Comprehensive REVIEWS in Food Science and Food Safety

Edible Insects in a Food Safety and Nutritional Perspective: A Critical Review

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Abstract: Increasing world population worsens the serious problem of food security in developing countries. On the other hand in industrialized countries, where the problem of food security is of minor concern, health problems related to food refer to 2 main factors: food safety and environmental sustainability of food production. For these reasons, new ways must be found to increase yields while preserving food quality, natural habitats, and biodiversity. Insects could be of great interest as a possible solution due to their capability to satisfy 2 different requirements: (i) they are an important source of protein and other nutrients; (ii) their use as food has ecological advantages over conventional meat and, in the long run, economic benefits. However, little is known on the food safety side and this can be of critical importance to meet society's approval, especially if people are not accustomed to eating insects. This paper aims to collect information in order to evaluate how insects could be safely used as food and to discuss nutritional data to justify why insect food sources can no longer be neglected. Legislative issues will also be discussed.

Introduction

Article 25 of the Universal Declaration of Human Rights states that food is a primary right of all people. Humans are probably unique in that they can potentially have access to a multitude of food sources. However, especially in developed countries, humans have selected a restricted number of plants and animals from which to obtain their energy and entire nutrient pool. Moreover, globalization is leading to the spread of the Western dietary habits to developing countries, with a consequent loss of food diversity (Paoletti and Dreon 2005; Turner and others 2011). This trend can have a negative impact on health due to alterations in nutritional balance resulting from ingredient substitutions that follow economic and market rather than biological and ecological principles (Johns and Eyzaguirre 2006).

The world population is continuously increasing with a growing requirement for food. Improvements in food production systems have been brought about by intensive farming policies, genetic selection, and, recently, by the development of genetically modified organisms (GMOs). In most situations, increasing yields through agricultural intensification reduces environmental sustainability and animal welfare.

Lengthening food shelf-life has also been a response to the growing need for food. This is and has been an important solution to reduce food waste and to improve food availability. However, longer shelf-life is made possible by the development of new packaging systems and food processing methods which could potentially raise food safety and environmental concerns. There is the potential for toxic material components to migrate into food and cause consumer exposure and, in addition, the material life cycle could lead to environmental pollution (Munro and others 2002; Cwiek-Ludwicka 2010; Wolfle and Pfaff 2010).

Less attention has been paid to widening sources of food of plant and animal origin. This is particularly true for food of animal origin, as the Western diet encompasses only a few animal species. From a "Western culture" point of view, the animal kingdom is nonscientifically divided into a few categories, comprising animals permitted to be eaten, pests (insects, rodents, and soon), pets, and others (Harris 1998). On the other hand, worldwide, thousands of insect species are consumed by humans as food as extensively reported by some publications describing food habits in different countries (Menzel and D'Aluisio 1998; DeFoliart 2002; Paoletti 2005).

This review focuses on insects as a food option and discusses Western society's misgivings about accepting them as such. According to Premalatha and others (2011) it is a "supreme irony" that "all over the world monies worth billions of rupees are spent every year to save crops that contain no more than 14% of plant protein by killing another food source (insects) that may contain up to 75% of high-quality animal protein."

Western legislation is very conservative about new food or new ingredients, as can be observed by reading, for example, the EU regulations on novel food (Regulation (EC) Nr 258/1997 of the European Parliament and of the Council 1997). Moreover, Western attitudes toward food are frequently characterized by the rejection of certain food sources for psychological rather than logical reasons (Taylor 1975; DeFoliart 1999; Paoletti and Dreon 2005).

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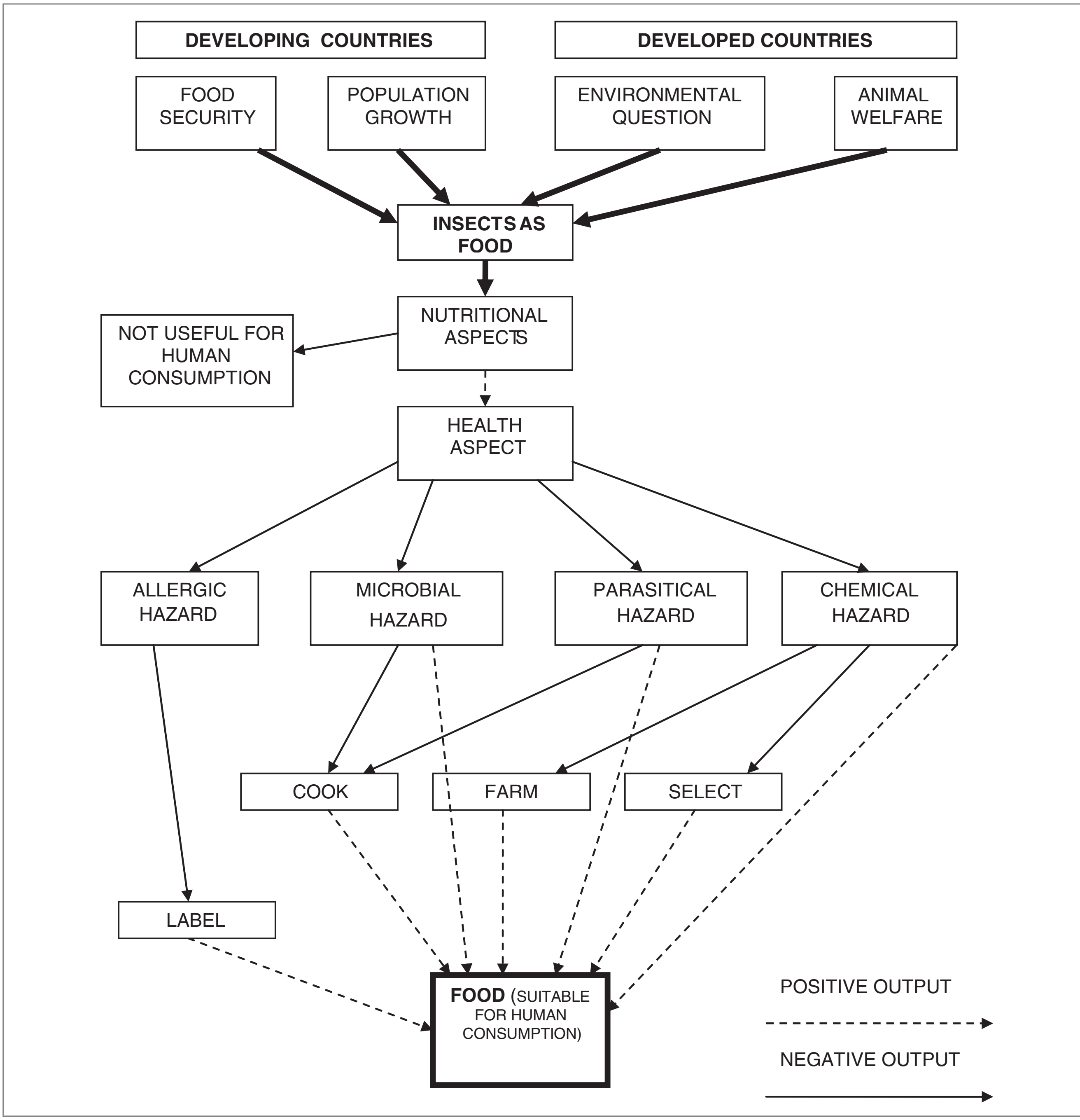

Figure 1–Flow chart used to address the study aim.

To better address this concept it might be useful to compare the meaning of the term "food" from a linguistic and legislative point of view. Various dictionary definitions associate food with nourishment. Accordingly, we will primarily address nutritional aspects of insects to explain what makes them a potentially high-quality food source. From a legislative point of view, however, taken alone, a nutritional assessment is an important but not a necessary or sufficient condition to justify categorizing items as food. The European law, for example, only defines food according to its edibility, while its nutritional properties are completely overlooked so that chewing gum is explicitly considered a foodstuff (Regulation (EC) Nr 178/2002 of the European Parliament and of the Council 2002), whereas there are many uncertainties about the status of insects. Therefore, in order for an item to be considered food, only safety concerns have to be addressed. Accordingly, the common hazards related to insect consumption will be discussed with a perspective that suggests their adoption as a food source in Western countries too. The design of this article is presented in Figure 1.

