insects are not managed by humans, so they are more likely to consume food previously threated by pesticides, resulting in the accumulation of residues in the edible parts [4].

The accumulation of pesticide residues was reported in yellow mealworms, a common human food source [54, 55]. Hence, it can be argued that safely farmed edible insects under controlled conditions can mitigate the risk of pesticide residues to human health.

Heavy metal accumulation in edible insects is another potential safety concern, particularly for wild-caught insects [4]. In contrast, the safety risks associated with heavy metals in farmed insects is significantly reduced. Cadmium, lead, arsenic and mercury are among the most commonly reported heavy metals in edible insects [56].

The concentrations of heavy metals found in edible insects are influenced by factors such as the species, developmental stage, environment and food source [57, 58]. Heavy metals in edible insects stem from both natural habitat environments and human pollution [4]. It has been reported increased lead concentration in local grasshoppers in Mexico, as they forage in heavily contaminated mining areas [59]. Other significant chemical hazards in edible insects include dioxins, residues of veterinary drugs, polychlorinated biphenyls, mycotoxins, plant toxins and polyaromatic hydrocarbons, all of which can pose important safety risks [3]. Despite the fact that insects can metabolise veterinary drugs, there are no information regarding their residues in the edible parts [3].

The presence of parasites in edible insects is another important safety issue [4]. Certain parasites found in edible insects, such as *Dicrocoelium dendriticum*, *Entamoeba histolytica*, *Giardia lamblia* and *Toxoplasma* spp., can also pose risks to human health upon consumption [60]. Furthermore, certain harmful toxins and antinutrients present in insects can also pose a safety risk to human health [61, 62].

The overview of most important safety risks in edible insects are summarised in Figure 3.

The main inquiry regarding animal welfare when insects are farmed arising from their status as "sentient beings" that can feel pain, fear and other emotions [3]. Ethical considerations emerge concerning whether they are merely commodities for human utility or whether humans should regard them as co-animals [3].

7. Animal welfare and edible insects

In spite of the fact that transition to a plant-based diet inevitably involves the killing of billions of insects [63], some authors argue against consuming insects due to the vast numbers of harvested individuals involved (e.g., one pig compared to thousands of crickets) [64]. In addition, part of scientific community claims that insect’s nervous system is not developed enough to be able to feel emotions like fear, while others claim they can and, thus, should have same welfare conditions like conventional farm animals [3]. Nevertheless, it has been assumed that insects may experience pain during farming and harvesting procedures [3, 58]. Addressing this requires establishing industry guidelines and/or standards for the welfare and harvesting of farmed insects, as well as further experiments into the cognitive and emotional capacities of these species [3].

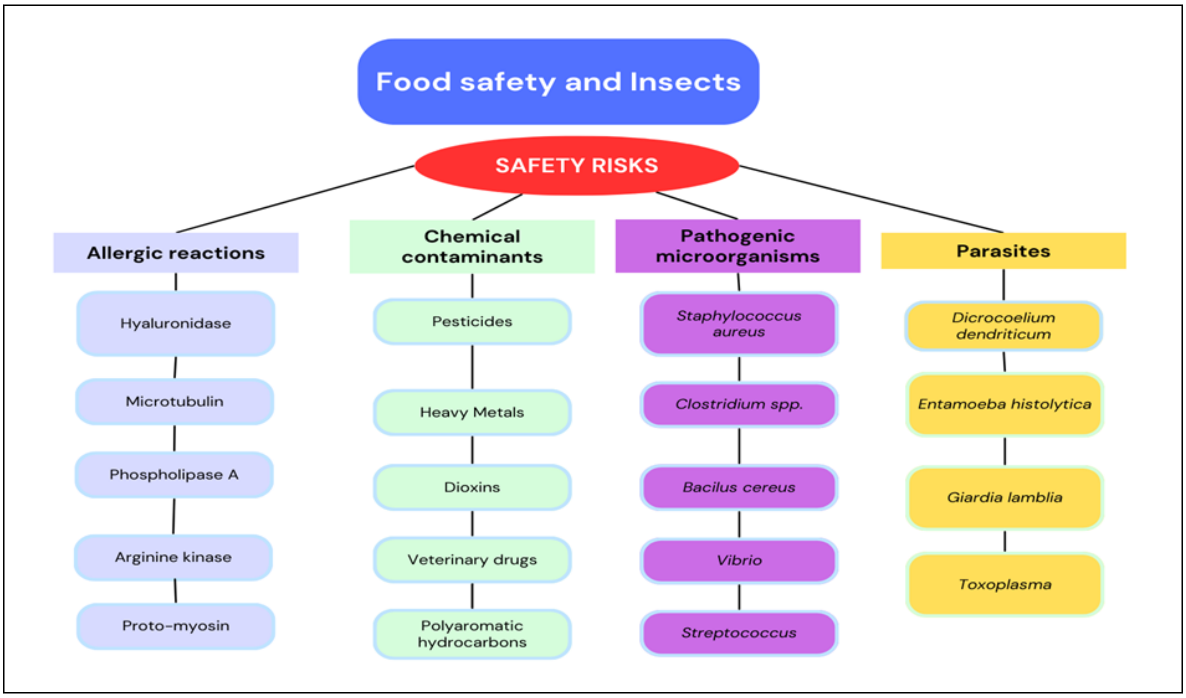

Figure. 3. Safety risks for consuming edible insects [3, 4, 7]

