



Review

Edible insects: An alternative of nutritional, functional and bioactive compounds

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ABSTRACT

The ingestion of insects has become a new trend in food science approximately since 2013, when the Food and Agriculture Organization of the United Nations (FAO) published a document entitled “Edible Insects: Future Perspectives of Food and Nutrition Security”. Since then, a growing number of researches relating insects as a food source has emerged, however, little is known about the composition of their nutrients. This review describes and compares the nutritional composition, functionality and the bioactive compounds present in different insects, as these have been shown to be a source of healthy food with high protein content, significant amount of lipids, vitamins, minerals and fibers, present in the form of chitin in the exoskeleton of the insects. Additionally, the issues related to entomophagy and the possible risks that should be taken into account when consuming insects are discussed.

1. Introduction

Sustainability is becoming increasingly important in the world we live in. Therefore, alternative food sources must be found in order to replace traditional, less sustainable ingredients. A possible alternative would be to use proteins, lipids and fibers from edible insects as food matrices, replacing those already existing (Sosa & Fogliano, 2017). Edible insects can compensate for the increased demand for animal protein and can avoid deforestation for pasture use; additionally, they present a high feed conversion efficiency compared to conventional livestock and are responsible for a relatively low emission of greenhouse gases and ammonia (Poma et al., 2017). Insects have an excellent nutritional composition, not only due to their high concentration of amino acids, when compared to other sources, but also for their potential to meet sustainable, healthy, accessible and palatable principles (Rutten et al., 2016; Ynsect, 2018).

Entomophagy, or the act of eating insects, began with early hominids, but it only gained momentum in Western cultures a few years ago. Approximately 113 countries around the world practice entomophagy (Barennes, Phimmasane, & Rajaonarivo, 2015). Insects are consumed in different ways by about 2 billion people, predominantly in parts of Asia, Africa and Latin America, with over 2,100 species already cataloged as edible (Jongema, 2017).

The Food and Agriculture Organization of the United Nations (FAO) has pointed out the need to examine modern food science practices to increase trade, consumption and acceptance of insects (FAO, 2013). Researchers in this field have innovated and sought alternative solutions to improve processing and to increase the shelf life of insect products, in order to increase availability and consumer acceptance. One of the proposed solutions would be the isolation of proteins and lipids from insects to be used as food ingredients (Sosa & Fogliano, 2017). However, this would require an in-depth knowledge of the physicochemical characteristics of these proteins and lipids, their functionality and an elaborating consumers' perceptions and motivations may be needed to promote entomophagy.

The production, marketing and use of edible insects as food and feed pervades a wide range of regulatory institutions, which should ensure aspects such as the quality and safety of the products obtained and the environmental impact of insect breeding. A crucial point is that consumer acceptance is probably associated with the development of an appropriate processing strategy, such as the extraction, purification and use of insect proteins as a food additives (Van Huis et al., 2013). It is very difficult to produce a general protocol on the processing of insect proteins, since each species has its peculiarities (size, culture and reproduction, different stages of life, protein content and digestibility and availability of amino acids) (Halloran, Roos, Eilenberg, Cerutti, &

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Bruun, 2016).

Further studies show a recent advance in the use of insect peptides as antihypertensive, antimicrobial and antioxidant agents, demonstrating the wide applicability of these proteins (de Castro, Ohara, Aguilar, & Domingues, 2018; Hall, Johnson, & Liceaga, 2018). As a future trend, promoting insects as food will require semi-cultivation and agriculture to become a priority. In addition, the large-scale production of insect bioactive peptides represents a promising biotech business. Therefore, to achieve all these objectives, a multidisciplinary approach will be absolutely necessary (de Castro et al., 2018). In view of the above, the present review aimed to describe and compare the nutritional composition, functionality and the bioactive compounds present in edible insects, as well as to discuss subjects related to entomophagy and the possible risks of insects consumption.

2. Relevance of entomophagy

During human evolution, it was customary to eat insects in many countries and regions. According to the history of entomophagy, the Chinese began eating insects more than 3000 years ago (Xiaoming, Ying, Hong, & Zhiyong, 2010). According to Tan, Fischer, Van Trijp, and Stieger (2016), the greatest barriers to the consumption of insects are cultural, because the idea that we are what we eat is present in all cultures. These beliefs make it difficult to incorporate insects into the diet, since all the associations and attributions related to these arthropods influence our perception of them as food, much more than their nutritional value. In fact, entomophagy is a practice that has always existed and was probably an important source of nutrients in the past as it is today in some parts of the world, so this is not the introduction of a new type of food, but the spread of a possible source of nutrition in the Western world (Van Huis et al., 2013).

Apparently, Western societies consider entomophagy a disgusting, primitive food habit or a sign of poverty, since being able to buy meat from bovine animal species, for example, is a way of demonstrating social and economic progress and marking the difference to economically weaker bands in their societies (Pootvliet, van der Pas, Mulder, & Fogliano, 2019). Food neophobia, characterized as the tendency to refuse new or unknown food is a common human characteristic; when it comes to edible insects, neophobia is particularly high (Gere, Zemel, Radványi, & Moskowicz, 2018; Megido et al., 2016).

Insects can be consumed at different stages of their development, as eggs, larvae, pupae and adults, but it is in the form of larva or pupa that most of the registered species is consumed. When consumed indirectly, the intake is in the form of products made and/or excreted by these insects, such as: honey, wax, pollen, oils, dyes, medicines, teas, infusions and flours, added or not to other ingredients. The main species consumed are, in order of importance, beetles (Coleoptera); caterpillars (Lepidoptera); ants, bees and wasps (Hymenoptera); locusts (Orthoptera); aphids and leafhoppers (Hemiptera); termites (Isoptera), flies (Diptera), among others (Stamer, 2015).

Large-scale industrial success begins with the exploration of the functional, nutritional and bioactive properties contained in insects (Xiaoming et al., 2010), as they represent a source of healthy food with high protein content, the main component of its nutritional composition, but also have significant amounts of other important nutrients, such as lipids, fatty acids, vitamins and minerals (Sun-Waterhouse et al., 2016; Ynsect, 2018). Although insects are considered a good source of nutrients with potential for application in human food, it is important to highlight some aspects related to the risks of consumption of this type of raw material.

3. Inherent risks of entomophagy

Among the issues that undermine the food potential of edible arthropods/insects, their allergenicity risks are worth evaluating. In arthropods, 239 individual allergens are registered in accordance with the

requirements of the World Health Organization Subcommittee on Allergen Nomenclature and the International Union of Immunology Societies. They are predominantly omnipresent or pan-allergenic proteins, which, in simple terms, can be classified as muscle proteins (tropomyosin, myosin, actin, troponin C), cellular proteins (tubulin), circulating proteins (e.g. hemocyanin, defensin) and enzymes (arginine kinase, triosephosphate isomerase, α -amylase, trypsin, phospholipase A, hyaluronidase) (Schlüter et al., 2016).