To the best of our knowledge, the last review to focus on the health aspects of insect consumption dates back to 1979 (Gorham 1979). Since then many works have been published on this topic, focusing on social, nutritional, and environmental aspects, but few have addressed safety concerns.

Conversely, Western interest in this topic is growing, as demonstrated by FAO, EU, and other national institutional projects (http://www.fao.org/world/laos/index_en.htm; KBBE.2012.2.3-05: Insects as novel sources of proteins—SICA Call: FP7-KBBE-2012-6 – single stage; Research project "Sustainable production of Insects Proteins" funded by The Netherlands Ministry of Economic Affairs and implemented by Wageningen Univ.).

Legal Requirements in Europe

In this section we consider European Communitarian law because it well represents the uncertainty and low attention of developed countries to insects as a food source. EU legislation on food follows the precautionary principle (Regulation (EC) Nr 178/2002 of the European Parliament and of the Council 2002) which states that, if potential risks from consumption of new foods are identified, a premarket risk assessment has to be performed. In the context of Regulation (EC) 853/2004 concerning animal foodstuffs, frogs'; legs and snails, but not insects, are mentioned among the "unconventional" foods of animal origin. Consequently, from a legal point of view, the suitability of insects for human consumption is a continuous challenge in the context of the current "Novel Food" Regulation (Regulation (EC) Nr 258/1997), but it will probably be better addressed in the forthcoming regulation (COM (2007) 872 final), which is still under debate. Many parts of Regulation (EC) 258/1997 are not completely clear. For example, according to Art 1(2), novel foods are "*foods and food ingredients which have not hitherto been used for human consumption to a significant degree within the Community*," where May 15, 1997 (date of entry into force) is considered the time-limit of the definition.

Moreover, novel food has to belong to one of the following categories:

> "*(c) foods and food ingredients with a new or intentionally modified primary molecular structure;*
> *(d) foods and food ingredients consisting of or isolated from microorganisms, fungi or algae;*
> *(e) foods and food ingredients consisting of or isolated from plants and food ingredients isolated from animals, except for foods and food ingredients obtained by traditional propagating or breeding practices and having a history of safe food use;*
> *(f) foods and food ingredients to which has been applied a production process not currently used, where that process gives rise to significant changes in the composition or structure of the foods or food ingredients which affect their nutritional value, metabolism or level of undesirable substances.*" In Figure 2 a flowchart assessing if a food has to be considered as novel is presented.

If a food complies with Novel Food definition a specific premarket risk assessment is required according to Recommendation 97/618/CE as presented in Figure 3.

In the general definition, however, there is some uncertainty surrounding both the meaning of the concept "*consumption to a significant degree*," which is not well specified, and the method for assessing consumption data. Insects are most likely not to be consumed in such large quantities, although they are already sold as food in some European countries.

Since the regulation is 15-y-old the "significant degree of consumption" is hardly demonstrated in an unequivocal way. A recent Guidance document (DG SANCO 2012) states that this should be demonstrated through: comprehensive sales information (invoices and other documents detailing sale of food, including evidence of large quantities of sale in the EU) and Government Import/Export Information (Official documents). Catalogues, recipes, and testimonies are only considered as supporting evidence.

Moreover, some interesting notes aimed at clarifying the "significant" adjective are:

-An established history of food use to a significant degree in at least one EU Member State (The deadline May 15, 1997 is applicable to all Member States, irrespective from the date of accession to the EU.) is sufficient to exclude the food from the scope of Regulation (EC) No 258/97. Paradoxically, food consumption in 3rd countries (outside EU) is not sufficient to demonstrate to Europeans a history of food use according to the same regulation.

-Food used at specific occasions like particular ceremonies, festivities, and so on, might be a significant use in the sense of the Novel Food regulation. If a product has only limited availability, for example, in pharmacies, health food shops, or specific restaurants, a significant use could be questionable.

-The availability over the years should also be considered. It is of interest, whether the food has been available regularly, such as for dozens of years, or only once in a while. For instance, if a product had only been presented once at a trade fair before May 15, 1997, this does not demonstrate significant use.

-Foods that were used a long time/many years ago only, but not in recent times, then a history of food use relevant for the Novel Food Regulation has not been established.

Insects will probably hardly fit these criteria, to be considered as novel food they need also to be enclosed in Article 1 categories. In our opinion, insects could certainly be considered within category (e), yet this depends on the possibility that their "history of safe use can be demonstrated." In any event, according to FSA (Food Standards Agency 15-Nov-2011), insects are exempt from the scope of the Novel Food category because they are normally eaten whole, while the Regulation definition (e) of foodstuffs of animal origin refers to foodstuffs "*isolated from animals*" but not "*consisting of animals*." As a result of this interpretation, insects are allowed into the UK market and, given the way the community market is organized, are consequently allowed into the EU. The British position probably is not well known or accepted. One example of insects not being accepted in the EU is reported in the RASFF (Rapid Alert System for Food and Feed 2012) database, which details a border rejection from Italy concerning a batch of domesticated silk-worm (*Bombyx mori*) from South Korea classified as *unauthorized novel food ingredient in food supplement*.

Under current legislation, excluding bee products (honey, royal jelly, propoli) there is a sole commercialized product isolated from insects: E120 (CI 75470). It is a red coloring authorized as a food additive, by Directive 94/36/EC, according to Reg. 1333/2008, and consisting of cochineal extract. However, together with other food additives, this coloring will be re-evaluated within December 31, 2015 as indicated in Reg. 257/2010.

Moreover, examination of the novel food application list on DG SANCO (DG SANCO – EU Commission Directorate-General for Health and Consumers – accessed July 27, 2012) showed a request for bee venom commercialization currently under evaluation from FSA (Food Standard Agency – UK).

The new Novel Food Regulation, which is already available in draft form (COM (2007) 872 final), will probably place insect foodstuffs into the category of "*Traditional food from a third country i.e. novel food with a history of food use in a third country, meaning that the food in question has been and continues to be part of the normal diet for at least one generation in a large part of the population of a country.*" In this

