Online ISSN: 2299-9884
Polish Journal of Entomology 90(2): 48–62 (2021) DOI: 10.5604/01.3001.0014.8764

Insects as a food source – potential and perspectives

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Abstract: The practice of consuming insects is called entomophagy. Compared to conventional livestock farming, insect farming (breeding insects for food) has led to increased food conversion efficiency, reduced greenhouse gas emissions, reduced water pollution, reduced land use and led to low environmental pollution. The great potential of insects as a food source is due to their main attributes: 1. Short life cycle, 2. Wide distribution, 3. Fast and prolific reproduction, 4. Reduced need of space compared to other farming practices. Insects have advantages over animal meat due to their high protein content and high levels of lipids, vitamins and minerals. But in general, these nutrients vary widely depending on the insect species, stage of development, sex and other factors. Insects are rich in elements such as calcium, potassium, manganese, sodium, iron, copper, zinc and phosphorus, probably due to their food sources. In the near future, insect-based food can be seen as a balanced food source obtained through environmentally friendly practices at low costs, thus making it widely available. In the long run, insects for human and animal consumption show an increasing potential as a nutritious, sustainable and efficient food source.

Key words: Entomophagy, edible insects, nutritional value of insects, insects in the human diet, food source perspectives

Introduction

Cultural differences and related eating habits display diversity in the use of food sources to meet the needs of different groups of people. These dissimilarities are observed especially in the different types of food and delicacies used in various parts of the world. In the continents of Africa, South America and Asia, insects are a commonly used food source (de Castro *et al.* 2018, Ayensu *et al.* 2019), unlike in Western countries where this is not so well received. Globalization has led to the mixing of different cultures, with both differences and similarities between them. However, this type of food, thanks to its rich composition of nutrients, especially protein, can be the solution to the problem of hunger and malnutrition (de Carvalho *et al.* 2020). Healthcare institutions registering global trends emphasize the great importance of malnutrition, respectively, micronutrient deficiencies and excessive weight as a global health emergency affecting the state of the world's population. According to the UN, it is estimated that 11% of the world's population is starving, with two billion affected by micronutrient deficiencies and 40% of the world's population being overweight or obese (Food and Agriculture Organization) (FAO 2017). Considering these facts, malnutrition is key to individual and community health. The fact that these figures are constantly growing is worrying, and for this reason an expedient and effective solution is being sought. Studies show that in the near future, insects may be an essential part of the solution to global nutrition, as they are a rich source of protein, fiber and fatty acids (Giron *et al.* 2017, de Castro *et al.* 2018, Ayensu *et al.* 2019, Patel *et al.* 2019). Several studies have revealed the true impact and importance of insects as a balanced food source, with added benefits for the human intestinal microbiota as reported by Stull *et al.* (2018) and de Carvalho *et al.* (2019). The purpose of this review is to provide summarized information related to the advantages and disadvantages of using insects as a food source, the impact on the environment and the benefits for humans.

Nutritional problems worldwide and the impact of insects in the human diet

The world population is projected to number close to 11 billion by the end of the century, bringing with it the urgent need for sustainable resource systems to respond to environmental and planet-wide effects and environmental challenges involving the introduction of new rules, and policy coherence (FAO 2017). Over time, the challenges become greater and more pressing when it comes to feeding the human population. The requirements of a balanced diet make this task even more difficult to achieve. This is no longer just a matter of food sources, but also of policies that allow the development of new solutions and food sources capable of meeting all these requirements (de Carvalho *et al.* 2020).

