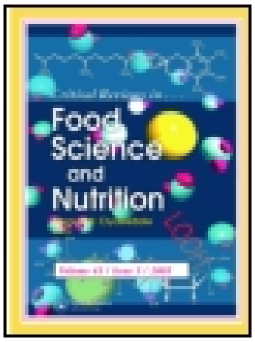

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

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To cite this article: Nelson Mota de Carvalho, Ana Raquel Madureira & Manuela Estevez Pintado (2019): The potential of insects as food sources – a review, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2019.1703170

To link to this article: https://doi.org/10.1080/10408398.2019.1703170

Published online: 23 Dec 2019.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2019.1703170

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REVIEW

The potential of insects as food sources – a review

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ABSTRACT

Entomophagy is a long-time practice and a food source for many cultures. Still, many societies have abandoned it a long time ago, and regard it as a primal behavior. However, nowadays, the challenge for food demand, with the urge of new nutritional sources, and the problems of undernourishment, mainly on underdeveloped countries, has reached a point where a new perspective is demanded. This review gathers some of the most recent studies regarding the potential benefits and concerns of entomophagy, trying to show the potential of insects as food source and possible ways to introduce them in cultures that have disregarded entomophagy. Entomophagy is taking its place, showing the grand potential of insects as feed and food source. As neophobia and disgust are the main western cultures barriers to accept entomophagy, today's comprehension of this practice and processing capabilities can take that source, to any dish in any form. A simple but nutritive insect powder can create a path to a widely, sustainable, rich food source—insects.

KEYWORDS
Edible insects; insect powder; neophobia; nutrition

Introduction

Nutrition is independent from cultural differences and has been seen as "the need to feed". Nevertheless, food habits are very different between cultures. Globalization brought together different generations and cultures over the whole world, showing at the same time, the differences, similarities and complementing aspects between them. These differences are especially observed in the type of foods or delicacies found worldwide. As example, insects that are widely eaten in Africa, South America and Asia but not so well accepted in western countries (Ayensu et al. 2019; de Castro et al. 2018; Shockley and Dossey 2014). Nevertheless, this food, owing to the composition rich in nutrients, especially protein, can be the solution for several problems associated with hunger and (under) malnourishment.

Worldwide, it is acknowledged that nutritional disorders are among the major causes of death. The acknowledge "triple burden" of malnutrition as highlighted by FAO (2017) consists of undernourishment, micronutrient deficiencies and overweight and obesity, these dimensions remain yet a "global health emergency", leading as main concerns affecting worldwide population. It is estimated that 11% of the world's population starves, two billion are affected by micronutrient deficiencies and 40%, by 2014, of the world's population had overweight and/or obesity (FAO 2017). Looking at these facts, malnutrition is a pertinent subject when it comes to individual and community health. The most alarming situation is that these numbers grow by the minute, and we are still struggling for a rapid and efficient solution.

Along with the idea of nourishment and health, a link to the maintenance of the gut microbiota can be established. The type of diet changes the composition and the activity of the complex microbial population in the gut, therefore malnutrition and dietary habits, can have an impact in the hosts well-being (Conlon and Bird 2014; Derrien and van Hylckama Vlieg 2015). Any gut microbiota variations can lead to dysbiosis, obesity, type II diabetes and even impact the maintenance of the immune system (Hemarajata and Versalovic 2013; Saraswati and Sitaraman 2015; Wang et al. 2017). The search for a nutritional source, capable of supporting the population demands in terms of availability, nutritional values and sustainability is not only a need but also a health pursuit.

Studies suggests that insects can, in the near future, be a solution to the presented demands as they are a rich source of protein, fiber and fatty acids (Ayensu et al. 2019; de Castro et al. 2018; Giron et al. 2017; Patel, Suleria, and Rauf 2019). Studies can reveal the true impact and relevance of insects as a balanced nutrition source, with benefits for the human gut microbiota as stated by Stull et al. (2018) and de Carvalho et al. (2019).

This review presents itself as an objective overview of the introduced themes, by establishing connections between identified problems, namely those derived from malnutrition, and near future solutions in the nutrition field, envisioning insects as a possible nutritional source.

Worldwide nutritional problems

Questions nowadays arise, when, at long term, the possibility of achieving 9.7 billion in world population by 2050, and

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possible peaking up to 11 billion by the end of the century, brings the urgent need for sustainable feed and systems that support such endeavor in terms of impact at ecological and land pressure dimensions, production and transformation capabilities, regulations, waste and even policy coherence (FAO 2017).

Over time, challenges have become bigger, more concerning, and more urgent when it comes to the populations feeding needs. The demands of a balanced nutrition make that task even harder to achieve. It is no more only a question of food sources, but also of policies that allow the development of new solutions and food sources, capable of responding to all those requirements.