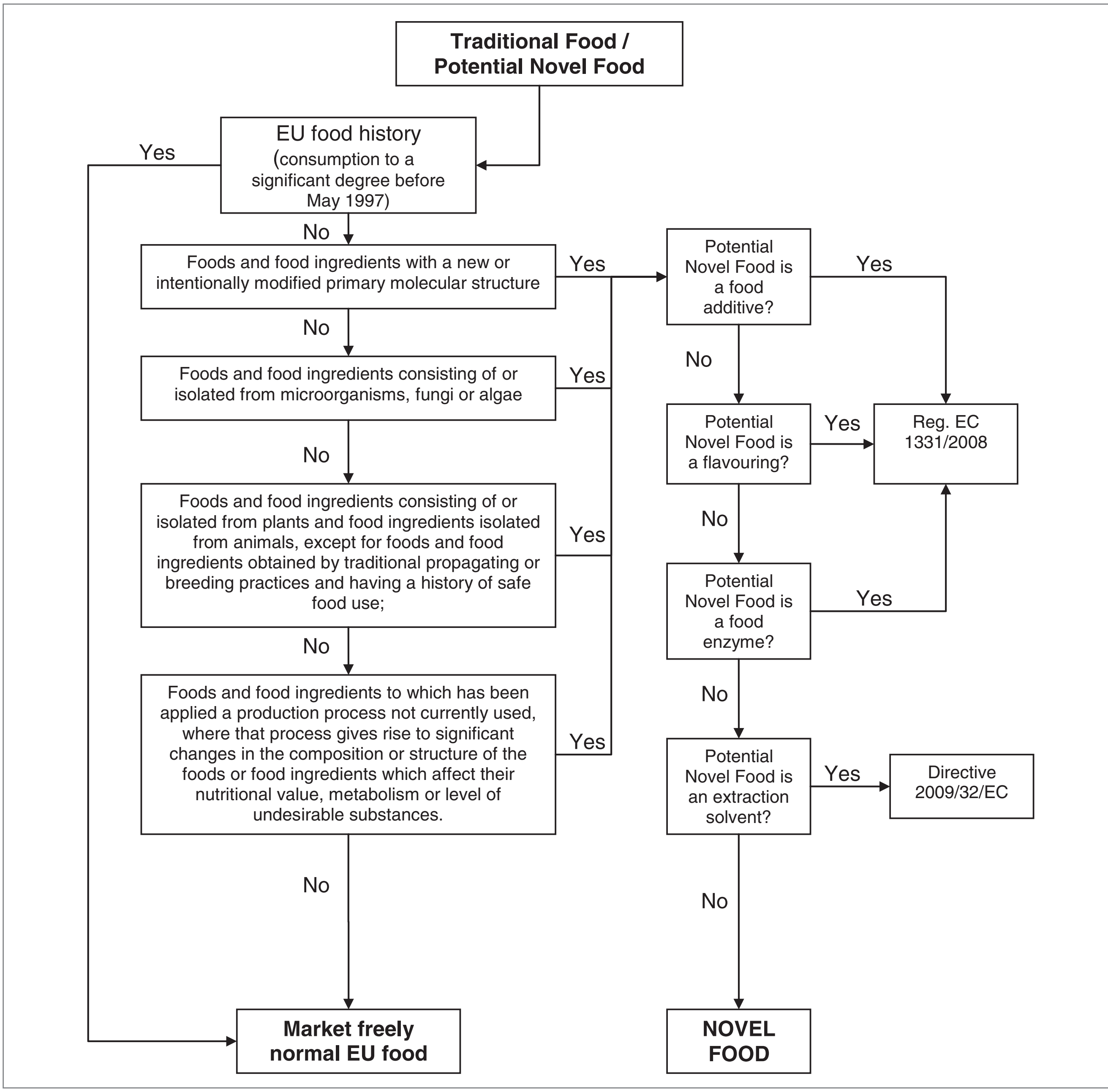

Figure 2–Flow chart assessing if a food has to be considered as Novel according to Reg. EC 258/1997 (Regulation (EC) Nr 258/1997 of the European Parliament and of the Council 1997).

case, demonstration of "*the history of safe use*" requires documented compositional data and wide experience of use.

Both the current and the new draft regulation state that if the "*history of safe use*" cannot be documented for a novel food, a complete risk assessment will be required, even if this is not a simple task considering the technical difficulty involved with performing such analytical tests on complex matrices (Neville Craddock Associates 2005).

In the event of market approval, the importation of insect products must follow general EU food law. Consequently, exporter countries will have to demonstrate observance of hygienic criteria in compliance with high standard requirements, which may limit exportation to EU (Regulation (EC) Nr 178/2002).

On the basis of these considerations, this review will discuss insects'; compositional data in the context of human nutrition. In order to assess the safety of insect consumption all relevant information concerning potential hazards were considered.

Nutritional Facts

The high consumption of animal-based proteins, particularly meat and processed meat, has been identified as one of the causes of the increased prevalence of noncommunicable diseases, including cancer, among Western consumers (Alexander and others 2010a, 2010b; Corpet 2011; Magalhaes and others 2012). The US Census Bureau (2012) estimates a very high average consumption of red meat per capita per year that is equivalent to 48 kg (meat

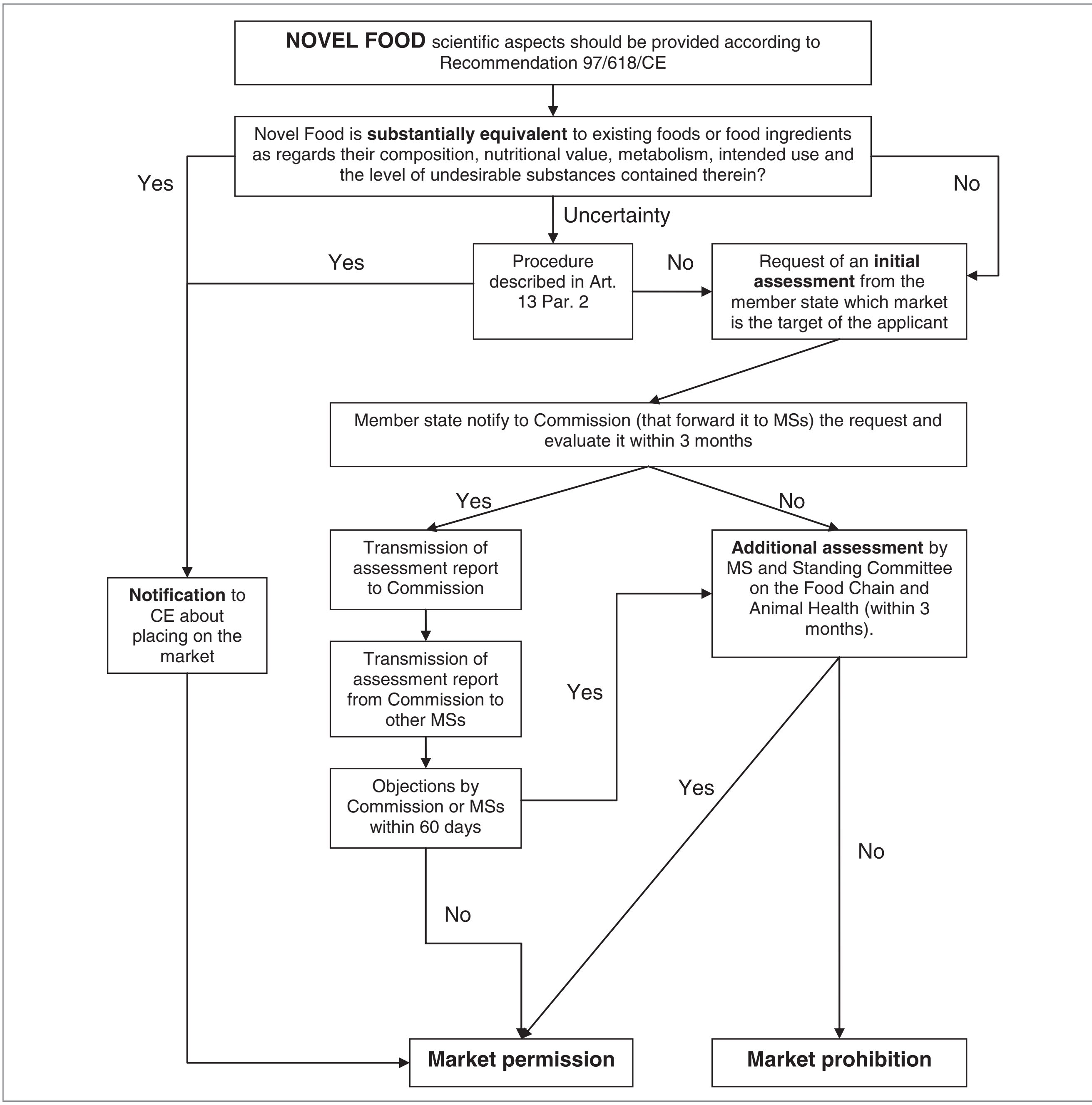

Figure 3–Flowchart reporting iter to obtain market permission for Novel Food following requirement of Recommendation 97/618/CE (Commission Recommendation of 29 July 1997).

without bones). In Europe the most representative data have been collected in The Netherlands, where red meat consumption has been stabilizing at around 39.2 kg (meat with bones) per capita per year (PVE 2012). Moreover, data from food consumption surveys show that actual daily mean protein intakes among adults in Europe stand at, or more often above, the Population Reference Intake (PRI) of 0.83 g/kg body weight. In Europe, adult protein intakes at the upper end (90 to 97.5th percentile) of the intake distributions have been reported to be between 17% and 27% of the total consumed energy (EFSA 2010). Because of the high levels of meat consumption, the main goal of nutritional guidelines is to achieve a reduction and partial substitution of meat-based proteins with other protein sources such as fish and plants (Gerbens-Leenes and others 2010; Aiking 2011). However, while fish consumption offers many health benefits, due in part to the high concentration of n-3 polyunsaturated fatty acids (n-3 PUFAs) in many species, fish also contain methylmercury (MeHg), a well-known and widespread environmental neurotoxins. Most of the human exposure to MeHg is through fish consumption (Mahaffey and others 2011). Thus the effect of dietary seafood intake, especially by pregnant women, remains an important issue and it is of particular importance in populations with a high intake of fish.