Insects are consumed in all stages of development: eggs, larvae, pupae and adults. They are included as a planned part of the diet throughout the year or when seasonally served as a side dish, breakfast or food ingredient. Insects in nature are an important biomass resource, distributed in aquatic, forest and agricultural ecosystems (New 2009, de Castro *et al.* 2018). They are found on all continents and there is historical evidence that they were consumed by people from all continents except Antarctica (Costa-Neto & Dunkel 2016, Schrader *et al.* 2016). There is a wide variety of insect species consumed in Mexico, India, and generally in Southeast Asia, as opposed to very low percentages in Europe and North America (Halloran *et al.* 2014, Shockley & Dossey 2014, Vantomme 2015). Edible insects have long been part of the human diet, especially in tropical countries (van Huis 2016). Among the most commonly consumed insects are ants, bees, crickets, flies, and others, but their consumption has become uncommon in Western societies, although insect proteins have advantages as nutrients over plant proteins (Zielińska *et al.* 2015, Patel *et al.* 2019). Insects also have advantages over animal meat due to their high-quality protein content and high levels of lipids, vitamins and minerals (Tables 1 and 2) (Sun-Waterhouse *et al.* 2016). This is a solid alternative, as it is a practice that has existed for a long time in some cultures (i.e. Southeast Asia). Insect consumption is part of the traditional diet of 2 billion people worldwide (Halloran *et al.* 2014, Vantomme 2015, de Carvalho *et al.* 2020). The use of insects as human food and livestock feed is an evolving concept due to their health, environmental and livelihood benefits (Gmuer *et al.* 2016). In addition, they can also be grown efficiently with the help of biowaste, which makes insect production economically viable and mass production meets many nutritional needs (Oonincx & De Boer 2012, Oonincx *et al.* 2015).

Compared to conventional livestock farming, insect farming has increased feed conversion efficiency, reduced greenhouse gas emissions, reduced water pollution, less land use and low environmental pollution (Oonincx *et al.* 2010, Premalatha *et al.* 2011, van Huis *et al.* 2013, Payne *et al.* 2016, Fischer & Steenbekkers 2018). For the future, insects for human and animal consumption show good potential as a sustainable and efficient food source, although available information on the extent of their impact, mainly on the environment, is still scarce (Halloran *et al.* 2016). Greenhouse gas emissions are of paramount importance, and insect breeding shows better results than conventional animal species (eg poultry, pigs and cattle), as insects are more efficient in converting plant protein into animal protein and accumulating energy in nutrients, with an expected higher conversion ratio (de Carvalho *et al.* 2020). However, more data are needed to confirm these findings, as it is known that insect rearing produces large amounts of methane, which is a greenhouse gas, and conditions such as light, temperature and CO_2 and O_2 concentrations will affect the production of this methane. In addition, the real impact of insect breeding is known and recognized, as these organisms are associated with the production of methane and ammonia (Halloran *et al.* 2016).

The promising potential of insects is due to several main facts: 1. their short life cycle, 2. their wide distribution, 3. high degree of reproduction, 4. no need for large areas, compared to a wide range of cultivation of other foods (Sun-Waterhouse *et al.* 2016, de Carvalho *et al.* 2020). Some studies show that the cost of edible insects exceeds traditional meat products (Agea *et al.* 2008). However, if the cost of production of insects in industry decreases and is combined with sustainable farming, agriculture and processing technologies, this may increase their availability on the market and at the same time led to a reduction in their selling price (Sun-Waterhouse *et al.* 2016). Insects may be an acceptable choice to meet nutritional needs, for example as feed additives for animals with the objective of improving their intestinal health, as well as for directly insect-based food. This frames a new dimension, as then humans will become direct or indirect consumers of insects (Sogari *et al.* 2019, La Barbera *et al.* 2020). In this perspective, insects could be an option as quality products, with potential environmental benefits, given their potential as food ingredients for fish, pets, poultry or pigs and even for direct human consumption (van Huis 2017, Sogari *et al.* 2019).

Edible insect species

There are many edible insect species distributed around the world. Jongema (2017) compiled a detailed list of edible insects listing 2 111 species, however, the actual number of insect species suitable as human food or animal feed applications could be much larger. Approximately 500 species of edible insects are consumed in Africa, however the exact number of edible insects in Africa is still under revision (Kelemu *et al.* 2015, Hlongwane *et al.* 2020). In Latin America, with 545 edible species, Mexico has the largest number reported for any country in the world. There are 95 species recorded in Brazil, 83 in Ecuador and 48 in Venezuela (Bermúdez-Serrano 2020).

