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Review

Nutritional, functional and biological properties of insect proteins: Processes for obtaining, consumption and future challenges

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ABSTRACT

Background: Consuming insects as an alternative protein source is considered a future trend and a viable strategy that could potentially contribute to global food security. Insects are a non-conventional source of protein, either for human consumption directly or indirectly as a component in recomposed foods or added to feedstock mixtures. Moreover, these proteins have demonstrated a broad range of applications as peptides with antihypertensive, antimicrobial and antioxidant properties. However, aspects such as food safety and processing of these proteins need further studies for their elucidation and optimization.
Scope and approach: In this review, aspects of nutritional value and risks of insect consumption are reported. Additionally, conventional processing techniques and recent advances in insect protein extraction and production are presented. The application of bioactive peptides obtained from insect protein hydrolysates is reported, focusing on their potential antihypertensive, antimicrobial and antioxidant properties.
Key findings and conclusions: Insect proteins have great advantages in terms of nutritional value, total protein level and amino acid profile. However, some safety concerns must be taken into consideration in large-scale production. The conventional processing of insects proteins is very particular, depending on several aspects such as species, larval stage, and cultivation, among others. Nonetheless, recent advances in insect protein production via enzymatic hydrolysis and heterologous expression have shown a promising technology for the study and exploitation of their bioactive properties, such as the antimicrobial, antioxidant and antihypertensive (inhibition of ACE) activity of insect peptides.

1. Introduction

Insects have been part of the human diet in some regions for centuries, more specifically as an alternative protein source, making them a subject of great interest in scientific research. Human consumption of insects is associated with countries located in many parts of Asia, Latin America and Africa (Bukkens, 1997). The production, trade, and use of edible insects as food and feed permeate a wide range of regulatory areas, which should ensure aspects such as the quality and safety of the products obtained and the environmental impact assessment of insect farming (Ball, 2014).

Insects/invertebrates possess a huge biodiversity and their biomass represents 95% of the animal kingdom (Vercruysse, Smagghe, Herregods, & Van Camp, 2005). They can be consumed in different life stages: eggs, larvae, pupae or adults and have been used as food for humans since prehistoric times to the present (Kouřimská & Adámková, 2016). The main orders of consumed insects are: Coleoptera (31%), Lepidoptera (18%), Hymenoptera (14%), Orthoptera (13%) and Hemiptera (10%) (Sun-Waterhouse et al., 2016; Yi et al., 2013).

According to the Federal Food, Drug and Cosmetic Act, insects are considered food if that is the intended use. However, insects must be processed according to the standardized rules for human consumption or for use in animal or pet food. In this context, they must be produced, packaged, stored, and transported under sanitary conditions (i.e., free from filth, pathogens, and toxins) and properly labeled, including the scientific name of the insect. Therefore, some recommendations are strongly considered in the marketing of insects for human consumption: a) the insects must be raised specifically for human food following current good manufacturing practices, b) insects raised for animal or pet food cannot be diverted to human food, c) they cannot be collected in the wild and sold as food due to the potential of carrying diseases or pesticides, and d) the manufacturer also needs to demonstrate the

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healthiness of the product (FDA, 2016).

When we talk about sustainability, insects can compensate for the rising demand for animal-source protein, avoiding deforestation of forests for use as grazing. In addition, they have a high food conversion efficiency compared with conventional livestock and are responsible for relatively low emissions of greenhouse gases and ammonia (Poma et al., 2017).

Although they have advantages, the production of insects as food faces two major challenges. First, low consumer acceptance remains one of the largest barriers to the adoption of insects as viable sources of protein (Mlcek, Borkovcova, Rop, & Bednarova, 2014). In general, attitudes towards insect-based food are frequently characterized by the rejection of certain food sources for psychological rather than rational reasons (Poma et al., 2017). Second, a current lack of clear legislation to regulate this new foodstuff may deter companies from producing and selling insects as food because the process is considered costly and lengthy by some stakeholders (Belluco, Halloran, & Ricci, 2017). Further details on the course of legislation regarding insect consumption can be found in Belluco et al. (2017).

To support the studies, in this review, the focus was to show that insects are a protein-rich food, presenting nutritional data, functional attributes, and types of processing of these proteins. The peptides formed using insect protein and their bioactive characteristics were also discussed.

2. Nutritional aspects of insects

Edible insects have a very diverse nutritional value mainly because there is a large quantity of species. Their nutritional values can vary within the same insect group depending on the origin, stage of life and feed (Finke & Oonincx, 2014). Insects have elevated levels of protein that represent the main component of their nutrient composition (Table 1), and they also possess significant amounts of other important nutrients such as lipids, beneficial fatty acids, vitamins and minerals (Bukkens, 2005; Nowak Persijn, Rittenschober, & Charrondiere, 2016; Rumpold & Schlüter, 2013; Sun-Waterhouse et al., 2016).