Insect and nourishment

In nature itself, insects are a significant biomass resource distributed across aquatic, forest and agricultural ecosystems (de Castro et al. 2018; New 2009). Insects can be largely found in every continent and there are historical records that confirm that they have been consumed by humans in all continents except in Antarctica (Costa-Neto and Dunkel 2016; Schrader, Oonincx, and Ferreira 2016). There is a large percentage of recorded edible insect species in Mexico, India, and generally in Southeast Asia, contrasting with very low percentages in Europe and North America (Halloran et al. 2014; Shockley and Dossey 2014; Vantomme 2015).

Mass production of insects is viable, and may satisfy nutritious and protein demands, compared to other sources as meat or fish. Edible insects are for a long time now a part of human diet, especially in tropical countries (Sun-Waterhouse et al. 2016; van Huis 2016). Among the most commonly consumed insects are ants, bees, crickets, flies, etc., but their consumption has become uncommon in western societies, even when insect proteins possess nutritional advantages toward plant protein (Patel, Suleria, and Rauf 2019; Rumpold and Schlüter 2013; Zielińska et al. 2015). Insects also have advantages toward animal meat due to their high-quality protein content and even over lipids, vitamins and minerals (Sun-Waterhouse et al. 2016).

Nutritional problems, economy and environment

The nutritional challenges presented today and the search for possible solutions become more relevant as global population grows. Along time, even with several measures being taken, those challenges remain and get even more demanding when faced to actual economic and social needs. Dynamically, nutritional challenges may vary and differ between and within population groups, but the focus remains—to investigate and develop practices and methods aiming the fulfillment of the population nutritional needs worldwide, the most economical and efficiently possible. On the other hand, mainly on developed countries, where nutritional challenges are different, one new demand is for foods that are perceive as healthy or that promote health (Ali, Alam, and Ali 2015).

As stated above nutritional needs are a demanding social problem, but nevertheless we cannot deny another urgent need—the sustainability. As it sits, the global pressure over biomass resources and land, is taking the demand into a crisis's situation, even on the meat production. Also, the resources needed to cope with actual demand are being too much and their starting to have their own negative effect on the planet (Garofalo et al. 2017; Poma et al. 2017; Premalatha et al. 2011). For the above stated, growing foods and efficiently using biomass resources is a priority, aiming sustainable farming practices (Sun-Waterhouse et al. 2016).

Sustainability, economics and insect-based food

To establish new ways in search of alternative nutrient sources along with sustainable practices, entomophagy, the human consumption of insects, presents itself as an efficient solution. It is a solid alternative, as it is a practice that has been taken on for a long time in some cultures (e.g. from Southeastern Asia). The consumption of insects is part of the traditional diet of 2 billion people worldwide (Halloran et al. 2014; Vantomme 2015). Insects as food and feed are a growing concepts because of its advantages toward health, the environment and livelihoods (Gmuer et al. 2016). Insects spend less energy and nutrients than the normal livestock animal, they are more efficient in generating proteins from phytomass, have a fast growth rate and have a good nutritive value. Insect farming has environmental and economic implications, since insects are easily maintainable, require fewer resources and, at the same time, have a smaller impact on the environment, mainly on the production of greenhouse gases (GHG) and water consumption compared to common livestock farming. These factors turn insect production a possible eco-friendly industry (La Barbera et al. 2020; Oonincx et al. 2010; Payne et al. 2016; Premalatha et al. 2011; Sun-Waterhouse et al. 2016).

Besides their efficiently conversion from plant proteins to insect proteins, they can also be raised efficiently using bio-waste streams, making insect production economically viable and its mass production satisfy many nutritional demands (Oonincx and De Boer 2012; Oonincx et al. 2015). Compared to common livestock farming, insect farming has increased feed-conversion efficiency, decreased GHG emission, reduced water pollution, smaller land use and low environmental contamination (Fischer and Steenbekkers 2018; Oonincx et al. 2010; van Huis et al. 2013; Sun-Waterhouse et al. 2016). In these perspectives, insects for human and animal consumption show a good potential as nutritive and sustainable efficient source, nevertheless the available information on the extent of their impact, mainly on the environment, is still scarce. As an example, it is yet necessary to attend to the complications on insect production systems to understand their environmental impact (Halloran et al. 2016). Overexploitation has been reported as one of the possible problems of insect farming, leading to habitat change and pollution when non-sustainable harvest practices are applied (van Huis 2017). In other hand, as a primary concern becomes the GHG emissions, insects seem