The most common insects consumed are beetles (Coleoptera, 31% of all insect species consumed). The next edible insect groups include moths and butterflies (Lepidoptera, 17%) and bees, wasps and ants (Hymenoptera, 15%). Moreover, grasshoppers and locusts (Orthoptera, 13%) and true bugs (Hemiptera, 11%) are consumed. Termites (Isoptera), dragonflies (Odonata), flies (Diptera) and other insects each comprise less than 3% of insects consumed (Jongema 2017).

The diversity and abundance of edible insect species structure used in human food is not the same everywhere and depends somehow on geographical regions (DeFoliart 1992, Kelemu *et al.* 2015, Costa-Neto & Dunkel 2016, de Carvalho *et al.* 2020). Caterpillars of large saturniids (Saturniidae) *Bunaea* Hübner, 1819, *Lobobunaea* Packard, 1901, *Gonimbrasia* Butler, 1878, *Imbrasia* Hübner, 1819, *Cinabra* Sonthonnax, 1901 along with larvae of large beetles like *Oryctes* Hellwig, 1798 or *Rhynchophorus* Herbst, 1795 are best known, and most commonly utilised food insects in equatorial Africa (Illgner & Nel

2000, Meutchieye *et al.* 2016, Bomolo *et al.* 2017). In the Amazon rainforest, the most important in the diet were those species, which formed large, highly predictable aggregations as large beetle larvae *Rhynchophorus* spp., but also ants *Atta* Fabricius, 1805, termites *Syntermes* Holmgren, 1909 and different large caterpillars (mainly from families Noctuidae and Saturniidae) (Dufour 1987, Reátegui *et al.* 2018).

In more arid areas of Africa (North Africa), no Lepidoptera as food source are consumed. Different species of Orthoptera, Heteroptera or Coleoptera are preferred. The same trend can be seen in a more arid south Africa, in Zimbabwe or Southern Africa. Several species of crickets are reported to be frequently consumed in these countries, *Brachytrupes membranaceus* (Drury, 1770), *Gryllus bimaculatus* (De Geer, 1773) and *Acheta* Linnaeus, 1758 (Kelemu *et al.* 2015).

Entomophagy is considered insects being traditionally consumed by populations which lived in tropical and subtropical countries (Macedo *et al.* 2017).

Nutritional value of insects

Today, there are thousands of identified species of insects considered edible, each with its own characteristics (Klunder *et al.* 2012, Giron *et al.* 2017, Fischer & Steenbekkers 2018, de Carvalho *et al.* 2020).

Table 1. Nutritional value of several insect species (according to Finke 2002, Shockley & Dossey 2014, de Carvalho *et al.* 2020).

Common name/ Species (Live stage)	Protein (g/kg)	Fat (g/kg)	Calories (kcal/kg)	Thiamin (mg/kg)	Riboflavin (mg/kg)
House fly *Musca domestica* (Linnaeus, 1758) (adults)	197	19	918	11.3	77.2
Black soldier fly *Hermetia illucens* (Linnaeus, 1758) (larvae)	175	140	1 994	7.7	16.2
House cricket *Acheta domestica* (Linnaeus, 1758) (adults)	205	68	1 402	0.4	34.1
Superworm *Zophobas morio* (Fabricius, 1776) (larvae)	197	177	2 423	0.6	7.5
Mealworm *Tenebrio molitor* (Linnaeus, 1758) (larvae)	187	134	2 056	2.4	8.1
Mealworm *T. molitor* (adults)	237	54	1 378	1	8.5
Giant mealworm *T. molitor* (larvae) *	184	168	2 252	1.2	16.1
Waxworm *Galleria mellonella* (Linnaeus, 1758) (larvae)	141	249	2 747	2.3	7.3
Silkworm *Bombyx mori* (Linnaeus, 1758) (larvae)	93	144	674	3.3	9.4

**Tenebrio molitor* larvae which have been grown to a large size by being hormonally treated to delay pupation

Table 2. Content of essential amino acids in different insect groups and requirements for adult humans (according to Ladron de Guevara *et al.* 1995, Ramos-Elorduy *et al.* 1997, Verkerk *et al.* 2007).