Grains and pulses provide other sources of proteins. Nevertheless, cancer prevention guidelines recommend avoiding consumption of moldy grains and pulses, which may be contaminated with mycotoxins, particularly aflatoxin, which can grow on agricultural commodities and is a known carcinogen (Weiderpass 2010).

A variety of other protein sources are currently available. Many conventional Western meat-free dishes contain other animal-based products such as milk, eggs, cheese, or other dairy products, which, environmentally, do not offer many advantages over meat (de Boer and Aiking 2011).

Many animal species could be regarded as suitable candidates for providing animal protein, and insects are being considered as potential candidates (Collavo and others 2005; Vogel 2010) also because their nutritional values has long be recognized for a long time (Taylor 1975).

Insects' protein content is very high, with many species ranging above 60%. For example, Finke and others (1989) reported that the house cricket (Acheta *domesticus*), when fed to weanling rats, was superior to soy protein as a source of amino acids at all levels of intake. Protein quality, and thus nutritional value, is determined by amino acid composition and the digestibility of the protein fraction of food. The 20 proteinogenic amino acids are classified as either indispensable or dispensable. Nine amino acids are classified as essential for humans (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine) as they cannot be synthesized in the human body from naturally occurring precursors at a rate that meets metabolic requirements. The remaining dietary amino acids are dispensable (alanine, arginine, cysteine, glutamine, glycine, proline, tyrosine, aspartic acid, asparagine, glutamic acid, and serine). Among the 9 essential amino acids, lysine and threonine are strictly indispensable since they are not transaminated and their deamination is irreversible. In contrast, the 7 remaining indispensable amino acids can participate in transamination reactions. In addition, some of the dispensable amino acids that can be synthesized by the body under normal physiological conditions can become limiting under special physiological or pathological conditions. One example is in premature neonates; when the metabolic requirement cannot be met, these amino acids must be supplied in adequate amounts with the diet; they are then called conditionally indispensable amino acids (arginine, cysteine, glutamine, glycine, proline, and tyrosine). The last parameter that needs to be considered for the correct assessment of protein quality is the ratio between essential (E) and nonessential (N) amino acids. According to FAO/WHO criteria, $E/(E + N)$ has to reach about 40% with $E/N = 0.6$ (FAO 1989). FAO/WHO/EFSA dietary criteria state that each adult must consume 0.66 g/kg of body weight of protein per day (EFSA 2012a).

As indicated in Table 1 and 2, insects can fulfil some human nutritional requirements and most of them can be grouped among the high value protein sources since their essential amino acid score (the essential amino acids requirement expressed as percentage in an ideal protein) ranges from 46% to 96% (Ramos-Elorduy and others 1997), although the majority of insects has been found to have limited levels of either tryptophan or lysine (Ramos-Elorduy and others 1997; Bukkens 2005).

One of the most widely eaten insects in China is silkworm, whose protein content is comparable to other animal proteins. As can be calculated from the same table, the ratio of essential to nonessential amino acids is about 0.6 in silkworm pupae (Longvah and others 2011).

Insect proteins are highly digestible (between 77% and 98%) (Ramos-Elorduy and others 1997), although insect forms with an exoskeleton have lower values, due to the presence of chitin. Chitin removal increases the quality of insect protein to a level comparable to that of products from vertebrate animals (DeFoliart 2002). Furthermore, humans are still able to digest some chitin, as 2 catalytically active chitinases have been discovered, AMCase and chitotriosidase, both belonging to the family of 18 glycosyl-hydrolases (van Aalten and others 2001; Synstad and others 2004). AMCase is more active at acidic pH (Boot and others 2001; Chou and others 2006), whereas chitotriosidase (Boot and others 1995; Renkema and others 1995) has a different pH optimum than AMCase. AMCase has the potential to moderately digest chitin in the human stomach (Paoletti and others 2007; Muzzarelli and others 2012).

Insects vary widely in fat content and thus energy. The fat content of insects ranges from 7 to 77 g/100 g dry weight and the caloric value of insects varies between 293 and 762 kcal/100 g dry weight (Ramos-Elorduy and others 1997). These values depend on insect diet and insect species. For instance, caterpillars and termites are known to contain more fat (Bukkens 2005) and, according to DeFoliart (1992), some insects contain more essential fatty acids, such as linoleic and/or linolenic acids, compared with meat. In order to be considered beneficial for human health, the balance of fatty acid groups has to cover an appropriate range (Dietary Reference Levels for the Italian population – LARN – 2012). The best composition of fat intake occurs when the ratio of fat sources is mammalian meat: plant: fish = 4: 5: 1, with an ideal ratio among saturated fatty acid (SFA), monounsaturated fatty acid (MUFA), and polyunsaturated fatty acid (PUFA) of SFA: MUFA: PUFA = 3: 4: 3.

Current data on edible aquatic and terrestrial insects do not show a higher level of PUFA for aquatic species, which suggests that foraging on terrestrial insects is not less beneficial for essential PUFA procurement (Fontaneto and others 2011).

Lastly, PUFA is divided into 2 categories: n-6 fatty acid from plants, rich in linoleic acid, and n-3 fatty acid from fish, rich in linolenic acid, eicosapentaenoic acid (EPA) or decosahexaenoic acid (DHA). The recommended ratio between n-6 and n-3 is 3:1. Lipid analyses on toasted chrysalis (*Bombyx mori*) showed an SFA content of 32.52%, consisting mostly of palmitic (C16:0, 24.6%) and stearic (C18:0, 7.56%) acids, and 35.43% of MFA consisting of oleic acid (C18:1n-9, 34.8%). The same study proved that toasted chrysalis contains 32% PUFA, consisting mostly of linolenic (C18:3n-3, 24.4%) and linoleic (C18:2n-6, 7.03%) acids (Pereira and others 2003). As far as total unsaturated fatty acids are concerned, Rao (1994) pointed out that pupa fat contained 66.8% of UFA of which linolenic acid accounts for 25.7%. The PUFA/SFA ratio in the lipids of toasted chrysalis was relatively high (about 0.99), above the recommended level of 0.45 for a healthy diet. In addition, the toasted chrysalis exhibited a good n-3/n-6 fatty acid ratio (0.30), close to the recommended one (Pereira and others 2003).

Finally, *Bombyx mori* chrysalis displays a higher lipid content than bovine meat 16% (Mills and others 1992), common sausage 17% (Pereira and others 2000), and chicken heart 22.2% (Pereira and others 2002). This type of chrysalis has also been found to contain a high cholesterol concentration (214 mg 100/g). However, this value is lower than the total cholesterol of bovine liver (273.9 mg 100/g) and common sausage (262.1 mg 100/g), as shown by Rowe and others (1997). Cholesterol levels in the insect world vary from low (none in the edible leaf-cutter ant, *Atta cephalotes*) to a level comparable with other animal foodstuffs (1 mg sterol/g tissue), depending on species and diet (Ritter 1990).

Table 1–Comparison in essential aminoacids composition among insect fresh weight (silkworm pupae) and common animal foodstudffs fresh weight (Longvah and others 2011).

Component (g/100 g)	Pupae	Beef meat	Pork meat	Chicken meat	RDA[a]
Protein g%	15.8	21.35	21.30	19.40	0.66 g/kg/d
Aspartic acid	1.54	2.07	1.13	1.91	2.20 mg/kg/d
Threonine	0.75	0.87	0.94	0.95	11 mg/kg/d
Serine	0.82	0.86	0.90	0.88	
Glutamic acid	2.03	3.61	3.26	2.85	
Proline	1.02	0.89	0.85	0.73	
Glycine	0.78	1.08	1.02	0.90	
Alanine	0.97	1.32	1.25	1.15	
Cystine	0.08	0.23	0.29	0.25	
Valine	0.84	1.02	1.21	1.04	15 mg/kg/d
Methionine	0.36	0.61	0.59	0.62	10 mg/kg/d
Isoleucine	0.69	0.92	1.14	0.98	15 mg/kg/d
Leucine	1.04	1.82	1.74	1.64	21 mg/kg/d
Phenylalanine	0.82	0.86	0.83	0.82	21 mg/kg/d
Histidine	0.42	0.82	0.82	0.69	15 mg/kg/d
Lysine	1.03	1.94	1.80	1.79	18 mg/kg/d
Arginine	0.69	1.30	1.33	1.34	

[a] Recommended daily allowances for adults.