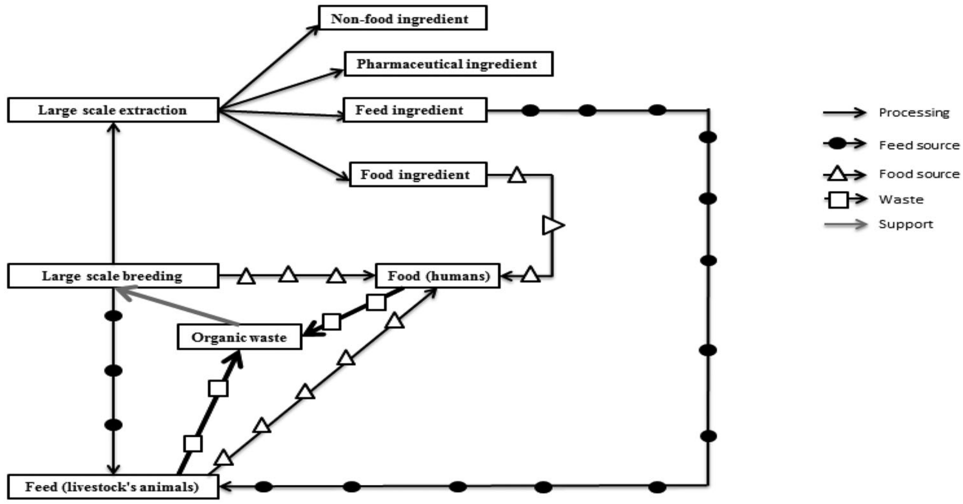

Figure 1. Edible insects' system of production in a circular economy concept. Adapted from van Huis et al. (2013) and Belluco et al. (2013).

to indicate better results than common livestock species (e.g. poultry, pigs and cattle), as they are more efficient into converting protein into animal protein and feed energy into food energy, with an expected higher feed conversion ratio. However, more data is necessary to corroborate these findings, as it is known that insect production produces large amounts of methane, which is a GHG, and the conditions of light, temperature and CO_2 and O_2 concentration will influence the production of this gas. In addition, it is not yet fully recognized the real impact of the insect's production waste, as it is associated with the production of methane and ammonia (Halloran et al. 2016).

Enlarging their economic potential, insects have short reproduction cycles, a high widespread distribution and high reproductive rates. They do not require large areas and they can be raised on a wide range of foods (Sun-Waterhouse et al. 2016).

Some surveys indicate that edible insects price exceed traditional meat products (Agea et al. 2008).

Nevertheless, if industrial insect production is increased and taken along with sustainable breeding, farming and processing technologies, this may boost their market availability and at the same time lead to its sale price decrease (Sun-Waterhouse et al. 2016).

Insects can then be introduced for food or feed as possible nutritional source. Insects can be an acceptable choice to meet nutritional dietary demands as for feed, for example as feed additives for animals, capable of improving their gut health, and as for food, for example insect-based products. This poses a new dimension, as people will then be direct or indirectly insect consumers (La Barbera et al. 2020; Sogari et al. 2019). Few studies up to now have suggested that consumer acceptance will not be a barrier for the development of insect protein industry for feed (Sogari et al. 2019). The market dynamic, may help introduce insects in nutrition of both animal and human, at the industry level, where it may be possible for both parties to benefit from this nutritional source and at the same time to help improve its acceptance and lower possible disgust attitudes (as correlated to Figure 1).

In such perspective, insects could then be an option as quality products, with possible environmental gains, when considering their potential as feed ingredients for fish, pets, poultry or pigs, and even for human direct and indirect consumption (Sogari et al. 2019; van Huis 2017).

Insects' nutritional value

Insects are food sources of high-quality protein, lipids, carbohydrates, mineral elements and certain vitamins (de Castro et al. 2018; Garofalo et al. 2017; Zielińska et al. 2015). Its mass production has great potential to provide animal proteins to humans and to livestock animals (for example poultry or pigs) through direct consumption or as food supplements (Mlcek et al. 2014; Premalatha et al. 2011; Sogari et al. 2019). This is not new, since so many nations have already used insect for those purposes (Mlcek et al. 2014).

One issue that is very important to highlight is that not all insects have the same nutritional values. Nowadays, there are thousands of identified insect species considered edible, and each one with its own characteristics (Fischer and Steenbekkers 2018; Giron et al. 2017; Klunder et al. 2012; Shockley and Dossey 2014). The nutritional content is no exception in terms of variability as it can be seen in Table 1.

The high protein content present in insects show us as an indicator of a possible valuable resource as human and animal nutritional source with a possible introduction as a diet on developing countries replacing higher animal protein absence. And also, the protein content from insects is generally of good quality and highly digestible (Kouřimská and Adámková 2016; Mlcek et al. 2014). The content of essential amino acids in insects is 10–30% of all amino acids (Chen, Feng, and Chen 2009). Nevertheless, it is necessary to keep in mind that nutrient content may differ from wild to commercially farmed insect species, and that their growth stage also has an impact on the content of some substances (Klunder et al. 2012). For example, adults of *T. molitor* contain more protein (237 g/Kg) than their larvae (187 g/Kg) (Oonincx and Dierenfeld 2012). The presence of amino

Table 1. Nutritional values of some relevant insects regarding other high-protein foods. Adapted from Finke (2002) and Shockley and Dossey (2014).