8. Environmental pollution and edible insects

Impact of rearing animals on environment is different and depends on animal species, their biological characteristics, nutritional needs and metabolism [3]. Every production has certain environmental concerns, especially when production is harvesting from nature or rearing animals [3]. Habitat changes, water pollution, pesticide use and overexploitation are major safety concerns regarding environmental pollution [3].
Most important environmental impact of farming insects as food or feed are the effects on global warming and water and land use [3].
Greenhouse gas emissions is much lower when farming and rearing insects compared to conventional farming animals [3]. In addition, edible part of insects (around 80%) is much greater in comparison to conventional farm animals, whereby varies from production cycle and developmental stage of insects [3, 65]. Also, it is much easier and require less expensive food to feed edible insects than conventional farm animals [3]. Moreover, insects have lower requirements for land and water than conventional farm animals [3]. For example, land use is about 10 times lesser for insects than beef cattle, which is mainly related to the use of the feed and can be improved by using vegetable or fruit remains or even weeds as feed substrate [66–68]. Table 3 shows differences in edible portion, feed conversion efficiency, land and water use between edible insects and conventional farm animals [3].

Table 3. Edible portion, feed conversion, water and land use of insects and conventional farming animals [3]

	Insect*	Poultry	Pig	Beef
Edible portion (%)	80	55	55	40
FCE[1] (kg feed / kg edible weight)	2.1	4.5	9.1	2.5
GHG[2] emissions (CO_2 equivalents)	14	19	27	88
Water use (LCA[3]) (L/g protein)	23	34	57	112
Land use (LCA[3]) (m^2 / kg protein)	18	47	55	201

*Edible portion and feed conversion efficiency is shown for crickets and the rest is shown for the mealworm.
[1]FCE – feed conversion efficiency; [2]GHG – greenhouse gases; [3]LCA – life cycle analysis

9. Current legislation on edible insects

Edible insects, rich in nutrients such as fat, protein, and minerals, are potential sustainable alternative food source worth promoting through legal recognition [3, 4, 14]. Hence, promotion of edible insects as both food and functional active compounds is crucial. Legislators have largely underestimated the extensive applications and potential of the insect food industry [69]. In the past years, insect industry was deemed too small-scale and underutilised to warrant inclusion within legislative frameworks. However, the absence of clear legislation regarding the breeding, consumption, and commercialisation of edible insects in many countries has significantly impeded insect industry development and their ability to contribute to human health benefits [70]. In most countries, edible insects are still recognised as "unconventional foods" [3].

Many factors influence development of legislation and regulations regarding insects as food such as food safety, environmental preservation, sustainability and consumer acceptability [4]. At the moment legislation on edible insects exists in EU, United States of America, Australia, Japan and China [4, 14]. However, the distribution of edible insects between countries on international level is major challenge, due to different legislation [4]. Several countries such as Belgium, United Kingdom, Netherlands, Kenia, Denmark and Finland have established regulations concerning the legality of crickets as human food, which are mostly based on regulations regarding animal food [4]. Since the beginning of insect use as human food in Europe, EFSA and FASFC (Federal Agency for Safety of the Food Chain) have created special legislation that regulates use of insects as human food [4]. These regulations include microbiological standards that have to be applied to edible insects as well as status of "Novelty food" for edible insects and insect-based food [4]. Prior to 2015, EU food regulations primarily treated insects as contaminants in food, with no explicit regulations mentioning them as food sources [71]. According to EFSA four types of edible insect are recognised and regulated as human food: (i) lesser mealworm (*Alphitobius diaperinus larva*); (ii) whole house crickets (*Acheta domesticus*); (iii) migratory locust (*Locusta migratoria*); and (iv) defatted house cricket powder (*Acheta domesticus*) [3,4,72]. These four new insect food products are governed by EU Regulation 2015/2283 [73] and have undergone safety evaluations by EFSA. Prior to this, EU Regulation 2017/893 [74], already permitted the use of seven insect species as aquaculture feed [4].

10. Conclusions and perspectives

Based on the available scientific literature, it can be concluded that edible insects have a great potential as a sustainable source of animal proteins. To achieve sustainable production, further research is necessary to enable more efficient commercial rearing of edible insects, the implementation of appropriate legislation and the formulation of safer and higher quality products that would be more acceptable to consumers, so that edible insects and their products could be consumed globally.

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