Isolated allergic episodes, including anaphylactic reactions, have been documented in the medical literature in connection with insect consumption, as well as recent data on allergies caused by ingestion of insects (Hall et al., 2018; Kamemura et al., 2019). Pan-allergenic structures were identified in arthropods (Arthropoda), including insects (bees, beetles, locusts and cockroaches), arachnids (mites) and crustaceans (shrimps, crabs and lobsters) (Gier & Verhoeckx, 2018).

This effect was confirmed in studies on cross-reactivity of mealworm larvae (*Tenebrio molitor*) (Verhoeckx et al., 2014) and cricket (*Gryllus bimaculatus*) (Kamemura et al., 2019) in patients with allergy to inhalants and food for mites, crustaceans and shrimp, respectively. In both cases, tropomyosin and arginine kinase were identified as cross-reactive proteins. Therefore, it is possible that people who are allergic to crustaceans and mites also experience an allergic reaction to foods containing mealworm larvae or cricket.

Tropomyosin, a major allergen in shrimp, is a myofibrillar protein composed of a spiral dimer with molecular weights of 35–38 kDa (Pedrosa, Boyano-Martínez, García-ara, & Quirce, 2015). As mites and other arthropods, such as crickets, have an identity of 75–85% with the tropomyosin sequence (Ayuso, Reese, Leong-Kee, Plante, & Lehrer, 2002), cross-reactivity of immunoglobulin E is highly expected in some species of edible insects. The present observations consider tropomyosin as the main allergen responsible for the cross-reactivity between crustaceans, mollusks, mites and cockroaches (Pedrosa et al., 2015).

Another molecule of potential risk associated with insects is chitin, that is a polysaccharide that comprises the exoskeleton of insects, but it is also found in fungi, parasites and crustaceans (Bertelsen et al., 2016). Chitin has been shown to function as a coadjuvant, a substance that helps to induce adaptive immunity, although the way it functions as an adjuvant is still not well understood. Several studies have demonstrated the different effects of chitin immunomodulation (Dubey, Moeller, Schlosser, Sorensen, & Holmskov, 2015; Sigsgaard et al., 2015). There is more information on allergy to insect bites or inhalation (Gier & Verhoeckx, 2018), and the most commonly reported is the allergy to cockroaches. Recently, an extensive review on cockroach allergy has been published (Pomés, Mueller, Randall, Chapman, & Arruda, 2017).

4. Edible insects as a dietary component

Insects are currently being considered as a promising food source because of their high nutritional value (Van Huis, 2016). Despite this enormous variety and the large number of studies that are emerging, little is known about the composition of insect nutrients. In general, edible insects are considered as good sources of proteins, fats, vitamins and minerals. The consumption of 100 g of caterpillars, for example, provides 76% of the recommended daily intake of protein and almost 100% of the recommended daily intake of vitamins for humans (Agbideye, Ofuya, & Akindele, 2009). Only three pupae of silkworms are considered as rich in nutrients as a chicken egg; its composition is about 50% protein and 30% lipid (Mitsuhashi, 2010).

Regarding the micronutrient content of insects, it is possible to affirm that most of them present high amounts of potassium, calcium, iron, magnesium (Zielińska, Baraniak, Karaś, Rybczyńska, & Jakubczyk, 2015) and selenium (Finke, 2002). Insects partially contain more iron and calcium than beef, pork and chicken (Sirimungkararat, Saksirirat, Nopparat, & Natongkham, 2010). For example, an average of 100 g of caterpillars provides 335% of the minimum recommended daily intake of iron (Defoliart, 1992). An overview of nutrient composition, as well

Table 1
Composition of nutrients, minerals and vitamins of six species of edible insects (dry basis).

		<i>Rhynchophorus phoenicis</i>	<i>Bombxy mori</i>	<i>Acheta domesticus</i>	<i>Ruspolia differens</i>	<i>Tenebrio molitor</i>	<i>Periplaneta americana</i>
Nutrients (%)	Proteins	10.3–41.7	48.7–58.0	64.4–70.7	44.3	65.6	49.43
	Fatty acids	19.5–69.8	30.1–35.0	18.5–22.8	46.2	28.2	38.07
	Fibers	2.8–25.1	2.0	–	4.9	3.0	6.53
	Ashes	2.5–5.7	4.0–8.6	3.6–5.1	2.6	2.48	2.84
Minerals (mg/100 g)	Calcium	54.1–208.0	158.0	132.2–210.0	24.5	47.18	–
	Potassium	1025.0–2206.0	–	1126.6	259.7	761.54	–
	Magnesium	33.6–131.8	207.0	80.0–1094.4	33.1	221.54	–
	Phosphor	352.0–685.0	474.0	708.0–957.8	–	697.44	–
	Sodium	44.8–52.0	–	435.1	121.0	125.38	–
	Iron	14.7–30.8	26.0	6.3–11.2	229.7	5.51	–
Vitamins (mg/100 g)	Ascorbic acid	4.2	–	9.5	0.1	36.10	23.84
	Folic acid	–	–	0.5	0.9	–	–
	Thiamine	3.4	–	0.1	–	–	–
	Riboflavin	2.2	–	11.1	1.4	–	–
	Niacin	3.4	0.9	12.6	2.4	–	–

Source: Adapted from Rumpold and Schlüter (2012, 2013).

as vitamin and mineral contents of six insect species are presented in Table 1.

Recent studies have shown that there is a greater willingness to consume products with shredded insects rather than with whole insects (FURG, 2017; Hall, Jones, O'Haire, & Liceaga, 2017; Oliveira, Lucas, Cadaval, & Salas-Mellado, 2017). Oliveira et al. (2017) used cinerea cockroaches (*Nauphoeta cinerea*) to obtain a flour with 63.22% of proteins and high-quality lipids. Different concentrations (5, 10 and 15%) of this flour were added in white bread formulation in order to proteinically enrich the product. The addition of 10% of cockroaches' flour in the white bread formulation led to a protein increase of 133% (increase from 9.7% to 22.7%) and a fat reduction of 64.53%. Megido et al. (2016) elaborated different formulations of hamburger (beef hamburger, lentil hamburger, and lentil and beef hamburger prepared with 50% of insects) by adding mealworm larvae (*Tenebrio molitor*) in order to reduce insects-related food neophobia. In this study, the level of sensorial preference of the different hamburgers was tested through hedonic tests. This strategy reduced insect neophobia as the participants assessed the taste and appearance of the insect-added burgers with higher results than neutral products, by positioning them between the all-meat hamburger and the all-vegetable hamburger.