Insect or food item common name	Scientific name	Protein (g/kg)	Fat (g/kg)	Calories (kcal/kg)	Thiamin (mg/kg)	Riboflavin (mg/kg)
Black soldier fly (larvae)	*Hermetia illucens*	175	140	1994	7.7	16.2
House fly (adults)	*Musca domestica*	197	19	918	11.3	77.2
House cricket (adults)	*Acheta domestica*	205	68	1402	0.4	34.1
Superworm (larvae)	*Zophobas morio*	197	177	2423	0.6	7.5
Mealworm (larvae)	*Tenebrio molitor*	187	134	2056	2.4	8.1
Mealworm (adults)	*Tenebrio molitor*	237	54	1378	1	8.5
Giant mealworm (larvae)	*Tenebrio molitor*	184	168	2252	1.2	16.1
Waxworm (larvae)	*Galleria mellonella*	141	249	2747	2.3	7.3
Silkworm (larvae)	*Bombyx mori*	93	144	674	3.3	9.4
Beef	–	256	187	2776	0.5	1.8
Milk powder	–	265	268	4982	2.6	14.8

acids in a diet is essential. Amino acids are the basic units of proteins and contribute as much for food nutrition, as to physical and sensorial proprieties. Amino acids are required for the biosynthesis of all proteins on the human metabolism and they can ensure its proper growth, development and maintenance. From the role of amino acids, eight of them are considered essential and indispensable because the human body cannot synthesize them, the essential amino acids—isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. These amino acids can only be obtained from food sources (van Huis et al. 2013). The composition in essential amino acids is depicted in Table 2 for *T. molitor*.

Table 2. Average content values of essential amino acids present in *Tenebrio molitor* and beef. Adapted from van Huis et al. (2013).

Essential amino acid	*T. molitor* (g/kg dry matter)	Beef (g/kg dry matter)
Isoleucine	24.7	16
Leucine	52.2	42
Lysine	26.8	45
Methionine	6.3	16
Phenylalanine	17.3	24
Threonine	20.2	25
Tryptophan	3.9	–
Valine	28.9	20

By weight, yellow mealworm larvae (*Tenebrio molitor*), one of insect species commonly bred in Europe has significantly higher contents of linoleic acid, isoleucine, leucine, valine, tyrosine, alanine and vitamins (except B12) than beef (Kouřimská and Adámková 2016; Mlcek et al. 2014; Sun-Waterhouse et al. 2016). Insect as food source (e.g. *T. molitor*) can satisfy the nutritional needs concerning the essential amino acids, and in some cases, in a higher percentage compared to more "common" food sources, as beef.

Fat content present in the edible insects is normally between 10–50% but it depends on many factors such as species, habitat, diet, reproductive stages, season, age and sex (Kouřimská and Adámková 2016; Mlcek et al. 2014). Insects present higher values of essential fatty acids than animal's fats, with high quality, especially on long chain omega-3 fatty acids (e.g. α-linoleic acid) (Mlcek et al. 2014). The omega-3 long chain polyunsatured fatty acids have important roles in the building of cerebral tissues (Carlson and Kingston 2007).

The carbohydrates present in insects (6.71–15.98%) are mostly found in the form of chitin (Raksakantong et al. 2010). Chitin, a poly-beta-1,4-N-acetylglucosamine, is insoluble in water and is the second most abundant polysaccharide in biomass after cellulose, and the main component of arthropod exoskeletons. It can be a source of nitrogen as well as carbon (Hajji et al. 2014; Khoushab and Yamabhai 2010). Generally, chitin represents 5–20% of dry weight of insects (Kouřimská and Adámková 2016; Mlcek et al. 2014).

Recent studies show that considerable amounts of polysaccharides might improve human immune functions (Mlcek et al. 2014; van Huis 2017). Chitin can be consumed as a form of low-calorie food with high nutritional, health and medical value (Burton and Zaccone 2007; Chen, Feng, and Chen 2009; Kouřimská and Adámková 2016). Chitin may promote selective growth of important bacteria populations in the human gut microbiota. These bacteria are responsible for maintaining the physiological state of the gut, for protection of organism immune system, efficiency of the metabolic process and it may even play a role in the prevention/reversion of modern disorders (e.g. diabetes and obesity) (Delzenne and Cani 2010; Geurts et al. 2013; Neyrinck et al. 2012). Chitin, however, may have negative impact on humans, as it will be later discussed. In addition, edible insects are rich in minerals elements, such as potassium, sodium, calcium, copper, iron, zinc, manganese and phosphorus, possibly due to their food sources (Ayensu et al. 2019; Kouřimská and Adámková 2016; Mlcek et al. 2014; Patel, Suleria, and Rauf 2019). They also contain carotene and vitamins B1, B2, B6, C, D, E and K. Insects apparently may be a good sources of vitamins B, but a number of insects have low levels of thiamin (vitamin B1) as it is possible to see in Table 1 (Mlcek et al. 2014).