Essential amino acids (g/100 g dry body weight)	Orthoptera Grasshoppers, locusts	Coleoptera Beetles	Lepidoptera Butterflies and moths	Hymenoptera Bees, wasps and ants	Requirements for adult humans (mg/kg) daily
Isoleucine	4.2–5.3	4.8–5.8	4.1–5.1	4.1–6.4	13
Leucine	8.7–8.9	7.8–10.0	6.9–8.0	6.3–11.5	19
Lysine	5.5–5.7	5.5–5.7	4.9–6.3	3.6–7.4	16
Methionine	1.8–2.5	2.0–2.0	2.1–2.6	1.3–3.4	17[b]
Cysteine [a]	1.3–1.8	2.0–2.2	1.3–5.4	0.9–2.9	
Phenylalanine	10.3–11.7	4.6–4.7	6.4–9.5	3.3–8.8	19[c]
Tyrosine [a]	6.3–7.3	4.2–6.4	4.4–9.5	4.1–7.5	
Threonine	3.1–4.4	4.0–4.0	3.8–4.7	4.0–4.9	9
Tryptophan	0.6–0.7	0.7–0.8	0.4–0.6	0.3–0.7	5
Valine	5.1–5.7	6.2–7.0	4.8–6.1	5.3–6.7	13
Histidine	1.9–2.4	1.5–2.2	1.6–2.9	2.2–3.6	16

Proteins in high-content insects are a possible valuable resource for humans and a food source for animals with possible introduction as a diet for developing countries, replacing the traditional animal protein in animal husbandry. Also, insect protein content is usually of good quality and easily digestible (Mlcek *et al.* 2014, Kouřimská & Adámková 2016). The content of amino acids in insects is between 10-30% of all amino acids (Chen *et al.* 2009). However, it is necessary to keep in mind that the content of nutrients may vary from wild to commercially farmed species of agricultural insects, and that their growth stage also affects the content of some substances (Klunder *et al.* 2012). For example, *Tenebrio molitor* adults contain more protein (237 g/kg) than their larvae (187 g/kg) (Oonincx & Dierenfeld 2012). Most insect species convert plant protein into insect protein very efficiently. DeFoliart (1992) estimates that the efficiency of food conversion in crickets is more than five times greater than that of beef.

Amino acids are required for the biosynthesis of all proteins in human metabolism and they can ensure proper growth, development and maintenance. Regarding the role of amino acids, eight of them are considered essential and necessary because the human body cannot synthesize them. These are isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine and can only be obtained from food sources (van Huis *et al.* 2013). The presence of amino acids in the diet is essential (Table 2.). They are the basic building blocks of proteins and contribute as much to nutrition as to physical and sensory abilities. In terms of weight, *T. molitor* larvae, one of the species of insects often bred in Europe, have significantly higher levels of linoleic acid, isoleucine, leucine, valine, tyrosine, alanine and vitamins (except B12) than beef (Mlcek *et al.* 2014, Sun-Waterhouse *et al.* 2016). As a food source, *T. molitor* can meet the nutritional needs of essential amino acids, and in some cases at a higher rate than more common food sources, such as beef.