The use of insect proteins and lipids as food ingredients requires a thorough understanding of the physicochemical characteristics of these ingredients, as well as of their functionality. Food scientists will need to address the food security challenge in the near future to ensure sufficient protein production for the 2 to 3 billion additional people who will populate the planet in the coming decades (Veldkamp et al., 2012).

4.1. Insects as protein source

Insects have been presented as one of the most promising alternative sources of protein to solve the global problem of protein production, the main advantage of insects over other sources of protein is the low environmental cost of production, which becomes essential to satisfy the global protein demand (Van Huis et al., 2013), from the nutritional point of view, not only by the high concentration of amino acids, when compared to other sources (Table 2).

Extraction and protein fractionation are necessary steps to produce ingredients derived from insect proteins. The protein concentration in the various species of insects is generally very high (50–70% on dry basis), which facilitates the concentration process (Sosa & Fogliano, 2017). Data on the amount of protein in powder form that can be extracted from insects previously dried, milled and resuspended in aqueous solutions showed an enormous variability. Factors such as the solid/water ratio, as well as pH and temperature, play an important role (Zhao, Vazquez-Gutierrez, Johansson, Landberg, & Langton, 2016). The

most used method to obtain the protein fraction consists of alkaline extraction followed by acid precipitation of the proteins at their isoelectric point (Foste, Elgeti, Brunner, Jekle, & Becker, 2015). The crude protein content in a high protein fraction of mealworm larvae (*Tenebrio molitor*) obtained by alkaline extraction and isoelectric precipitation at pH 4 increased by 14.4% in relation to the initial extract (Bubler, Rumpold, Jander, Rawel, & Schlüter, 2016).

Estimates of protein content in edible insects can be obtained by the Kjeldahl method using the nitrogen (N) conversion factor into protein (6.25). However, recently, Jonas-Levia and Martinez (2017) pointed out that this factor may not be suitable for insects and leads to protein overestimation, because the insect exoskeleton contains a large amount of chitin fiber, which is rich in polysaccharides and nitrogen, and presents proteins firmly incorporated into its matrix. For example, Kaya, Erdogan, Mol, and Baran (2015) determined that a few grasshopper species contain from 5.3 to 8.9% of chitin (dry weight). For this reason, a new conversion factor of nitrogen into protein would have to be recalculated for insects.

However, the study by Finke (2007) reports that, although detailed amino acid analysis is preferred, the nitrogen conversion factor of 6.25 provides a reasonable estimate of the total protein for most insects. When analyzing the amount of chitin contained in whole insects, the author observed that the recovery of proteins from the studied species is relatively high, with an average of 92.4%. In most cases, when insects are analyzed for amino acids and when all amino acids are reported, relatively high nitrogen recovery suggests that chitin nitrogen is a relatively small fraction of the total nitrogen content of the insect, since the chitin is present only in the exocuticle and endocuticle of the insect, and in most of the insects studied, protein, not chitin, is the predominant compound in the cuticle. All these data indicate the need for further studies in this area, since the protein content in insects directly influences the other studies involving this subject.

There are studies in the literature evaluating the nutritional and functional properties of the proteins of different insects (Mishyna, Itzhak, Chen, & Benjamin, 2019; Oliveira et al., 2017; Hall et al., 2017; Zielińska et al., 2015; Zielińska, Karaś, & Baraniak, 2018; Zhao et al., 2016) but, unfortunately, due to lack of standardized fractionation processing, studies on the technological functionality of insect proteins are still scarce. Authors further stated the need for the quality of insect proteins (compared to other animal and plant proteins) to be evaluated in physiological tests (Fink, Defoliart, & Benevenga, 1989).

Sosa and Fogliano (2017) have studied not only the nutritional but also the functional benefits of insect proteins and reported that the main functional properties to be evaluated are water and lipid retention capacity, thickening capacity, emulsifying capacity, foaming ability, gelling ability, and structuring ability. Yi, Van Boekel, Boeren, and

Table 2
Quantification of amino acids from different protein sources.

Protein source (mg/g _{protein})	Histidine	Isoleucine	Leucine	Lysine	Methionine	Cysteine	Threonine	Tryptophan	Valine	Methionine + cysteine	Phenylalanine + tyrosine
<i>Acheta domesticus</i>	22.7	36.4	66.7	51.1	14.6	8,3	31.1	6,3	48.4	22.9	74.2
<i>Tenebrio molitor</i>	31.6	50.3	106.4	54.5	12.8	8,6	41.8	8,0	58.8	21.4	109.8
Beef	38.1	39.4	92.2	95.9	–	–	–	–	43.0	35.6	83.8
Egg powder	22.1	34.6	83.9	91.4	–	–	–	–	47.5	40.0	98.6
Casein	18.9	46.9	93.0	78.6	–	–	–	–	54.9	30.1	109.7
Soy	32.8	45.7	81.3	82.7	–	–	–	–	48.1	18.6	96.9
Beans	28.5	31.4	78.3	94.3	–	–	–	–	40.8	19.9	113.1
Amino acids required in human nutrition (FAO)	15.0	30.0	59.0	45.0	16.0	6,0	23.0	6,0	39.0	22.0	30.0

Source: Adapted from Pires, Oliveira, Rosa, and Costa (2006) and Rumpold and Schlüter (2013).

Lakemond (2016) confirmed that insect proteins have good digestibility; *in vitro* data showed that the time of digestion also depends on the fraction of the proteins considered. Beverly et al. (2012) studied the chemical and nutritional status of two insect types and found protein values of 31.23% in larvae of white worm (*Aegiale hesperiaris*) and 37.79% in larvae of Red worm (*Comadia redtem-bacheri*). Oliveira et al. (2017) analyzed the amino acid profile of the proteins of cinereous cockroach (*Nauphoeta cinerea*) and also calculated 68.50% of total protein in its composition.

Mishyna et al. (2019) used soluble grasshopper (*Schistocerca gregaria*) and European bee (*Apis mellifera*) proteins. The samples were degraded and the protein was extracted by sonication (ultrasound). New nitrogen-to-protein conversion factors based on amino acid analysis were estimated for both insects: 4.5 for adult grasshoppers, and 4.9 and 5.6 for pupae and larvae, respectively, as opposed to the 6.25 factor commonly used. All fractions were characterized by their composition, yield, color, protein solubility and functional properties. There was an increase in protein content to up to 57.5 and 55.2% for grasshopper and bee, respectively. The higher emulsion stability after 120 min was determined for sonicated grasshopper powder (85.5%). Changes in protein functionality were also observed related to protein load change, surface hydrophobicity and protein distribution, according to the protein's molecular weight.