Therefore, insects present themselves as excellent nutritional sources that even exceed the traditional nutritional sources, as can been seen in comparison of *T. molitor* versus beef in Tables 1 and 2.

Human nutrition and the link to gut microbiota

As an assessment of the well-being is essential, recent studies have proven it link to the maintenance and modulation of the gut microbiota (Carvalho et al. 2018; Ercolini and Fogliano 2018). The composition and function of the gut microbiota is altered by diet, and therefore by the eating habits (Ercolini and Fogliano 2018; Graf et al. 2015; Telle-Hansen, Holven, and Ulven 2018). This impacts on one of the roles of the gut microbiota—the production of short chain fatty acids (SCFA) (Brüssow and Parkinson 2014; Louis, Hold, and Flint 2014; Ríos-Covián et al. 2016). SCFA have been proven to impact the function of the gut itself and of the human body (Zhao et al. 2016). One example of SCFA, is acetate, which is an essential co-factor/metabolite for the growth of bacteria, provide the ability of bifidobacterial to inhibit enteropathogens and reduce the appetite of the host trough the interaction with the central nervous system (Ríos-Covián et al. 2016; Rowland et al. 2018). Diet is one of the most important factors influencing the gut microbiota with a large range of effects to the host (e.g. affect intestinal permeability) (Carabotti et al. 2015; Fung, Olson, and Hsiao 2017; Mayer, Tillisch, and Gupta 2015; Powell, Walker, and Talley 2017).

Insects as food sources have a potential to provide benefits to the human health thanks to their already mentioned nutritional value. However, it is necessary to consider that the transformation of the food matrix (e.g. boiling) changes the nutrient digestibility of the product (Ercolini and Fogliano 2018). The gut microbiota brings an enormous potential to the host, and diet, by modulating the microbiota function and composition, is a key factor in such potential (e.g. inflammatory and immune statuses) (Ercolini and Fogliano 2018; Graf et al. 2015).

The possibility of reaching the gut and provide nutrients to the microbial populations present in it, is an interesting research field in order to understand how the consumption of insects can influence the modulation of the gut microbiota, the hosts metabolism and therefore health.

Insect hazards

Not all insects are safe to eat, and they can be vectors of zoonotic agents and carry toxins to humans. Microbiological contamination is also a main concern (Belluco et al. 2013; Rumpold and Schlüter 2013). Along this, it must be also considered the dangers of consuming the inappropriate developmental insect stages, of wrong culinary preparations or even of the wrong insect handling (Mlcek et al. 2014). The risk of pathogens is even higher considering the "raw" practice of entomophagy, discarding cooking processes. Also, the problem of collecting insects in nature that can carry on their systems pesticides and herbicides turning their consumption dangerous to every organism in the food chain, increasing the odds of toxicity to humans after ingestion (Mlcek et al. 2014). The way that insects deal with biological and chemical contaminants is then a concern (van Huis 2017). Species like the African silkworm have to be subject to heat treatments for detoxification and thus making the worm a safe source of high-quality protein; otherwise, their consumption could lead to acute ataxic syndrome (Nishimune et al. 2000).

Edible insects present themselves as a low risk food and feed for humans and animals as they belong to the "normal" diet of some humans and livestock animals (e.g. poultry, pigs and fish). Despite the nutritional qualities of some insects, they may pose a risk of allergy to humans that already have allergies to others arthropods (e.g. shrimp, lobster, crayfish, dust mites) (Halloran et al. 2014; Mlcek et al. 2014).

Allergy is a potentially life-threatening situation and a big risk when considering the entomophagy practice or just even the contact with insect products (Belluco et al. 2013). Sensitivity to insect proteins has been observed when inhalation and/or contact occur with particulate airborne insect products (Mlcek et al. 2014). Upon the idea of reported allergic reactions, it is significant those concerning chitin. Although not entirely consider as a potential allergen, chitin can many times cause sensitization and it is a recognition element for tissue infiltration by innate cells associated with immunity (Mlcek et al. 2014; Patel, Suleria, and Rauf 2019). Studies showed that inhaled particulates from *T. molitor* are potent sensitizers and may lead to asthma, thus making the *Tenebrionid* family beetles potentially significant allergens (Bernstein, Gallagher, and Bernstein, 1983; Mlcek et al. 2014). Chitin may also present digestibility problems. It is usually considered as an indigestible fiber for humans, despite the presence of chitinases in human gastric juices (e.g. AMCase and chitotriosidase) as it may be inactive in some humans (e.g. European countries), while in others the chitinase response in their body prevails (e.g. people from tropical countries) due to their traditional diets containing insects. This could be related to the absence of chitinous food in the western diets. A possible approach to this problem would be the removal of chitin of these insects and improve the digestibility of their protein (Belluco et al. 2013; Dobermann, Swift and Field 2017; Kouřimská and Adámková 2016; Mlcek et al. 2014; Muzzarelli et al. 2012; Paoletti et al. 2007).