Table 2–Comparison in minerals composition among insect fresh weight (silkworm pupae) and common animal foodstuffs fresh weight (Longvah and others 2011).

Component (mg/100 g)	Pupae	Beef meat	Pork meat	Chicken meat	RDA[a]
Phosphorus	175	191.50	160.00	nd	1000 mg
Iron	7.0	1.67	0.80	nd	10 mg
Calcium	24.0	6.50	8.00	8.00	1000 mg
Zinc	2.10	3.41	1.60	1.26	10 mg
Copper	0.45	0.05	0.13	0.06	1.2 mg
Magnesium	54.0	19.25	17.0	26.00	nd
Manganese	0.69	nd	nd	nd	1 mg

[a] Recommended daily allowances for adults.

Interestingly it has recently been observed that generally insects eaten by humans spanned a wide range of protein-to-fat ratios but are generally nutrient dense, whereas insects with high protein-to-fat ratios are eaten by primates (Raubenheimer and Rothman 2013).

Insects can also be a source of fiber due to their high chitin content, accounting for about 10% of the whole dried insect. Chitin is a carbohydrate polymer, supposedly the most abundant in nature, exceeding cellulose, found in invertebrate exoskeletons, protozoa, fungi, and algae and provides a caloric value dependent on the insect species. For example, the winged sexual forms of the African termite, *Macrotermes falciger* (Gerstacker), have been estimated to have a calorific value of 761 kcal (∼3196 kJ)/100 g (dry, ash-free, weight basis) while the winged forms of another African species, *Macrotermes subhyalinus (*Rambur), were found to contain 613 kcal (∼2575 kJ)/100 g (dry weight) (Oliveira and others 1976). Ashiru (1989) reported a caloric value of 611 kcal (∼2566 kJ)/100 g for the caterpillar *Anaphe venata* (Butler) (Notodontidae) in Nigeria. Twenty-three species of caterpillars in Zaire, mostly Saturniidae, were found to average 457 kcal (∼1919 kJ)/100 g dry weight, ranging from 397 to 543 kcal (1667 to 2281 kJ) (Malaisse and Parent 1980). However, the estimated energy value of insects cannot be completely metabolized by humans since the calories that could be produced by chitin oxidation are not completely available for human nutritional needs. Accordingly, however, the insect fiber fraction could replace plant fibers leading to a reduction in glycemic load when consumed together with sugar.

Chitin from the shells of lobsters, crabs, and crayfish has been approved in Japan for use in cereals as a source of fiber and calcium. If protein concentrates from dechitinized insects became acceptable and were produced on a large scale, the chitin by-product could be of significant value as a fiber source as supposed by DeFoliart (1992).

Insects also have high vitamin and mineral content as indicated by many studies. Oliveira and others (1976) found the Angolan caterpillar, *Usta terpsichore* (Saturnidae) to be a rich source of iron, copper, zinc, thiamine (vitamin B1), and riboflavin (B2). Kodondi and others (1987) reported that 3 Saturnidae caterpillar species, prepared by traditional smoking and drying techniques, revealed high riboflavin and niacin, but not thiamine and pyridoxine (B6), contents. Feeding trials confirmed that, except for thiamine and pyridoxine, the caterpillars supplied sufficient vitamins to allow proper growth of young rats (Kodondi and others 1987). The 21 species of caterpillars studied in Zaire by Malaisse and Parent (1980) were a good source of iron as 100 g of these insects provided on average 33.5% of the minimum daily requirement.

In Mexico, *axayacatl* (a mixture of several species of aquatic Hemiptera), *ahuahutle* (eggs), and *jumiles* (several species of edible stink bugs) have been found to be rich sources of riboflavin and niacin (Massieu and others 1958; Massieu and others 1959). *Sphenarium* grasshoppers are high in niacin, while *axayacatl* is also a rich source of iron. The high content of iron and zinc in many edible insects is of particular interest as a way to alleviate deficiencies that could be found in women's diets, particularly among pregnant women in developing world, and in vegetarian diet everywhere (Scholl 2005; Craig 2010; Habimana and others 2013).

Hazards

Allergy hazards

Food allergy is defined as an adverse health effect arising from a specific immune response that occurs reproducibly after exposure to a given food (NIAID-Sponsored Expert Panel and others 2010). The clinical picture of food allergy is pleomorphic and can range from mild symptoms, such as urticaria, to severe reactions, such as anaphylaxis. Anaphylaxis is defined as "a serious allergic reaction that is rapid in onset and may cause death" (Sampson and others 2006).

Although any food can potentially be allergenic, arthropods, such as shellfish (mainly shrimp, lobster, and crayfish) are widely known to be able to induce allergic reactions in susceptible individuals (Ayuso 2011). Studies on cross-reactivity among crustaceans have shown a high degree sequence similarity with tropomyosin, suggesting that this protein is a major allergen in crustaceans and represents an important cross-sensitizing allergen, responsible for the immunological relationship between crustaceans, cockroaches, and house dust mites. Tropomyosin belongs to a family of highly conserved proteins with multiple isoforms, found in both muscle and non-muscle cells of all species of vertebrates and invertebrates. It is known that patients allergic to shrimp may also be allergic to other shellfish and some evidence suggests that shrimp may cross-react with Arthropoda such as house dust mites (Arachnida) and insects, including chironomids, cockroaches, grasshoppers, and fruit flies (Leung and others 1996; Reese and others 1999).

To our knowledge, few studies have been published on allergic reactions due to insect ingestion. Differences in geographical food traditions can result in differences in food allergy risk. In many countries insects are considered to be an important food source because of their high-quality protein content. Also, scale insects have long been used to produce crimson-colored dyes.

Carmine dye is a biologically derived colorant obtained from the dried bodies of female cochineal insects (*Dactylopius coccus Costa/Coccus cacti L*). Carmine is used as a food dye in many different products such as juices, ice cream, yogurt, and candy, and as a dye in cosmetic products such as eyeshadow and lipstick (DiCello and others 1999). Although carmine is widely consumed in foods and beverages, it has been rarely implicated in adverse reactions experienced by consumers (Lucas and others 2001). The most probable mechanism involved in adverse reactions to carmine is an IgE-mediated allergy. The sensitization would occur to protein residues present in carmine (Acero and others 1998), and the carmine-specific IgE antibodies would be directed against one or more of those specific carmine-associated proteins (Chung and others 2001). However, the protein content of carmine is likely quite small, depending upon processing (Taylor and Dormedy 1998). IgE sensitization to carmine-associated allergens is more likely to occur through higher-level exposures such as occupational or cosmetic exposure to carmine. Once IgE sensitization to these carmine proteins occurs, the level of exposure to these residual proteins through carmine-containing foods and beverages may be sufficient to elicit allergic reactions. A number of instances of allergic reactions to cochineal, including anaphylaxis, have been reported (Kagi and others 1994; DiCello and others 1999). Five individuals reacted following the ingestion of alcoholic beverages which contained this colorant (Wuthrich and others 1997). In that case, a series both skin prick test and specific IgE to carmine were positive. Anaphylaxis has been reported to cochineal contained in yogurt. Approximately 1.3 mg of cochineal was present in the yoghurt (the acceptable daily intake is up to 5.0 mg per kg of body weight) (Beaudouin and others 1995). Skin prick tests were performed using that yogurt, which the patient had consumed the day of the reaction, and with carmine; both skin prick tests were positive. Also, a leukocyte histamine release test was performed to determine if exposure of patient's blood basophils to carmine would elicit the release of histamine. The test was positive.