Zhao et al. (2016) used a fractional factorial design (two levels, four factors) to evaluate the simultaneous impact of four variables during the extraction of mealworm larvae proteins with NaOH. The four factors studied were: NaOH concentration (0.1 M to 0.5 M), NaOH to defatted larvae ratio (6:1 mL:g to 20:1 mL:g), temperature (20 °C and 80 °C) and time (30 min and 120 min). The actual protein content of the protein extract was about 75%, with an extraction yield of 70% under optimized extraction conditions using 0.25 M NaOH, a 15:1 mL:g NaOH:fat-free larvae ratio, 40 °C for 1 h of extraction. The lowest protein solubility in distilled water was obtained between pH 4 and 5, and the solubility increased in pH values above or below this range. The lowest solubility was observed in 0.5 NaCl solution, demonstrating that the functional properties of mealworm larvae can be modified according to the different food applications.

4.2. Insects as lipids source

Lipids represent the second largest fraction of the nutritional composition of edible insects and its content is higher in the larval stage of insects' life. Their content ranges from 10 to 50% on dry basis (Xiaoming et al., 2010). The fatty acids content and composition of insect lipids are related to species, sex, stage of life, diet, environmental temperature, and migratory flight (Oonincx, Van Broekhoven, Van Huis, & Van Loon, 2015). For larvae insect the major fatty acids in the oils are palmitic and oleic acids while for mature insect the major fatty acids are palmitic and linoleic acids (Ekpo, Onigbinde, & Asia, 2009). It is not uncommon to find a wide variability of fatty acid profiles among the insects themselves (Table 3). The lipids in insects come from their

diet or are synthesized by them. These lipids are stored in the body fat, degraded, processed and then transported to the site of use (Beenackers, Vanderhorst, & Vanmarrewijk, 1985). They are mainly composed of triacylglycerol, other types of lipids present in smaller amounts include cholesterol, partial glycerides, free fatty acids, phospholipids and wax esters (Downer & Mathews, 1976). However, about 80% of the lipid content is present in the form of triacylglycerol (Gilby, 1965), which serve as an energy deposit for periods of high energy demand (Beenackers et al., 1985). The second most important lipid class is phospholipids, which have an important role in cell membrane structure. The phospholipid content in the crude fat is generally < 20%, varying according to life stage and insect species (Ekpo et al., 2009).

The essential fatty acids are linoleic (18:2n-6) and α -linolenic (18:3n-3), they are polyunsaturated and are not synthesized by mammalian cells and should therefore be ingested in the diet (Bazinet & Layé, 2014). They can act in the prevention of cardiovascular disease and cancer (Baker, Miles, Burdge, Yaqoob, & Calder, 2016). These fatty acids act as precursors for the synthesis of long chain polyunsaturated fatty acids such as arachidonic acid, eicosapentaenoic acid and docosahexaenoic acid. They are necessary to maintain under normal conditions cell membranes, brain function and nerve impulse transmissions (Bazinet & Layé, 2014; Nakamura, Yudell, & Loor, 2014). Some studies report the presence of these polyunsaturated fatty acids in edible insects (Ekpo et al., 2009; Zhang et al., 2020). As well, according to Table 3 it shows that insects have a higher value of linoleic acids (18: 2n-6) and α -linolenic (18: 3n-3) when compared to other sources.

The extraction of lipids from insects for application as edible oils was investigated using the Soxhlet method, Folch extraction and supercritical CO₂ extraction (Purschke, Stegmann, Schreiner, & Jäger, 2016; Tzompa-Sosa, Yi, Van Valenberg, Van Boekel, & Lakemond, 2014). The solvents possible to be used include carbon disulfide, petroleum naphtha, benzene, trichloroethylene, alcohol, pentane, supercritical carbon dioxide, and especially commercial hexane (Kemper, 2013). The lipid extraction process does not have a great impact on the fatty acids composition of the extract, but strongly influences the lipid extraction yield and the types of lipids extracted. For example, when aqueous extraction is used, only triacylglycerols are extracted. In contrast, when organic solvents are used, phospholipids, glycerides and triacylglycerols are extracted (Tzompa-Sosa et al., 2014).

The aqueous extraction of insect lipids provides a high oil quality, similar to virgin oils (Purschke et al., 2016; Tzompa-Sosa et al., 2014). Therefore, the extraction process must be carefully selected according to the desired application and the costs of each extraction process. Main advantages for the use of supercritical CO₂ extraction are reported: (i) reduced oxidation of solutes; (ii) extraction of thermally sensitive components due to low critical temperature; (iii) modulation of solvent selectivity by operating conditions; (iv) solvent-free residues; and (v) appropriate solvent properties (chemical inert, non-toxic, and non-explosive) (Mariod, Abdelwahab, Gedi, & Solati, 2010; Roy, Sasaki, & Goto, 2006; Stahl, Schuetz, & Mangold, 1980).

Most insect lipids are liquid at room temperature (25 °C), so they are

Table 3
Quantification of fatty acids from different sources.

	Fatty acid (g/ 100g)														
	C12:0	C14:0	C16:0	C16:1	C18:0	C18:1 n9	C18:2 n6	C18:3 n3	C20:0	C20:1	C20:2	C22:0	C22:1	C24:1	
<i>Tenebrio molitor</i>	0.23	3.11	18.52	2.09	2.43	49.50	21.82	0.84	0	0	N.D.	N.D.	N.D.	N.D.	Tzompa-Sosa et al. (2014)
<i>Alphitobius diaperinus</i>	0	0.65	25.18	0.22	8.55	38.49	23.28	1.14	0.38	0	N.D.	N.D.	N.D.	N.D.	
<i>Acheta domesticus</i>	0.30	1.80	25.99	2.09	6.09	29.14	29.11	1.56	0	0	N.D.	N.D.	N.D.	N.D.	Melo et al. (2019)
<i>Blaptica dubia</i>	0.16	1.05	18.05	5.17	3.71	51.38	17.36	1.24	0.14	0	N.D.	N.D.	N.D.	N.D.	
<i>Eucommia ulmodie</i>	N.D.	N.D.	6.21	0.11	2.46	16.00	11.68	61.85	N.D.	0.31	N.D.	0.26	0.06	0.05	Belghit et al. (2018)
<i>Salmo salar</i>	0	2.2	8.5	N.D.	3.0	40.0	14.0	6.5	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	
<i>Camellia sinensis</i>	N.D.	N.D.	14.15	0.09	3.48	61.62	18.05	0.37	0.10	0.97	0.03	N.D.	0.10	0.08	Zhang et al. (2020)
<i>Mylossoma paraguayensis</i>	0.06	0.25	15.14	3.26	9.21	32.97	18.96	9.55	0.49	0.30	N.D.	0.55	0.01	N.D.	

*N.D.: not detected

called “insect oil”. These oils are rich in essential unsaturated fatty acids, such as linoleic acid, alpha-linolenic acid and ω -3. The liquid nature of insect oils makes them ideal for use in mayonnaise, frying oils, food grade lubricants, among others. Insect lipids that are solid at room temperature are called “insect fat”. The solid state of this insect fat confers a high content of saturated fatty acids, ranging from 57 to 75% of the total (Ushakova et al., 2016), being especially interesting for application in pasta, confectionery and margarine, among other food systems (Sosa & Fogliano, 2017).