Besides these threats, it is still taken in account the microbial, physical chemical and parasitical risks.

On the insect's microbiota, two perspectives are considered, the microbiota intrinsically associated with insects, and the microbiota introduced during farming and processing. Therefore, bacterial hazards must be considered in relation to the residential insect's microbiota as to the one related to the feed, handling, processing and preservation (EFSA Scientific Committee 2015).

Zoonotic pathogens are present in substrates but, in the insect's intestinal tract, active replication of the pathogens does not seem to happen. On non-processed insects, pathogenic bacteria (e.g. E. *coli*) may be present due to the used substrate and the rearing conditions. The risk of transmission of these bacteria may be decreased through effective processing. In addition, pathogenic viruses in insects intended for food and feed are not considered hazardous for vertebrate animals and humans (EFSA Scientific Committee 2015). As so, in these steps it should be considered the possibility of parasitic hazards that may lead to infections or even death, however the environment of a well-managed closed farm would not allow the completion of the parasite's life cycle (EFSA Scientific Committee 2015; Pereira et al. 2010). Microbial safety of edible insects is therefore relevant mainly during insect handling and/or processing.

The chemical hazards can include those of natural occurrence, the ones synthesized or accumulated by insects or even those added during food processing (Sun-Waterhouse et al. 2016). Finally, insects can produce poisons that may accumulate heavy metals from the environment (Zagrobelny et al. 2009).

The transfer of heavy metals from substrates seems to be the most important route for contamination in insects. Such accumulation will depend on insect species, growth stage, and the heavy metal. In cases of insects with a short life cycle, bioaccumulation is less likely to happen. Nevertheless, data on contamination thru substrate is still limited.

In addition, external contamination factors should not be disregarded, such as some physical hazards as stones, glass, plastic or metal fragments.

Insect food acceptance by the world population

Insects are eaten as food across the history of mankind. For example, in Thailand, wasps, bamboo caterpillars, crickets and other insects are eaten by rural people and served to local and foreign people as a delicacy (Yen 2015). In China, along with the entomophagy practice, insects are commonly found on restaurant menus and medicinal practices (Chen, Feng, and Chen, 2009). On the other hand, western societies tend to show phobias and disgust toward eating insects. Some exceptions may occur, but the urge is to try to take entomophagy to western societies even because these are normally recognized as role models and their acceptance and practices may take other cultures to follow (Sun-Waterhouse et al. 2016).

Many cultures around the world consume insects as a normal part of their diet or as a delicacy. Up to 80% of the world's nations eat insects with greater representation of the countries located in the tropics. Example of that is, in Africa, Ghana, where winged termites are a popular dish and are prepared in different ways. In Asia, Thailand, local bars serve fried bugs as the salty complement to beer. In Oceania, Australia, a standard of the aboriginal diet is roasted witchetty grub, which the flavor is not that quite different from almonds. In Americas, more precisely in Mexico, is possible to find and consume, in the street Taco Carts, agave worm, chapulines (grasshoppers) and escamoles (ant eggs) (van Huis et al. 2013).

Some researches indicate that people are becoming increasingly aware of the many possibilities of insects as food (Caparros Megido et al. 2014; House 2016; Mlcek et al. 2014). Nevertheless, some people have aversion to new foods (food nephobia) becoming the acceptance of insects as food difficult (Patel, Suleria, and Rauf, 2019; Verbeke, 2015), and others have disgust for this kind of food. Neophobia and disgust have been the major barriers on the acceptance of insects as food or food source (Fischer and Steenbekkers 2018; La Barbera et al. 2018; La Barbera et al. 2020). These are big issues considering entomophagy especially in Western cultures, which have negative perceptions of insect products (Gmuer et al. 2016). Neophobia is the tendency to avoid unfamiliar food, and it has been develop and validate an instrument to access, quantitatively, this "avoidance", the Food Neophobia Scale (FNA) while, disgust, is consider a basic emotion, and protects individuals from any potential source of disease. In this matter (disgust), La Barbera et al. (2020) validated a new instrument capable of measuring individual's attitudes toward the eating of insects—the Entomophagy Attitude Questionnaire (EAQ), and in their work found that it can predict intention in both direct and indirect entomophagy.