Anaphylaxis has also occurred with cochineal contained in cosmetics (Park 1981) and in a campari-orange drink (Kagi and others 1994). Anaphylaxis was reported in a child after ingestion of a popsicle colored with carmine. A skin-specific IgE test was positive (Baldwin and others 1997).

Three female patients were found with a history of anaphylaxis and/or urticaria/angioedema after ingestion of carmine-containing foods (popsicle, artificial crab, red grapefruit juice). Two patients experienced an immediate, pruritic, erythematous eruption after applying a blush, colored with carmine, directly to facial skin, but not when the blush was used over foundation makeup (Chung and others 2001). The same authors showed that patients had IgE-targeting protein impurities in cochineal extract, but not purified carmine. Immunoblotting and immunoblotting inhibition experiments suggested that several different cochineal insect proteins appear to be present in commercial carmine (Yamakawa and others 2009).

Infestation of lentils with lentil pests, mainly *Bruchus lentis* in Spain, is a very common event (Armentia and others 2006). Sixteen patients with allergic symptoms associated with inhalation or ingestion of lentils parts have been evaluated, in which sensitization to legume protein was not clear. A skin prick test was performed with extracts prepared from both noninfested and infested lentils and from the lentil parasite *B. lentis.* All patients displayed positive results to infested lentils and to *B. lentis,* while 6 patients were negative to noninfested lentils. Oral food challenge with boiled infested lentils was performed in 7 patients, 6 of whom proved positive. These results indicate that lentil pest proteins can be a cause of IgE-mediated anaphylaxis and asthma in patients eating or inhaling infested lentil particles.

Ingestion of caterpillars (like other foreign bodies) is common in children, presumably due to their natural curiosity. Lee and others (1999) reported the case of 8 children who had accidentally ingested caterpillars with consequent local and general effects (drooling, difficulty in swallowing, and generalized urticaria). In the vast majority of cases (6 of 8 patients) caterpillars were the hickory tussock moths, *Lophocampa caryae* (Family: Arctiidae), a caterpillar that lives in the United States, Canada, and Mexico. Pitetti and others (Pitetti and others 1999) described the case of 26 children who ingested or had oropharyngeal contact with caterpillars and cocoons (mostly belonging to *Lophocampa caryae* specie). Symptoms consisted of drooling, difficulty swallowing, pain, and shortness of breath. It is important to note that the ingestion of caterpillars may provoke toxic reactions, even when symptoms suggest an underlying allergic reaction. In order to distinguish between these possibilities, allergological testing should be performed, but it was not done in this case. On the other hand, Balit and others (2003) reported the case of 4 children who ingested caterpillars (one belonging to the Arctiidae family, the others were not identified due to damage) without any symptom.

Caterpillars, as well as termites, are commonly eaten insects in Africa where they provide an important amount of protein in the daily diet. Among these are Mopane caterpillar (*Imbrasia belina*), which are usually sun-dried after the harvest to obtain a longer shelf-life. Only a few cases of anaphylactic shock have been described following consumption. Okezie and others (2010) reported the case of a 36-y-old female who had 2 different episodes of anaphylactic shock after Mopane caterpillar ingestion (the patient had previously eaten this mopane without reactions). In this case no skin prick test was performed. Recently, Kung and others (2011) described a case of anaphylactic shock in an atopic adolescent who had previously eaten this caterpillar, with mild reactions. They performed both a skin prick test and Western blot with positive results.

In China the most commonly eaten insect is the silkworm pupa. Chinese people often eat it fried in oil, boiled in water or powdered. Silkworm pupa is allergenic. It has been estimated that each year in China over 1000 patients experience anaphylactic reactions after consuming silkworm pupa and 50 of them present a severe reaction requiring emergency room admittance (Ji and others 2008). Fourteen cases of severe anaphylactic reactions caused by consumption of silkworm pupa have been reported: 13 involved Chinese patients and one involved a French male visiting China who ate oil-fried silkworm chrysalis for the 1st time. One possible explanation may be cross-reactivity among related, as well as taxonomically dispersed, groups of insects and other allergens. Liu and others (2009) identified arginine kinase from silkworm as an important allergen. This enzyme cross-reacts with cockroach arginine kinase. They also evaluated cross-reactivity among invertebrate tropomyosins but, when tested in an immunoblot assay, less than 12% of patients reacted.

The risk of food allergy after insect consumption needs further investigation and greater attention is required in distinguishing between toxic and allergic symptoms (Lee and others 1999; Pitetti and others 1999).

Microbial hazards

Specific studies on the microbiological safety of insects as food are rare in the scientific literature. Evaluating the ability of insect vectors to transmit pathogens to farm animals can give us some information about their presence, prevalence, and survival ability in different hosts. The insects generally investigated are beetles, cockroaches, and flies. The aim of this section is to evaluate the insect microbiota scenario in order to identify common, potentially new hazards for possible Western consumers.

Studies on 4 commercial species of insects (*Zoophobas morio, Tenebrio molitor, Galleria mellonella, and Acheta domesticus*) showed a high total microbial charge (10^5 to 10^6 cfu/g) on samples originating from a closed-cycle farm, mainly composed of Gram-positive bacteria, as fecal and total coliforms. The Gram-positive population was mostly formed by *Micrococcus* spp., *Lactobacillus* spp. (10^5 cfu/g), and *Staphylococcus* spp. (approximately 10^3 cfu/g). *Salmonella* spp. and *Listeria monocytogenes* were never isolated in the tested samples (Giaccone 2005).

In any event, *Salmonella* is widely distributed in flies living near contaminated livestock units and is detectable in beetle to a lesser extent. Persistent carriage appears to be common among flies, and arthropod-mediated transmission is supported by extensive experimental evidence, particularly in the case of poultry, between closed flocks. *Campylobacter* can also be easily isolated from arthropods in contact with affected poultry flocks, especially from flies which have been described as infecting C*ampylobacter*-negative poultry flocks with *Campylobacter* (Wales and others 2010).

Templeton and others (2006) focused their research on darkling beetle (*Alphitobius diaperinus*) ability to be a reservoir and vehicle of *Campylobacter* in a broiler farm. This kind of bacteria is the leading zoonotic cause of foodborne illness in the EU (EFSA 2012b) and its importance is increasing in food safety. The study investigated in particular the fallow period between batches. *Campylobacter* from poultry feces can infect darkling beetle, both larvae and adults; likewise, *Campylobacter* from insects can infect poultry. However, in experimental conditions, the maximum survival time of *Campylobacter* in this insect was 72 h (Templeton and others 2006). Hazeleger and others (2008) also quantified *Campylobacter* spp. persistence in an empty shed and observed a decrease in bacterial charge until disappearance, occurring after 1 wk. This led to the conclusion that *Alphitobius diaperinus* has limited ability to harbor *Campylobacter*.

The study of campylobacteriosis is of critical importance in Australia and New Zealand, where chickens are responsible for 40% of foodborne cases of human disease. The darkling beetle (*Alphitobius diaperinus)* does not seem to be involved in the phenomena, while the housefly (*Musca domestica*) is undoubtedly the most critical mechanical vector (Nelson and Harris 2006).

In 1986, a study conducted at farms with large populations of *Alphitobius diaperinus* demonstrated high average contamination of this insect with bacteria. Interestingly, Salmonella was isolated in only one out of 7 controlled farms (Goodwin and Waltman 1996).

In another study on both adults and larvae, *A. diaperinus* harbored high levels of multiple poultry pathogenic bacteria. Interiors were more contaminated with Gram-negative bacteria such as coliforms and streptococci; these bacteria could be natural inhabitants of the intestinal tract of this insect. The exterior part of larvae was more contaminated with *Staphylococcus* spp. and *Micrococcus* spp. About 5% of adults'; surfaces were *Salmonella* Arizona-positive and no thermophilic campylobacters were identified (Agabou and Alloui 2010).