When compared to plant proteins and meat proteins, insect proteins have high levels of high quality proteins in terms of nutritional value, total protein level and essential amino acid profile (between 50 and 80%) (Bukkens, 2005; Rumpold & Schlüter, 2013).

Fat represents the second largest fraction of the nutrient composition of edible insects and its content is higher in the larval stage of life. Triacylglycerols constitute approximately 80% of that, followed by phospholipids, which represents less than 20% varying by the stage of life (Ekpo, Onigbinde, & Asia, 2009; Tzompa-Sosa, Yi, Van Valenberg, Van Boekel, & Lakemond, 2014). The fatty acid profile depends on the species and insects' feed. There are large amounts of C18 fatty acids including oleic, linoleic and linolenic acids in insect fat and high amounts of palmitic acid (Bukkens, 2005; Tzompa-Sosa et al., 2014). In general, according to the literature, lipids from insects possess high amounts of unsaturated fatty acids relative to saturated fatty acids (Finke, 2002; Rumpold & Schlüter, 2013; Tzompa-Sosa et al., 2014).

Many minerals can be found in insects, such as iron, zinc, potassium, sodium, calcium, phosphorus, magnesium, manganese and copper, and they also contain a great variety of lipophilic vitamins as well as riboflavin, pantothenic acid, biotin, and in some cases, folic acid (Finke, 2002; Rumpold & Schlüter, 2013; Van Huis et al., 2013; Xiaoming, Ying, & Hong, 2010). Currently, there is little information on the relative bioavailability of the various insect species, especially on the bioavailability of minerals, for which information is scarce. The work of Latunde-Dada, Yang, and Aviles (2016) was the first work to evaluate the bioaccessibility of some minerals from common edible insects. According to the authors, insects could provide significant proportions of daily mineral recommendations; they can also be excellent sources of bioavailable iron. Grasshoppers, crickets, mealworms, and buffalo worms can provide excellent sources of Fe, Ca, Cu, Mg, Mn, and Zn in human diets depending on the form of consumption and portion sizes. However, more studies are required to increase the range of information on this relevant topic. Table 2 provides some examples of nutritional values of different insects.

Although insects are considered a good source of nutrients with potential for application in human nutrition, it is important to highlight some aspects related to the risks of consumption of this type of raw material.

3. General aspects on the risks of insect consumption

There exist many doubts about the use of insects as food. Considering only safety concerns, the common hazards related to insect consumption are microbiological, parasitological and allergenic (Spiegel, Noordam, & Fels-Klerx, 2013). Some considerations and examples on these aspects are presented below.

Regarding microbiological risks, some studies have demonstrated high microbial content in some commercial insect species (i.e., *Zoophobas morio, Tenebrio molitor, Galleria mellonella* and *Acheta domesticus*). The results showing microbiota composed of Gram-positive bacteria, as fecal and total coliforms. The Gram-positive population was mostly formed by *Micrococcus* spp., *Lactobacillus* spp. and *Staphylococcus* spp. (Belluco et al., 2013; Giaccone, 2005). Klunder, Wolkers-Rooijackers, Korpela, and Nout (2012) evaluated the microbiota of the mealworm (*Tenebrio molitor*) and cricket (*Acheta domesticus* and *Brachytrupes* sp.) that were analyzed in five conditions: fresh (stored refrigerated and in an ambient environment), boiled (stored refrigerated and in an ambient environment) and roasted. The results indicated that in fresh insects, Enterobacteriaceae and spore-forming bacteria were isolated, but the presence of pathogenic species was not detected. Boiling insects for 5 min was an efficient process to eliminate Enterobacteriaceae but not spore-forming bacteria. Thus, storage at a refrigerated temperature (5–7 °C) was suggested. In addition, a 5–7 °C temperature can prevent the spoilage of boiled insects (stable for more than 2 weeks). Roasting was not sufficient treatment to eliminate Enterobacteriaceae; therefore, a few minutes of boiling was suggested before roasting.

An important case in which insects show their potential as a biological vector is trypanosomiasis. The disease is transmitted by insects of the *Reduviidae* family, such as barbers infected with *Trypanosoma*

Table 1
Amount of protein in the major consumed orders of insect (based on dry matter).
Source: Xiaoming et al. (2010).

Insect common name	Insect order	Stage	Amount of protein (%)
Beetles	Coleoptera	Adults and larvae	23–66
Butterflies and moths	Lepdoptera	Pupae and larvae	14–68
Cicadas, aphids, honeyants, planthoppers, scale insects, leafhoppers and true bugs	Hemiptera	Adults and larvae	42–74
Wasps, bees and ants	Hymenoptera	Adult, pupae, larvae and eggs	13–77
Dragonflies	Odonata	Adults and naiads	46–65
Locusts, crickets and grasshoppers	Orthoptera	Adults and nymphs	23–65