Research shows that neophobia affects people's willingness to eat insect-based food (Alemu et al. 2015; La Barbera et al. 2018; Pedersen 2014; Tan et al. 2016; Tan, van den Berg and Stieger 2016; Verbeke 2015) and disgust is mentioned in the case of entomophagy. Especially within western societies, many times due to associations between insects and insect-related items (e.g. feces and decaying matter) to the attitudes toward them (La Barbera et al. 2018; Mancini et al. 2019). These aversions decrease the probability of accepting insects as a food source, which could be a meat substitute (Verbeke, 2015).

In this subject, some studies have been made, showing that, concerning insects as food substitutes for meat, insects are rated much more negative than other alternatives, and that very few people (among a Belgium sample group) are willing to consume insects. Even those with ecological concerns were just as adverse (Schösler, De Boer, and Boersema, 2012; Vanhonacker et al. 2013). De Boer, Schösler, and Boersema (2013) appointed the aversion of a Dutch group study to snacks based on insect proteins. Caparros Megido et al. (2014) showed satisfaction on eating insects among consumers with such interests, or the evidences of marketed products with insect as food or as protein source in western countries (UN News Centre, 2013). Also, restaurants have been increasingly using insects in dishes (Cunningham and Marcason 2001; Schösler, De Boer, and Boersema 2012; Verkerk et al. 2007). The aversion to insect food is then the big social-cultural challenge, especially among western communities, which acceptance of insect-based foods probably faces adaptation to flavor profiles, textures and dish esthetics (Hartmann et al. 2015).

Despite all these possibilities, a study by La Barbera et al. (2018), showed that making insect food more familiar does not make it more acceptable. A set of strategies can be appointed as possible ways to approach the disgust factor, e.g. the dish presentation, the recipe choices, sensory information and social learning (relating it to change of attitudes toward insects). All these can be subject to further study to find paths capable of improving consumer acceptance of insects or insect based food (La Barbera et al. 2018, La Barbera et al. 2020; Mancini et al. 2019).

Insect products

Insects can be used as food/feed ingredients/additives or even be consumed for medicinal purposes. Many insect products are already used in our day-by-day like bee honey, food coloring, royal jelly, propolis and others (Schabel 2010). Insect based foods and its processing should, at the same time, maximize retention of nutrients and bioactives components, and, in some cases decrease the human "disgusting" perception, along with potential allergens by efficient technologies.

As already mention before, there are many edible insects spread around the world. The most common insects consumed are *Coleoptera* family (e.g. beetles). Other families that are also consumed as well are, in decreasing order of consumption, *Lepidoptera* (e.g. caterpillars), *Hymenoptera* (e.g. wasp, bees and ants), *Orthoptera* (e.g. grasshoppers and crickets), *Hemipteara* (e.g. cicadas), *Isoptera* (e.g. termites), *Odonata* (e.g. dragonflies) and *Diptera* (e.g flies) (Costa-Neto and Dunkel 2016; van Huis et al. 2013). The consumption of those insects can be of the most varied forms, depending of the region, and treated as standard dish or as a delicacy.

In the actual market insects may be found as food ingredients, for instance mealworm/cricket powders, roasted seasoned mealworms/crickets, mealworms prepared with sea salt and pepper or even toffee and crickets with honey mustard and chili lime. Insects can also be found on prepared/processed products such as lollipops, flavor bars, mixed with chocolate, in granola or even in biscuits and crackers.

A large array of products is available for the consumer, however the most recognized and well-established products in the market belong to a selected few companies. In the product itself, the ingredient usage is sometimes limited in the sense of the insect products present - maybe due to consumption history and acceptance many presented products based on a specific insect like crickets and mealworms.

As a proven source of proteins, lipids, carbohydrates, vitamins and minerals, insects show a great potential as food source. Its introduction is not needed in many cultures, but this subject may be open to discussion, mostly on developed countries, mainly for cultural habits.

Insect consumption is, in many countries, far from being a habit, causing lack of demand and consequently a lack of offer and product development. Today we may say that entomophagy is slowly coming as an option. Market offers products containing derived insect products. The design of insect-based products has to aim the retention of nutrients and bioactives, and at the same time to familiarize people with this source, altering people's perceptions about it. A tailored use and manipulation of insect foods for human is then required. The appropriate food formulations and processes may facilitate insect food to be incorporated in consumeŕs diets by creating particular flavors/textures (Sun-Waterhouse et al. 2016). The choice of recipes and the way dishes are present are two other ways to avoid the disgusting factor (La Barbera et al. 2018). The success of such product implementation on the market will depend on consumer acceptance (La Barbera et al. 2020).