Feeding experiments of houseflies with *Escherichia coli* 0157:H7 showed that the ingested bacteria were harbored in the intestine; after proliferation they were found in the mouth parts and accumulated in the crop, and the bacteria continued to be excreted for at least 3 d after feeding. These results strongly suggest that houseflies are not simple mechanical vectors of *E. coli* and that the potential of houseflies to disseminate *E. coli* O157:H7 may be greater than initially suspected (Kobayashi and others 1999).

The role in the dissemination of this pathogen in the cattle environment has also been demonstrated by Ahmad and others (2007) who observed the capability of house flies to transmit *E. coli* O157:H7 to the cattle digestive tract and to play a role in the ecology of this human food-borne pathogen in the cattle-production environment.

However, the main aspect in a food perspective is not the microflora composition of live animals but the possibility to safely store and preserve derived products. In this context, Klunder and others (2012) recently evaluated the microbiological content of fresh, processed, and stored edible insects. The study focused on mealworm (*Tenebrio molitor*) and cricket (*Acheta domesticus* and *Brachytrupes* sp.) that were analyzed as fresh, boiled, roasted, fresh, and stored (refrigerated and ambient environment) and also boiled and stored (refrigerated and ambient environment). Results indicated that in fresh insects Enterobacteriaceae and sporeforming bacteria can be isolated, but generally they do not belong to pathogenic species. Boiling insect for 5 min is an efficient process for eliminating Enterobacteriaceae but not sporeforming bacteria. Thus, storage at refrigeration temperature (5 to 7 °C) is suggested. Moreover, a 5 to 7 °C temperature will prevent spoilage of boiled insects (stable for more than 2 wk), while it is not efficient against spoilage of fresh ones. Roasting alone did not kill all Enterobacteriaceae; therefore, a few minutes of boiling is suggested before roasting. The authors also showed that lactic acid fermentation was able to inactivate Enterobacteriaceae and keep remaining sporeforming bacteria stable at acceptable levels where they were unable to germinate and grow (Klunder and others 2012).

For the above-mentioned reasons, insect hygienic handling and correct storage should be strongly addressed, in order to avoid potential risk following their consumption.

Parasitical hazards

Parasites represent another potential hazard in relation to insect consumption. Their presence has been well documented in a recent review about foodborne intestinal flukes in southeast Asia (Chai and others 2009). The great importance of this work is linked to the geographical area investigated, where there is a long, widespread tradition of insect consumption. Six out of 65 species of intestinal flukes considered in the paper were isolated from insect samples. Among these is *Phaneropsolus bonnei* (Lecithodendriid), 1st described at a human autopsy in 1951 in Jakarta, Indonesia and later found in monkeys in Malaysia and India in 1962. This fluke was then reported in 15 human autopsies in Udornthani Provincial Hospital in northeast Thailand. Subsequently, the same fluke infection was found to have a high prevalence in other countries. Metacercariae were discovered in naiads and adult dragon- and damselflies, insects which are commonly eaten in these parts of the world. The same insect can harbor the fluke, *Prosthodendrium molenkampi* (Lecithodendriid), which characteristically has 12 to 30 vitelline follicles on each anterolateral side. First isolated from 2 human autopsies by Lie Kian Joe in 1951 in Jakarka, Indonesia, this fluke was then found in 14 human autopsies in Udornthani Provincial Hospital, Thailand. Later, high prevalence was reported in different areas of northeast Thailand. In Laos PDR, a total of 8899 adult specimens were recovered from 52 infected people residing along the Mekong riverside areas of Vientian Municipality, and Savannakhet, Khammoune, and Saravane Provinces. Metacercariae were discovered in naiads and adult dragon- and damselflies in Thailand. Another member of this genus, *Phaneropsolus spinicirrus,* was described in 1991 as a new species from a human infection case in northeast Thailand.

Another relevant fluke family is Plagiorchid. *Plagiorchis harinasutai* was reported as a new species in 1989 based on worms recovered from 4 human cases, probably originating from insect larvae. The fluke *Plagiorchis javensis* can also infect humans, and it is also present in birds and bats (reservoir). *Plagiorchis* was originally described in Japan, based on worms recovered from mice experimentally infected with the metacercariae. An experimental human infection was reported in the United States. Natural human infections have been reported in Japan and the Republic of Korea. Freshwater snails (*Lymnea pervia* in Japan and *Stagnicola emarginata angulata* in the United States) shed the cercariae, while aquatic insects (mosquito larvae), insect naiads, fresh water snails, and fresh water fish harbor the metacercariae. Rats are an experimental definitive host. House rats in Japan, and rats, mice, and cats in the Republic of Korea are the natural definitive hosts. *Plagiorchis philippinensis* was 1st recovered at autopsy of a resident of Manila in the Philippines, by Africa and Garcia in 1937. Infection was acquired by eating insect larvae. Birds and rats are reservoir hosts (Chai and others 2009).

Moving westward, we find case reports related to *Gongylonema pulchrum*. *Gongylonema* is a genus of nematodes belonging to the Spiruroidea superfamily with about 25 species infesting wild and domestic mammals and various species of birds, worldwide. Sporadic cases of one species, *G. pulchrum*, known as the "gullet worm" because of its location in the upper digestive tract, have been reported in humans in many places around the world (Molavi and others 2006). This nematode has insects, especially beetles and cockroaches, as the intermediate host. Consequently, it is a possible zoonotic agent related to raw insect consumption. In humans, localization is subcutaneous in the oral cavity and the effect is an easily diagnosed larva *migrans* syndrome. In 2001, a clinical observation reported a 25-mm spidery structure moving about 2 to 3 cm a day in the oral cavity of a 38-y-old Massachusetts woman who had returned from Mexico where she had ingested a raw insect. The woman had no symptoms. This was the 11th U.S case in about 50 reported worldwide (Wilson and others 2001).

Battyany and others (2011) described a case of Hydatid cyst following a wasp sting, opening the question of potential transmission through this kind of vector, mainly in endemic areas. No other studies have focused on this topic.

An important case in which insects show their potential as a biological vector is trypanosomiasis. The World Health Organization (WHO Media Centre 2010) has estimated that about 10 million people are infected with Chagas in the Americas, 2 million of them in Brazil alone. More than 10000 die each year. Historically, transmission occurs predominantly in rural areas of Latin America, where poor housing conditions promote contact with infected vectors. The importance of the oral route has been overlooked for a long time because the parasite is an example of a vector-borne pathogen, but researchers' attention was turned toward it during investigation of several outbreaks. Cases have been reported in the literature linking infection with the accidental ingestion of insects or consumption of contaminated food (Pereira and others 2010).

Myiasis is the infestation of human and vertebrate animals with dipterous larvae. Broadly speaking, myiasis can be divided into 3 groups: cutaneous, body cavity, and accidental. Among the latter is intestinal myiasis which occurs when fly eggs are ingested, reach the gastrointestinal tract, and pass into the feces as larvae. Usually the problem is transient and asymptomatic. *Musca domestica*, the common house fly, is a rarely reported cause of myiasis, while recognized agents are: *Megaselia scalaris*, *Sarcophaga* spp., *Phormia regina, Parasarcophaga, Sarcophaga crassipalpis, S. peregrina, Hermetia illucens, Eristalis tenax,* and *Dryomiza formosa* (Sehgal and others 2002).

Among potential foodborne and waterborne pathogens also Protozoa, such as *Entamoeba histolytica* and *Giardia lamblia,* have been isolated in cockroaches. These insects can also harbor *Toxoplasma* spp. and *Sarcocystis* spp., but only for a limited time as demonstrated for *Toxoplasma* spp. in *Periplaneta americana* and *Blatella germanica* (Graczyk and others 2005). Also in flies a variety of Protozoan parasites of importance for human health have been isolated (*Sarcocystis, Giardia, Toxoplasma gondii, Isospora, Giardia, Cryptosporidium*). Particular attention should be paid to *Cryptosporidium parvum,* which is an important lethal agent for immunocompromised individuals (Graczyk and others 2005).

These parasites could be present also in edible insects and should be considered in the case of insects consumption as food.

Chemical hazards

When the query "insects and toxicity" is launched in any scientific search engine, it produces a great amount of data concerning pesticides; very few findings relate to the insects themselves. This output gives some idea of the fact that insect studies are targeted at their destruction rather than at their management and appropriate use.