Fat in edible insects is normally between 10-50%, but this depends on many factors such as species, habitat, diet, stages of development, season, age and sex (Kouřimská & Adámková 2016). Insects have higher levels of essential fatty acids than other high-quality animal fats, especially omega-3 fatty acids (eg α-linoleic acid) (Mlcek *et al.* 2014). Also, according to DeFoliart (1992) some insects contain more essential amino acid compared to meat (like linoleic acid). Long-chain omega-

Table 3. Average rate of nutritional composition of edible insects in Africa, based on dry matter, from six orders (according to Hlongwane *et al.* 2020)

Nutrients	Blattodea (termites, cockroaches)	Coleoptera (beetles)	Hemiptera (bugs)	Hymeno–ptera (bees and ants)	Lepidoptera (caterpillars)	Orthoptera/ grasshoppers locust, crickets
Protein (%)	20.4–64.7	16.8–50.6	35.2–43.3	21.0–42.5	18.9–79.6	6.3–66.2
Fats (%)	8.4–36.1	11.8–66.6	45.0	38.2–47.5	1.9–55.0	2.0–53
Carb (%)	23.2	13.1–51.6	5.0–7.6	–	8.2–40.2	15.1–47.2
Fibre (%)	2.2–13.1	1.5–28.1	5.3	2.0–14.1	1.7–16.2	1.5–15.0
Vitamin A (mg/100 g)	2.6–2.9	8.6–12.5	0.2	12.4	2.8–3.4	0–8.9
Vitamin B2 (mg/100 g)	1.5–2.0	0.1–2.6	0.9	3.2	1.3–2.2	0–1.2
Vitamin C (mg/100 g)	3.0–3.4	4.3–7.6	–	10.3	2.0–4.5	0–9.8
Ca (mg/100 g)	18–132	15.7–61.3	91.0	15.4–32.6	7.0–15.4	2.0–42.2
Mg (mg/100 g)	0.2–0.3	6.1–18.2	109.0	5.2–10.4	1.0–160	0.1–33.1
P (mg/100 g)	114–136	1.5–136.4	57.0	108.0–125.0	100.5–1160.0	100.2–131.2

Table 4. Nutritional value of different groups of insects (g/100 g dry weight) (according to Bukkens 1997, Ramos-Elorduy *et al.* 1997).

Insect group	Protein	Fat	Mineral	Carbohydrates Structural	/ Others	Kcal
Orthoptera: Grasshoppers, locusts	61–77	4–17	2–17	9–12	4–21	362–427
Coleoptera: Beetles	21–54	18–52	1–7	6–23	1–19	410–574
Lepidoptera: Butterflies, moths	15–60	7–77	3–8	2–29	1–29	293–762
Hymenoptera: Bees, ants	1–81	4–62	0–6	1–6	8–93	416–655
Meat [a]	45–55	40–57	1.4–2.3	0–1.5	0	433–652

[a] The values for meat are derived from Nevo-tabel, original data in g/100 g product

3 polyunsaturated fatty acids play important roles in building brain tissue (Carlson & Kingston 2007).

Carbohydrates present in insects (6.7–16.0%) are most commonly found in the form of chitin (Raksakantong *et al.* 2010). Chitin, a polysaccharide (poly-beta-1,4-N-acetyl glucosamine), is insoluble in water and is the second most abundant carbohydrate in biomass after cellulose. It is the major component of arthropod exoskeletons. It can be a source of nitrogen as well as carbon (Khoushab & Yamabhai 2010, Hajji *et al.* 2014). Chitin usually accounts for between 5–20% of the dry weight of insects (Mlcek *et al.* 2014, Kouřimská & Adámková 2016) and can selectively promote the growth of important bacteria from the intestinal microbiota in humans. These bacteria are important for the body's immune defenses, the effectiveness of metabolic processes and may even have a prophylactic effect with regard to diabetes and obesity (Neyrinck *et al.* 2012, Geurts *et al.* 2013). They contain large amounts of zinc and iron (DeFoliart 1992), which is more than in beef (Bukkens 1997). The calcium concentration is about 920 mg/100 g dry weight (Bukkens 1997). In addition, edible insects are rich in mineral elements such as calcium, potassium, manganese, sodium, iron, copper, zinc and phosphorus, probably due to their food sources (Ayensu *et al.* 2019, Patel *et al.* 2019). In general, the mineral content of insects varies from 3 to 8 g/100 g of dried sample (Ramos-Elorduy *et al.* 1997). They also contain carotene and vitamins B1, B2, B6, C, D, E, and K, but also low levels of thiamine (vitamin B1) (Mlcek *et al.* 2014, de Carvalho *et al.* 2020). In general, these nutrients vary widely (Table 3 and 4).