To the date only limited data is available on extraction of insect lipids. Defoliart (1991) evaluated the fat content of insects and concluded that it generally ranges from < 10% to more than 30% of fat, based on fresh weight, and this content is higher in larvae and pupa stages than in adult stages, with termites and caterpillars presenting the highest lipid content. Live termites have 350 kcal/100 g and are composed of 28% of fat, being the second most consumed insect in the world, after locusts (Chung, 2010). Oliveira et al. (2017) analyzed the fatty acid profile of the cinereous cockroach (*Nauphoeta cinerea*) and obtained 18.45% of lipids in their composition and 10.94% of unsaturated fatty acids. In order to show the possible applications of insect lipids, Sosa and Fogliano (2017) fractionated the lipids extracted from the mealworm larvae (*Tenebrio molitor*) and performed physicochemical analyzes of this original lipid extract and its fractions.

5. Functional properties of insect protein hydrolysates

The large-scale industrial success begins with exploring the functional and nutritional properties of potential insect ingredients as protein hydrolysates. However, there has been very little consideration towards the functional properties of insect proteins (Hall et al., 2017). The successful use of such protein ingredients depends upon their abilities to fulfil one or more of the functionality requirements, e.g. good solubility, emulsion/foam stabilization and/or gel formation. Studies on functional properties of insects are very limited. Enzymatic modification of proteins is a useful mechanism to improve their functionality compared with the native unhydrolyzed proteins (Hall et al., 2018).

Solubility is an important prerequisite of functional food proteins because it influences the potential applications of specific proteins and it is related to their emulsifying and foaming properties (Zhao et al., 2012). According to Akpossan et al. (2015) the fatted and defatted protein fractions of flours made of caterpillar larvae (*Imbrasia oyemensis*) presented functionality. Furthermore, a low solubility was observed in both flours, which was attributed to the isoelectric point of the protein. These results also showed that the full fat flour presented no foam capacity and poor foam stability, while the defatted flour presented low foaming properties. However, both flours exhibited good emulsion and water absorption characteristics. The solubility of the hydrolysate fraction was higher than 80%. The solubility was not dependent of the pH value (pH range 2.0–10.0) (Nongonierma & FitzGerald, 2017).

African cricket (*Gryllidae* sp.) also showed low solubility at pH 3 and 4. However, in both pH values, the insect proteins were not enzymatically hydrolyzed. The results from this study suggest that the isoelectric point of cricket (*Gryllodes sigillatus*) protein is at or near pH 3.0. This value is similar to the isoelectric point of large African cricket protein, which is reported to be at pH 3.5 (male) and 4.4 (female) (Adeyeye & Awokunmi, 2010). According to Nongonierma and FitzGerald (2017), insect peptides generally have limited water solubility. However, significantly higher solubility ($p < 0.05$) at pH 3.0, 7.0, 8.0 and 10.0 was reported following hydrolysis.

Generally, the emulsifying activity of proteins are affected by their molecular weight, hydrophobicity, conformation stability, surface charge, and their physicochemical properties, such as pH, ionic strength and temperature (Zhao et al., 2012). There are a few reports in the literature on emulsifying properties of insects that can serve as a comparison. Higher emulsifying activity index (EAI) values represent a smaller number of dispersed oil droplets and a high adsorption ability of the protein at the oil–water interface (Pacheco-Aguilar et al., 2008). Hall et al. (2018) verified that the treatments that showed the highest emulsion capacity (27–32 m²/g) were trials 1 and 2 (0.5% E/S for 30 and 60 min, respectively) and trial 8 (3% E/S, 60 min). Trials, 5–7 and 9 (1.5% E/S, 30–90 min and 3% E/S for 90 min, respectively), showed a decreased EAI relative to the other treatments and the unhydrolyzed protein values were significantly different ($p < 0.05$) among emulsions stabilized by crickets (*Gryllodes sigillatus*) – CPH hydrolysates.

Foams are two-phase colloidal systems with a continuous aqueous phase and a dispersed gas phase. Good foam expansion requires rapid migration, unfolding and rearranging at the air/water interface to reduce surface tension (Khaled et al., 2014). The hydrolyzed cricket protein in this study showed superior foaming properties compared with that of other insects found in the literature. For example, whole large African cricket (*Gryllidae* sp.) powder was reported to have a foam capacity of only 6% with a FC of 3.05% after two hours. Yi et al. (2013) reported poor or no foam capacity, over a range of pH, for acid-extracted protein fractions from five different insect species, including cricket (*Acheta domesticus*) protein.

6. Biological properties of insect proteins

6.1. Insect enzymatic hydrolysis

In many organisms, there is a variety of evidence that bioactive peptides are naturally produced by dietary proteins during the gastrointestinal process. In the last decades, there has been growing interest in identifying and characterizing bioactive peptides from vegetal and animal sources (Sarmadi & Ismail, 2010). Protein hydrolysates are proteins digested into smaller fragments, peptides and amino acids. These fragments of peptides may contain 2–20 amino acids, which are inactive within the sequence of the original protein, and can be released by enzymatic hydrolysis, solvent extraction and microbial fermentation (Najafian & Babji, 2012). The enzymatic hydrolysis process is a

breaking of the linkage between the amino acids that make up a peptide chain, consuming one molecule of water for each linkage break resulting in smaller peptides. The enzymatic hydrolysis has a typical curve: initially, rapid hydrolysis occurs, indicating that numerous peptide bonds were hydrolyzed, followed by a decrease in the reaction rate (Najafian & Babji, 2012; Sarmadi & Ismail, 2010).

Several hydrolysates have been produced from proteins of several animal sources, such as Argentine croaker (*Umbrina canosai*) protein (Da Rocha et al., 2018), tilapia (*Oreochromis niloticus*) by-product protein (Roslan, Mustapa Kamal, Khairul, & Abdullah, 2017) and of vegetal sources, such as rice, soy, pea and wheat (Rudolph, Lunow, Kaiser, & Henle, 2017). The bioactive peptides from insects and others sources have beneficial effects on human health or in food systems, such as antioxidant, antimicrobial and antidiabetic properties, angiotensin I converting enzyme (ACE) inhibition activity, and can also be used as functional food ingredients (Zielińska et al., 2015; Yang et al., 2013). However, there is little research related to the obtainment of bioactive peptides from insect protein hydrolysates. Insects are highly nutritious and present high protein content, as previously mentioned, and have been used for the elaboration of protein hydrolysates.