The degree of processing of insect food can also influence people's acceptance and reduce the negative emotions toward the entomophagy (Schouteten et al. 2016). Appropriate food formulations and processes may smooth the introduction of insects as an edible source. Creating insect ingredients for specific foods and/or dishes may also be a path to take (Sun-Waterhouse et al. 2016). Especially in places where entomophagy is not a current practice, there is the preference of incorporating insects in food in a way that they are not visible or not perceived as such. This could take entomophagy to many of those with neophobia. The insect transformation, making them unrecognizable, may facilitate its consumption (Mitsuhashi 2010).

Some recipes can be executed with resource to pulverized insects and show good acceptance and similar aspect to those executed with "normal cooking ingredients". Tortilla, with *T. molitor* larvae powder is an example, furthermore having increased total protein, fat content and essential amino acids (Mlcek et al. 2014). To incorporate insect powders in our daily life dishes is possible and it is very easy to do it. It is possible to prepare cakes, muffins, cookies, smoothies, juices, protein bars, pancakes, protein shake and other recipes. Therefore, it is not very difficult to insert insect flours in the western modern lifestyle; it is only a question of time.

However, it must be taken in consideration that insect processing affects its nutritional potential, thus it implies the control of the processing conditions not as to lose protein and vitamin percentage (Kinyuru et al. 2010).

Regulatory restrictions and measures

The regulatory framework for food and feed has developed significantly in recent times, standards and regulations for the use of insects as ingredients for food and feed may be found mainly in the European Union legislation for food and novel food.

In the European Union (EU) major barriers are found when considering large scale insect market establishment like the strict sanitary regulations for setting up farms, the lack of guidelines for the mass-rearing of insects and of clarity on the authorized insects for market by the EU Novel Food recommendations, the deficient information about the eaten species prior to 1997 and restriction to the feeding of poultry and pig with processed animal protein. Before July 2012 this restriction was also applied to farmed fish but starting at this date a regulatory relaxation for feeding aquaculture species was agreed (van Huis et al. 2013).

In 2015, the European Parliament and the Council of the European Union established the Regulation (EU) 2015/2283 on novel foods, not only updating its definition, but also updating the criteria for food to be considered as novel food and reestablishing the novel food status, its procedures for placing it in the EU market along with the necessary safety and scientific requirements (Official Journal of the European Union 2015).

The EU Standing Committee on Plants, Animals, Food and Feed (SCoPAFF) endorsed a regulation authorizing the insect protein use for fish food (Entomo Agroindustrial, 2016). This regulation was adopted during 2017 in the Commission Regulation (EU) 2017/893 of 24 May 2017, thus allowing processed animal protein derived from farmed insects to be used as feed for aquaculture animals (Official Journal of the European Union 2017).

Food regulatory bodies as the European Food Safety Authority (EFSA), Food Standards Australia and New Zealand (FSANZ), United States Food and Drugs

Administration (US FDA) and Health Canada have been working on regulations and guidelines on edible insects.

The Novel Food concept (food that was not used for human consumption to a significant degree in the European Union before 1997) help on the establishment of rules and standards for insects as human food, mainly at some national levels within the EU. It also must be considered the idea of "foods from third countries" (as described on Regulation (EU) 2015/2283), where the novel food definition applies to the EU, and they are derived from primary production, according to proper regulation, regardless of whether, or not, they are processed or unprocessed. Novel foods must comply the obligations regarding the definition itself, the procedures for determining its status, the requirements for placing them into market, and comply with the general conditions for inclusion of novel foods in the Union list, all this according to the EFSA and the European Commission (Official Journal of the European Union 2015).

Efforts have to be developed in the sense of promoting standardization, national and internationally, for insects as food and feed, premarket safety evaluations have to be conducted regarding the Codex Alimentarius, standards and frameworks have to be established for the insect industry, and studies are necessary in order to evaluate the impact of such sector regarding the environment and sustainability (van Huis et al. 2013).

Conclusions and future perspectives

Today's populational nutritional needs differ by for reasons ranging from social-economic factors to cultural habits. Studies have shown that many eating disorders came with changes on the metabolism, as for example at the gut microbiota level, thus indicating its importance in an individual's well-being.

Insects are a large biomass resource, and their nutritional potential as a source of high-quality nutrients, even when compared to actual "widespread" meat and fish sources.

In a near future, insect-based food can be widely seen as a balanced nutritional source, offered along with possible eco-friendly practices and low-cost, thus making it more accessible to everyone.

Regarding its pros and cons, a new food source can be established - insects. And processed insects, as in a form of a powder for example, can facilitate the introduction of the positive aspects of insect nutrition, environmentally friendly, and in a balanced diet form.

Acknowledgements

The authors would like to thank Mr. Diego Amores from Entomo Agroindustrial for his help in interpreting the regulatory restrictions associated with insect-based foods.

Disclosure statement

The authors have no financial or other type of relationship with insect industries that would present a conflict of interest.

Funding

Funding for this work was supported by National Funds from FCT - Fundação para a Ciência e a Tecnologia through project UID/Multi/50016/2019.

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