Because the assessment of well-being is essential, recent studies have demonstrated an association with maintenance and changes in the intestinal microbiota (Carvalho *et al.* 2018, Ercolini & Fogliano 2018, de Carvalho *et al.* 2020). The composition and function of the intestinal microbiota is altered by the diet (Graf *et al.* 2015, Ercolini & Fogliano 2018, Telle-Hansen *et al.* 2018). One example of a short-chain fatty acid (SCFA) is acetate, which is an essential metabolite for bacterial growth, providing the ability of beneficial bacteria to inhibit enteropathogens and reduce host appetite by interacting with the central nervous system (Rios-Covián *et al.* 2016, Rowland *et al.* 2018). Diet is one of the most important factors influencing the intestinal microbiota, with a wide range of effects on the host (Carabotti *et al.* 2015, Mayer *et al.* 2015, Fung *et al.* 2017, Powell *et al.* 2017). Insects as food sources have the potential to provide benefits to human health thanks to the already mentioned nutritional value. However, it is necessary to keep in mind that the transformation of the nutrient matrix (eg boiling) changes the digestibility of the nutrients of the product (Ercolini & Fogliano 2018). The intestinal microbiota carries enormous potential for the host and modulates it through diet, which is a key factor for potential beneficial effects (e.g. with respect to inflammatory and immune conditions) (Graf *et al.* 2015, Ercolini & Fogliano 2018).

Dangers of entomophagy

Not all insects are safe to use as a food source because they can be vectors of pathogens for animals and humans. Microbial contamination is also a potential hazard (Belluco *et al.* 2013, Rumpold & Schleuter 2013, de Carvalho *et al.* 2020). The risk of pathogens is even higher when eating uncooked or "raw" insects. The issue of collecting insects in nature, which may contain pesticides and herbicides, is also important. Their consumption can be dangerous for any organism, as it increases the chances of ingestion of toxic substances (Mlcek *et al.* 2014). Edible insects are low-risk food for humans and feed for animals, as they belong to the usual diet of many of them (i.e. birds, pigs, and fish). Despite the nutritional qualities of some insects, they may pose a risk of allergy in humans who are already allergic to other arthropods (e.g. shrimp, lobster, crabs, mites) (Mlcek *et al.* 2014, Halloran *et al.* 2014). Allergy is a potentially life-threatening condition and carries a high risk during entomophagy or even contact with insect products (Belluco *et al.* 2013). When inhaled, insect protein sensitivity is also observed, due to airborne insect products (Mlcek *et al.* 2014). Frequent allergic reactions caused by chitin in insects have been reported. Although not fully considered a potential allergen, chitin can cause immune-related sensitization in humans (Patel *et al.* 2019). One problem is that insects can produce secretions as a defense mechanism and are a source of inhalatory allergens, which can cause reactions in humans (DeFoliart 1992). Studies have shown that inhaled *T. molitor* particles are potent sensitizers and can lead to asthma, thus the Tenebrionidae family is a potentially significant allergen (Bernstein *et al.* 1983). Chitin can also be a problem with digestibility. It is often considered indigestible to humans, despite the presence of chitinases in human gastric juices (eg AMCase and chitotriosidase), as in some people it may be inactive (i.e. in European countries), while in others chitinase in their body is active (i.e. people from tropical countries) due to their traditional diets containing insects. This may be due to the lack of chitinous foods in Western diets. A possible approach to this problem would be to remove chitin from these insects and improve the digestibility of their proteins (Paoletti *et al.* 2007, Muzzarelli *et al.* 2012, Belluco *et al.* 2013, Dobermann *et al.* 2017). In addition to these threats, microbial, physicochemical and parasitic risks must be considered. With regard to the insect microbiota, from the perspective of food safety, first is considered the insect-related microbiota introduced during agriculture and processing. Therefore, bacterial hazards must be considered into account in relation to insect handling and preservation (EFSA Scientific Committee 2015). Zoonotic pathogens are present in substrates, but active replication of pathogens in the intestinal tract of insects has not been reported. The risk of transmission by these bacteria can be reduced by effective treatment. In addition, pathogenic viruses in insects intended for food and feed are not considered dangerous to vertebrates and humans (EFSA Scientific Committee 2015). In this sense, the possibility of parasitic hazards that can lead to infections or even death should be considered, but in a well-managed closed farm environment, it would not be possible to complete the life cycle of a particular parasite (EFSA Scientific Committee 2015). Therefore, the microbial safety of edible insects is important mainly during handling or processing of insects. Chemical hazards may primarily include hazards of a natural origin, synthesis and accumulation of various insect substances or addition of chemicals during food processing of insects (Sun-Waterhouse *et al.* 2016). In addition, insects can produce toxins and accumulate heavy metals from the environment (Zagrobelny *et al.* 2009). The presence of accumulated heavy metals is a major mechanism for insect contamination. Such accumulation will depend on the type of insect, stage of development, and type of heavy metal. In the case of insects with a short life cycle, bioaccumulation is less likely. However, data on substrate contamination are still limited. For example, in Thailand, wasps, bamboo caterpillars, crickets, and other insects are eaten by villagers and served to foreigners as a delicacy (Yen 2015). In China, insects are common in restaurant menus and in medical practice (Chen *et al.* 2009).