According to de Castro et al. (2018) the production, appreciation and success of a specific insect peptide with bioactive properties (e.g., antioxidant, antimicrobial, antihypertensive) can motivate investments and research into insect protein extraction and food supplementation through the hydrolysis process. The bioactivity of these peptides might be influenced by different parameters, such as source of protein, degree of hydrolysis (DH), peptide structure, amino acid composition and type of protease used. Furthermore, the amino acid composition of peptides in a protein hydrolysate is entirely dependent on the protein's substrates and the protease used (Najafian & Babji, 2012).

The enzymatic hydrolysis of insects is generally performed on insect homogenates or on insect protein isolates (de Castro et al., 2018). According to Xiaoming et al. (2010) the edible insects are also an important source of lipids, ranging from 10 to 50% on dry basis. Thus, this compound can have several pro-oxidants, such as unstable oxidized lipid substrates and can be removed by pH-shifting process. Prior to enzymatic hydrolysis, a protein isolate can be elaborated by the following steps: homogenization, defatting, protein solubilization, protein isoelectric precipitation and protein solubilization, which may be followed by a drying step (Nongonierma & FitzGerald, 2017).

The proteolytic enzymes most commonly used to the hydrolysis process of insect proteins are of different sources including animal, vegetal and microbial. Enzymes derived from animals, such as pepsin and trypsin, are used in the hydrolysis process of *Bombyx mori chrysalises* (Yang et al., 2013). Some microbial enzymes, such as Alcalase, Flavourzyme and thermolysin have been described for the hydrolysis of insects, such as *Bombyx mori*, *Bombus terrestris*, *Schistocerca gregaria*, *Gryllosid sigillatus* and *Spodoptera littoralis* (Hall et al., 2017; Yang et al., 2013).

The proteases obtained from microbial sources present a low cost, due to the minimal nutritional requirements of the involved microorganisms and short obtainment time. The microbial enzymes are used in the food industry because they have a variability of catalytic actions and can easily suffer genetic manipulation. Furthermore, microbial proteases are as diverse as the microorganisms in nature and the recent technological developments can assess nature's many microorganisms and their products (Carrasco-Castilla et al., 2012). Nevertheless, the use of enzymes from vegetal sources in the hydrolysis process of insect protein appears to be rare. Yang et al. (2013) hydrolyzed *Bombyx mori chrysalises* using the papain enzyme.

The catalytic action of protease enables the peptide bonds to cleave during the reaction, which can be monitored by the degree of hydrolysis (DH). The DH can be defined as the percentage ratio between the number of peptide bonds cleaved and the total number of peptide bonds in the substrate studied (de Castro & Sato, 2014). The DH can be influenced by the specific activity of the protease, the characteristics of

the substrate (protein) and the reaction conditions (Najafian & Babji, 2012). The insect species also governs the DH achieved (Nongonierma & FitzGerald, 2017). Zielińska et al. (2015) elaborated hydrolysates from baked *Gryllosid sigillatus* and boiled *Schistocerca gregaria* using α -amylase, pepsin, and pancreatin, and achieved a DH of 37.76% and 37.65%, respectively. These authors verified that the samples of baked and raw *Tenebrio molitor* showed a DH of 11.32 and 14.78%, respectively. Hall et al. (2017) elaborated hydrolysates with whole crickets (*Gryllosid sigillatus*) using Alcalase and reached DH values ranging from 15 to 85%. The DH influences the bioactivity of the protein hydrolysates because the peptide chain and the exposure of the terminal amine groups of the peptides produced depend on the DH or/and are related to them (Najafian & Babji, 2012).

6.2. Antioxidant peptides

The oxygen is essential for maintaining vital energy production, but, at the same time, reactive oxygen species (ROS), such as superoxide anion (O_2^-), hydrogen peroxide (H_2O_2) and hydroxyl radical ($\cdot OH$), are continuously generated in cellular metabolism, which can be extremely deleterious to cell constituents in high concentrations (Najafian & Babji, 2012). Oxidative stress has been related with cellular toxic processes that can result in numerous pathologies, including chemical carcinogenesis, heart diseases, reperfusion injuries, rheumatoid arthritis and ageing (Rahal et al., 2014).

Table 4 shows the different bioactive properties presented by insect protein hydrolysates. The antioxidant properties of the peptides obtained by *in vitro* gastrointestinal digestion of edible insects were reported by Zielińska, Karaś, and Jakubczyk (2017). Zielińska et al. (2017) showed antioxidant activities of the Dubia roach, Madagascar hissing cockroach, locust, superworm and cricket hydrolysates evaluated using different methods, such as free radical-scavenging activity, ion chelating activity and reducing power assays. These hydrolysates were obtained using different solutions: α -amylase, pepsin, saliva simulator, intestinal juice and the human digestive system. *Amphiacusta annulipes* hydrolysates presented a high antioxidant activity measured by the antiradical activity against DPPH ($IC_{50} = 19.1 \text{ l g/mL}$), Fe^{2+} chelation ability (58.82%) and reducing power (0.652).

Vercruysse, Smagghe, Beckers, and Van Camp (2009) reported the antioxidant activities of peptides from *Spodoptera littoralis* (Lepidoptera) produced by thermolysin, Alcalase and a gastrointestinal digestion simulator containing several peptidases. The antioxidant properties of these protein hydrolysates were evaluated by the FRAP and DPPH methods. The gastrointestinal digestion simulator allowed for the obtainment of protein hydrolysates with 14% of antioxidant activity measured by FRAP and 24% of DPPH scavenging activity.

Hall et al. (2018) elaborated crickets (*Gryllosid sigillatus*) hydrolysates with DH values ranging from 15 to 85%, using Alcalase. These authors verified that the hydrolysates showed lower ($p < 0.05$) ABTS scavenging values (except for the cricket protein hydrolysates with 85% DH) compared with the non-hydrolyzed cricket protein (control). Nevertheless, the cricket protein hydrolysates with DH ranging from 15 to 40% presented higher DPPH radical scavenging activities when compared to the control and the hydrolysates with DH of 50–85%. However, Zielińska et al. (2017) evaluated the antioxidant potential of various insect proteins digested with gastrointestinal proteases and found that the activity varied depending on the insect and not the DH. Nevertheless, silkworm (*Bombyx mori*) protein hydrolysates were prepared with different proteases, including Alcalase, and the results showed a correlation between DH and scavenging activity (Yang et al., 2013). According to Chalamaiah, Dinesh Kumar, Hemalatha, and Jyothirmayi (2012), the ABTS radical is more accessible to hydrophilic peptides, whereas hydrophobic peptides can readily interact with peroxyl radicals, such as DPPH.

The mechanisms through which the protein hydrolysates exert the antioxidant activity are not fully understood; however, it is known that

Table 4
Bioactivities of insect protein hydrolysates.

Raw Material	Enzymes	Degree of hydrolysis-DH (%)	Concentration or volume tested	Bioactivities	References
<i>Tenebrio molitor</i> , <i>Schistocerca gregaria</i> and <i>Gryllobates sigillatus</i>	α -amylase, pepsin and pancreatin	12 to 37	0.88 to 5.88 mg/mL	Cytotoxicity	Zielinska et al. (2017)
<i>Gryllobates sigillatus</i>	Alcalase	15 to 85	1 mg/mL	Angiotensin converting enzyme (ACE) and dipeptidyl peptidase-4 (DPP-IV) inhibition, antioxidant activity	Hall et al. (2018)
<i>Spodoptera littoralis</i>	Thermolysin, Alcalase and a gastrointestinal digestion simulator	Not cited	211 to 1392 μ g/mL	Antioxidant activity and ACE inhibition	Vercruysse et al. (2009)
<i>Bombyx mori</i>	Alcalase	1 to 30	5 mg/mL	Antioxidant activity	Yang et al. (2013)
<i>Tenebrio molitor</i>	Alcalase	20	0.017 to 0.39 mg/mL	ACE inhibition	Dai et al. (2013)
<i>Bombyx mori</i> , <i>Spodoptera littoralis</i> , <i>Schistocerca gregaria</i> and <i>Bombus terrestris</i>	Pepsin, trypsin, and R-chymotrypsin	52.60 to 105.55	25 and 50 μ L	ACE inhibitory activity	Vercruysse et al. (2005)
<i>B. pascuorum</i> and <i>B. terrestris</i>	-	-	200 μ M	Antimicrobial activity	Rahnamaei et al. (2015)

the amino acid constituents and the sequence of the resulting peptides are very important for their antioxidant activity (Sarmadi & Ismail, 2010). Some authors reported that hydrophobic and aromatic amino acids, as well as histidine, methionine, tyrosine, lysine, and cysteine, enhance the potency of antioxidant peptides through proton-donation ability, electron-donation ability, and/or direct lipid radical scavenging ability (Chalamaiah et al., 2012; Da Rocha et al., 2018; Najafian & Babji, 2012). According to Hall et al. (2017), insects peptides with a low molecular weight have more amino acids exposed to interact with free radicals and this improves their antioxidant effect. According to Hall et al. (2018), the high scavenging capacities presented by insect hydrolysates can be a result of smaller molecular weight peptides (likely di- or tri-peptides), which have demonstrated to confer greater antioxidant potential.

6.3. Dipeptidyl peptidase IV (DPP-IV) inhibition

The Diabetes is important problems among the various metabolic disorders, and its incidence is increasing throughout the world. According to the World Health Organization (WHO), about 3% of the world's population have diabetes, and the prevalence is expected to double by the year of 2025 (Abdelatif, Mariam, & Amal, 2012). The type 2 diabetes (T2D) is one of the health problems. About 50–60% of the total insulin secreted after a meal results from incretin response, mainly mediated by the combined effects of glucose-dependent insulinotropic polypeptide (GIP) and glucagon like peptide 1 (GLP-1), and are secreted in response to the presence of nutrients in the intestinal lumen (Sila et al., 2016). Incretins, such as GLP-1 and GIP, are cleaved by DPP-IV resulting in a loss in their insulinotropic activity. Thus, to increase the half-life of the active GLP-1 and GIP, synthetic DPP-IV inhibitors are used as drugs. Thus, blocking dipeptidyl peptidase-IV (DPP-IV) represents an alternative for T2D treatment (Halim, Yusof, & Sarbon, 2016; Ketnawa, Benjakul, Martínez-Alvarez, & Rawdkuen, 2017).

The GIP and GLP-1 can be inactivated by cleavage and/or by the action of serine proteases, such as DPP-IV (Sila et al., 2016; Nongonierma & FitzGerald, 2017). Several DPP-IV inhibitors have recently emerged as a new class of oral agents for the treatment of T2D, including insect proteins hydrolysates produced from crickets (*Gryllobates sigillatus*) (Hall et al., 2018) in addition to and other proteins hydrolysates. However, there are few studies evaluating the antidiabetic properties of other insect-derived proteins (Hall et al., 2018).

Nongonierma, Lamoureux, and FitzGerald (2018) studied the DPP-IV inhibition capacity of protein hydrolysates from tropical banded cricket (*Gryllobates sigillatus*) and verified an improvement in activity of both hydrolyzed and non-hydrolyzed samples. The DPP-IV catalytic activity is mostly determined by the amino acid sequence and by the substrate's structural characteristics, as reported by several authors (Hall et al., 2017; Ketnawa et al., 2017; Neves et al., 2017; Sila et al., 2016).

Hall et al. (2018) elaborated protein hydrolysates from crickets (CPH) and evaluated the DPP-IV inhibition capacity before and after a simulated gastrointestinal digestion (SGD). After SGD, DPP-IV inhibition increased for all samples, with CPH of DH of 60–85% exerting the highest ($p < 0.05$) inhibition between 62 and 69% of DH. The CPH composed of smaller molecular weight peptides (DH of 60–85%) showed the highest inhibitory activity both before and after SGD. Furthermore, according to these authors, the inhibitory activity can be attributed to substrate-like features of CPH peptides that have interfered with the combination of DPP-IV and Gly-Pro-pNa (assay substrate). The peptide Val-Thr-Gly-Arg-Phe-Ala-Gly-His-Pro-Ala-Ala-Gln from the protein hydrolysate revealed the highest α -glucosidase inhibitory activity (Zambrowicz et al., 2015).

6.4. Inhibition of angiotensin converting enzyme (ACE)

The hypertension or high blood pressure is one of most important public health problems of epidemic proportions that affects the population worldwide and it is a factor for cardiovascular diseases (Cheung & Li-Chan, 2017; Nongonierma & FitzGerald, 2017). The anti-hypertensive peptides inhibit the action of Angiotensin-I converting enzyme (ACE) and reduce the arterial blood pressure. This enzyme is able to cleave angiotensin-I and angiotensin-II (a vasoconstriction-releasing compound), as well as to inactivate a vasodilator compound (bradykinin), thus, resulting in an increase in blood pressure (Cheung & Li-Chan, 2017; de Castro et al., 2018).

The ACE inhibitors have been studied as important antihypertensive agents, since they have the ability to lower blood pressure by inhibiting the formation of angiotensin-II. Inhibition of ACE is considered to be an effective approach in the treatment of hypertension, which has been commonly treated with synthetic drugs. However, the search for natural antihypertensive drugs has been studied by important scientific researches, given that synthetic drugs offer numerous side effects to hypertensive patients (Priyanto et al., 2015; Udenigwe & Mohan, 2014).

The different methods for the evaluation of ACE inhibition have been reported using different substrates and analytical techniques. Nevertheless, numerous studies use the cleavage of hippuryl-histidyl-leucine by ACE to release histidyl-leucine dipeptide and hippuric acid, which is measured by spectrophotometry at 228 nm after extraction with ethyl acetate (Priyanto et al., 2015).