On the other hand, Western societies tend to show phobias and aversion to eating insects. 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 a higher representation of countries located in the tropics (de Carvalho *et al.* 2020). An example of this is Ghana, Africa, where winged termites are a popular dish and are prepared in different ways. In Thailand, local bars serve fried insects as a savory addition to beer. In America, specifically in Mexico, it is possible to find and consume on the street Taco Carts, agave worm, chapulines (locusts) and escamoles (ant eggs) (van Huis *et al.* 2013). Some studies show that people are becoming increasingly aware of the possibility of using insects as food (Caparros Megido *et al.* 2014, House 2016). Some research has been done on this topic, showing that with regard to insects as meat substitutes, insects are rated much more negatively than other alternatives (Verbeke 2015), and that very few people are willing to consume insects. Caparros Megido *et al.* (2014) show satisfaction with insect nutrition among consumers with such interests, or evidence of insect products marketed as food or as a protein source in Western countries (UN News Center 2013). Also, restaurants are increasingly using insects in their dishes (Cunningham & Marcason 2001, Verkerk *et al.* 2007, Schösler *et al.* 2012). Despite all these possibilities, a study by La Barbera *et al.* (2018) showed that cooking food from known insects does not make it more acceptable. All of this could be the subject of further research to find ways to improve consumer perceptions of insects as food and to increase the desirability of insect-based foods (La Barbera *et al.* 2018, Mancini *et al.* 2019).