The antihypertensive peptides derived from insect hydrolysates have been demonstrated potent inhibitory activity against ACE, as shown in Table 3. There are numerous *in vivo* and *in vitro* studies evaluating the antihypertensive properties of edible insect protein hydrolysates. Dai et al. (2013) isolated the Tyr-Ala-Asn peptides from *Tenebrio molitor* larvae produced by Alcalase hydrolysis and administered it in rats at doses ranging from 100 to 400 mg peptide/kg body weight (BW). These authors verified a moderate ACE IC₅₀ value and the oral administration of Tyr-Ala-Asn caused a significant reduction in SBP, i.e. – 27 mm Hg, 4 h after the intake of the highest dose evaluated (400 mg peptide/kg BW).

Hall et al. (2018) elaborated cricket protein hydrolysates (CPH) and verified that the ACE inhibition increased with DH. CPH with DH values of 40% and 60–85% inhibited ACE activity by greater than 80% and greater than 90%, respectively, at the concentration tested (5 mg/ml). The relationship between the structure and the inhibitory activity is not yet fully established, but, generally, these compounds have between 2 and 12 residues of low molecular weight amino acids and their connection with ACE is strongly influenced by the degree of hydrolysis and by the sequence of the C-terminal peptides (Ko et al., 2016). Furthermore, the active site of ACE interacts preferentially with peptides having hydrophobic C-terminal amino acid residues (aromatic side chain or branched, respectively) (de Castro et al., 2018; Neves et al., 2017).

Vercruyse, Smagghe, Herregods, and Van Camp (2005) observed the presence of inhibitory activity against ACE in protein hydrolysates from different insects, such as Lepidoptera (*Bombyx mori* and *Spodoptera littoralis*), Orthoptera (*Schistocerca gregaria*) and Hymenoptera (*Bombus terrestris*). A subsequent hydrolysis with pepsin, trypsin, and R-chymotrypsin was conducted to simulate the human gastrointestinal digestion process. These authors verified that the insect proteins presented inhibitory activity against ACE; the hydrolysates produced from *Bombyx mori* showed 100 and 50% of ACE inhibition for the gastrointestinal hydrolysates and the non-hydrolyzed samples, respectively.

Vercruyse et al. (2009) also reported ACE-inhibition by *B. mori* hydrolysates with ACE IC₅₀ of 0.61 and 0.24 mg/mL, respectively. The ACE inhibitors peptides derived from insects have been identified, to date, in studies conducted with *Bombyx mori*. Two relatively potent ACE-inhibitors peptides, Val-Phe-Pro-Ser and Val-Trp, having ACE IC₅₀

of 0.46 and 1.50 μ M, respectively, were identified by *in silico* analysis of *Bombyx mori* actin.

6.5. Antimicrobial activity

The antimicrobial peptides (AMP) are gene-encoded, ribosomally synthesized polypeptides. They usually have the following common characteristics: small peptides (30–60 amino acid), strongly cationic (pI 8.9–10.7), stable to heat (100 °C, 15 min), present no drug fastness and effect on eukaryotic cells (Li, Xiang, Zhang, Huang, & Su, 2012). Insects are known to be one of the major sources of AMPs defensins, cecropins, attacins, lebecins and other proline-rich peptides, gloverins and moricins and their application as antimicrobials has been widely studied during the last decades (de Castro et al., 2018).

Rahnamaeian et al. (2015) studied two AMPs isolated from *Bombus pascuorum* and *Bombus terrestris*: abaecin (a proline-rich peptide) and hyme-noptaecin (a glycine-rich peptide). However, abaecin alone was not able to act against *Escherichia coli* at concentrations of up to 200 μ M. Hyme-noptaecin showed microbial activity at concentrations above 2 μ M. However, when combined, abaecin reduced the minimal inhibitory concentration of hyme-noptaecin (IC₅₀ = 0.8–1.1 μ M) leading to the enhancement of its bactericidal effects. Nevertheless, the studies on antimicrobial edible insect hydrolysates are scarce.

The number of AMPs in insects varies significantly according to the different species and they can have different modes of action, such as the production of reactive oxygen species, inhibition of protein synthesis and permeabilization, and rupture or change in the electrochemical membrane gradient (de Castro et al., 2018; Rahnamaeian et al., 2015). Insect AMPs can be classified into four groups: the α -helical peptides, cysteine-rich peptides, proline-rich peptides and glycine-rich proteins (Yi, Chowdhury, Huang, & Yu, 2014).

Cytryńska, Mak, Zdybicka-Barabas, Suder, and Jakubowicz (2007) verified that the hemolymph of *Galleria mellonella* showed eight peptides with molecular weights below 6.5 kDa, which demonstrated antimicrobial activity. Gram-positive bacteria were more sensitive. About four of the purified peptides inhibited yeast growth, five were active against *Micrococcus luteus*, and four of these five were effective against *Listeria monocytogenes*, but in a relatively high concentration range.

7. Future prospects

The insect farming produce fewer greenhouse gas and uses less water and space than beef, chicken and pork. Furthermore, as cited, are also good sources of protein, fiber and fatty acids. The burgeoning edible insect industry churns out protein bars, pastas and chips made from insects (FAO, 2013; Hall et al., 2018; Nongonierma & FitzGerald, 2017; Zielinska et al., 2016). In view of the growing market demand for edible insects and considering the inclusion of this new source as food, it is very important, from the point of view of food safety, that some parameters needed to be evaluated. Analyzing the available bibliography, it is clear that only a small range of edible insects is studied for this purpose. Few studies consider the risk of allergies or other important parameters when consuming insects (Nongonierma & FitzGerald, 2017). It can also be seen that studies are more directed to the protein fraction contained in insects. Studies evaluating the lipid and saccharide fraction are still smaller. Studies are also needed proposing the extraction of insect components in order to replace these components in processed foods. Studies directed at the extraction and purification of specific components, such as enzymes, for use in the pharmaceutical area were not found.

In the other hand, the insect-based products are very much an emerging value chain. Thus, that there will be challenges, such as in legislation and the regulation of the edible insect sector, which cannot be solved by individuals. Therefore, stakeholders need to work together to further their common agenda, strengthen recognition for their activities and increase their bargaining power (FAO, 2013; Nongonierma

& FitzGerald, 2017).

8. Conclusion

This review has shown that certain edible insects represent good potential sources of proteins, amino acids and lipids, among other molecules. These insects have a balanced nutrient profile, and amino acid requirements for humans. Furthermore, entomophagy may be a key idea to some of the world's food problems, such as undernutrition and starvation. Edible insects and foods enriched with insects may potentially prevent several health problems, such as diabetes, hypertension, and cardiac problems, through the elaboration of protein hydrolysates. Although the number of studies using insects as a source of food is increasing, there is still a need for further investigations in several fields.

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.

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