Insect food products and their regulation

Insects can be used as food/feed ingredients/supplements or even consumed for medicinal purposes. Many insect products are already widely used nowadays, such as honey, food coloring, royal jelly, propolis and others (Schabel 2010). As already mentioned, there are many edible insects distributed around the world. Entomophagy can take a variety of forms and depending on the region - from a common dish to a delicacy. Insects can be found on the market as food ingredients, such as mealworms/powder crickets, baked seasoned mealworms/crickets, mealworms treated with sea salt and pepper, or crickets prepared in various ways and with different spices. In many countries, the consumption of insects is far from such a habit, leading to a lack of demand and, consequently, supply and development of such products. Today we can say that entomophagy is slowly emerging as an alternative. The design of insect-based products must aim to retain nutrients and bioactive substances and at the same time to familiarize people with this source, which is a challenge to people's perceptions. Appropriate nutritional composition, through the use of certain processes, can facilitate the perception of such foods among consumers by creating specific tastes and textures (Sun-Waterhouse *et al.* 2016). The success of the introduction of such products on the market will depend on consumer perception (La Barbera *et al.* 2020). The degree of food processing of insects can also affect human intake and reduce negative emotions towards entomophagy (Schouteten *et al.* 2016). Especially in places where entomophagy is not a common practice, there is a preference for including insects in food in a way that they are not seen or perceived as such. Using insect as food is considered safe because humanity has a long history of insect consumption. In the Western world, however, they are not known as a food group. Nevertheless, interest in insects as food in the Western world is beginning to increase. Transformation of insects, which makes them unrecognizable, can facilitate their consumption (Mitsuhashi 2010). Tortilla with *T. molitor* larvae powder is an example, in addition to increased total protein, fat content and essential amino acid content (Mlcek *et al.* 2014). To include insect powders in our daily meals is possible and very easy to do. It is possible to prepare different food products (protein bars and shakes, cakes and muffins, cookies, smoothies, juices) (de Carvalho *et al.* 2020). It is therefore not very difficult to insert insect meals into the Western modern way of life, it's only a matter of time. However, it should be borne in mind that processing affects the nutritional potential, so appropriate control is needed to preserve valuable proteins and vitamins (Kinyuru *et al.* 2010).

Many of the food regulatory institutions such as the EFSA (European Food Safety Authority), FDA (Food and Drugs Administration of the United States), FSANZ (Food Standards Australia and New Zealand), and Health Canada have been working on adequate regulative rules and guidelines on the consumption of insects.

In the European Union, novel foods (NF) must comply to strict requirements regarding the procedures for determining their status, the procedures for placing them on the EU market and the criteria and general conditions for including NF in the Union list, according to EFSA (European Food Safety Authority) and the European Commission (Official Journal of the European Union 2015). In accordance with EU regulation № 2283/2015 on NF, the definitions and criteria for determining the status of a particular food and the relevant procedures for placing it on the EU market have been updated together with the necessary safety requirements in line with valid scientific results (Official Journal of the European Union 2015). In 2016, the EU Standing Committee on Plants, Animals, Food and Feed (SCoPAFF) regulated the use of insect proteins for fish feed (Entomo Agroindustrial, 2016) (EU regulation № 893/2017), as thus processed animal proteins derived from insects farms are allowed to be used as aquaculture food (Official Journal of the European Union 2015). EFSA's latest reports are regarding the use of the larval stage of the yellow mealworm *Tenebrio molitor* as a NF. In this case Novel Food is defined as a thermally dried yellow mealworm or a common dried insect, available also in powder form. The main components of NF are proteins, fat and fiber (chitin). The Scientific Panel notes that given the composition of NF and the proposed conditions of use, NF consumption is not nutritionally unfavorable. The toxicity studies presented in the literature do not raise safety concerns (EFSA NDA Panel, 2021). The panel believes that the consumption of protein, derived from the dried yellow mealworm *T. molitor* can cause allergic reactions in people with allergies to crustaceans and dust mites. The NF is intended to be marketed as a whole, thermally dried *T. molitor* larva (blanched, kiln-dried larva), or as a powder of said thermally-dried larva. The whole mealworm larva is intended for human consumption. The reared larvae must be under controlled rearing conditions. The larvae are must be farmed under controlled rearing conditions. The research panel concluded that this NF (thermally dried *T. molitor* larva) was safe according to the proposed mode of use (EFSA NDA Panel, 2021).

Conclusion

In the near future, insect-based food can be seen as a balanced food source, offered together with environmentally friendly practices and low costs, thus making it widely available. Insects are an excellent resource of biomass and have a high potential as a source of high quality nutrients, even compared to widespread animal food sources such as meat and fish. Insects in powder form, for example, can facilitate their introduction into the food industry with the related positive effects-environmentally friendly farming and the ability to balance the diet in humans.

Acknowledgements

This research was supported by the Slovak Research and Development Agency (APVV) via grants APVV-19-0119. The authors thank Dr. Peter Ostoich for his editorial support.

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Received: 07.02.2021
Accepted: 02.03.2021
Published online: 10.05.2021