The 1st chemical consideration concerning insects as dietary components is that all pesticides used against them are potentially dangerous for consumers, particularly if the products have been obtained by wild harvesting rather than controlled farming. This observation is supported by a case occurring in Thailand where, after a major disinfestation program, dead insects were placed on the market causing health problems for consumers (DeFoliart 1999).

A 2nd case that highlights this concern took place in Kuwait in 1988–1989 where locusts that invaded the country were sprayed with pesticides to save crops and vegetation. Results obtained from captured locusts showed that chlorinated pesticides were not present at relevant levels in the residues, whereas a relatively high amount of organophosphorus pesticides were found, in particular sumithion and malathion, respectively, considered as moderately and slightly toxic. This posed a risk for people eating locusts (Saeed and others 1993).

A complete discussion on insect content in noxious substances, as for other animals and vegetables, should encompass natural toxicants, defined hereto as compounds naturally present in insect feed or synthesized by insects. The world of natural toxicants is complex. As stated very early (Holt 2007), it is important to distinguish between safe and unsafe insects, as in the mushroom world. Some produce noxious substances against predators or warn their enemies through advertising color patterns (Zagrobelny and others 2009). Others try to deceive attack by mimicking the colors of true toxins (batesian mimicry). In order to simplify this distinction and avoid the risk of ingesting a toxicant, Holt concluded that insects feeding on edible plants can be considered safe, while others need to be more accurately selected. In general, the accumulation of toxins from feed is an easy survivor strategy in the evolutionary process, but fortunately some of these substances can lose their properties through the cooking process (Berenbaum 1993). More specifically, poisonous insects can be divided into 2 categories, phanerotoxics and cryptotoxics. Phanerotoxics have organs for the synthesis of poisons, as in the case of bees and ants. These substances are generally inactivated in the digestive tract. There are potential risks during the oral and esophageal passage of stings. Some biogenic amines can become dangerous if present at a high level. Insects are cryptotoxic when potentially noxious substances are present as a consequence of synthesis or accumulation. These substances can be localized in specific structures or diffused in different body areas. This kind of insect is potentially dangerous for humans after ingestion.

Among insect-related chemical hazards are metabolic steroids (including testosterone and dihydrotestosterone) found in beetles (Dytiscidae family). If frequently consumed, they can cause growth retardation, hypofertility, masculinization in females, edema, jaundice, and liver cancer. Cyanogenetic substances can also be present in insects (Coleoptera and Lepidoptera), causing inhibition of enzymes such as succinate dehydrogenase and carbonic anhydrase, and inhibiting some metabolic pathways like oxidative phosphorylation, due to a high affinity for ferrocytochrome oxidase (Blum 1994).

Insect consumption is practiced not only in developing countries but, for example, has also been discovered in Friuli-Venezia Giulia, a Region of eastern Italy. Mountain inhabitants from this area report the tradition of eating Lepidoptera of the genus *Zygaena*, which are bright in color and potentially dangerous as they accumulate cyanogenetic glycosides. These kinds of chemicals can be partially detoxified by rhodanase activity in the presence of sulfur, increasing risk among undernourished subjects with a low sulfur diet. However, consumers in these areas discard most of the body and eat the sweet ingluvies, where toxicants are not accumulated (Zagrobelny and others 2009).

According to Blum (1994), another noxious substance contained in Longhorn beetles (genera *Stenocentrus* and *Syllitus*), is toluene, a nervous system depressant toxic for brain, kidneys, and liver. These insects are the only known sources of toluene among Arthropoda, and cannot be recommended for ingestion. *Lytta vescicatoria (coleoptera)* harbor cantharidine in ovaries and eggs causing bladder and urethral irritation, occasionally priapism. This substance can be lethal if enters the blood stream (Blum 1994).

The presence of benzoquinone in insects was demonstrated (Brown and others 1992). This substance belongs to the family of quinones, phenolic compounds widely distributed in plants. Most quinones are bitter in taste (Schwartz and others 2008). This compound is present in Tenebrionidae, insects used in alternative medicine, as *Ulomoides dermesetoides* reared in Argentina and used as treatment against asthma, Parkinson's disease, diabetes, arthritis, HIV, and certain cancers. The presence of benzoquinones was demonstrated in 30-d-old adults (Crespo and others 2011). This kind of insect can be cytotoxic against the human lung carcinoma epithelial cell line A-549, resulting in DNA damage. However, cytotoxicity seems to be directed not only toward cancer cells but also against other targets. Some researchers affirm that the mechanism of DNA damage could lead to cancer in people coming into contact with benzoquinones, specifically methyl-benzoquinones and ethyl-benzoquinones, which are also contained in the flour beetles (adults) *Tribolium confusum* and *Tribolium castaneum* (Lis and others 2011). However, IARC (International Agency for Research on Cancer) officially states that no epidemiological data are available on the carcinogenicity of 1,4-benzoquinone. There is *inadequate evidence* in experimental animals for the carcinogenicity of 1,4-benzoquinone, which consequently is *not classifiable as to its carcinogenicity to humans (Group 3*; IARC and WHO 1999).

Great attention should also be paid to antinutritional substances. This problem is particularly relevant for people with poor diets where there are limited sources of vitamins and other important nutrients. A specific case of antinutritional activity of insects is described in Africa following *Anaphe venata* caterpillar ingestion. This insect can cause thiamine deficiency, with a consequent ataxic syndrome during the season when it is typically consumed. Analyses have demonstrated a 3-fold higher thiaminase level than in the common silkworm. Since dietary intake is limited in this way, some Nigerians present thiamine deficiency. However, proper cooking methods can minimize or eliminate thiaminase (Nishimune and others 2000).

The Chinese Ministry of Health recently inserted silkworm pupae among its new food sources, boosting scientific interest about this topic. These insects were already consumed as a silk industry by-product and, after a period of decline, have recently regained importance. For this reason, toxicological studies have been performed to evaluate PSP (protein of silkworm pupae) safety by Zhou and Han (2006). They performed an acute toxicity test, a mutagenicity test (Ames test, mouse bone marrow cell micronucleus test, and mouse sperm abnormality test) and a 30-d feeding study, concluding that 1.50 g/kg body weight of PSP daily can be regarded as safe.

In Australia, arsenic accumulation was discovered in *Agrotis infusa* (Lepidoptera). This noxious element is ingested with diet and originates from both natural sources and human pollution. Due to its migration habits the insect is able to disseminate arsenic over a wide radius (up to 100 km) (Green and others 2001).

Heavy metals are not a negligible problem as they can be bioaccumulated in insect bodies. In an outbreak study, Handley and others (2007) demonstrated a high lead content in chapulines (dried grasshopper) from Oaxaca (Mexico) and associated them with elevated blood lead levels in Californian children and pregnant women. Chapulines were not the only source of lead in the investigated population. Obviously food metal levels depend on environmental contamination and food preparation, and dehydration contributes to increasing toxicant concentration, as in the case of Oaxacan grasshoppers.

Bioaccumulation and potential heavy metal content has also been investigated along the soil-plant-insect-chicken food chain. Results indicate that Cd steadily declines with increasing trophic level, but concentrations of Zn and Cu slightly increase from plant to insect larva. An important route by which to avoid bioaccumulation is elimination through the feces. Metal concentrations in chicken liver, muscle, and blood were highly variable, but were found to be higher in liver and lower in blood. Chickens fed with insect larvae accumulated significantly high Pb levels in their livers, suggesting that the accumulation of heavy metals in specific animal organs cannot be neglected (Zhuang and others 2009). Nevertheless, insect consumption did not represent a risk factor according to this evaluation.

Crickets, as other soil-dwelling insects, are also able to introduce contaminants from solid waste into the food web by preying on discarded consumer products (Gaylor and others 2012).

Chemical hazards in insects depend, in most cases, on habitat and plant feed contamination and can be controlled by selected farming and dietary conditions.

Concluding Overview

Insect consumption by humans has always been a worldwide practice. This food habit dates back to prehistory (McGrew 2001; Lanfranchi 2005; Tommaseo-Ponzetta 2005; Bogart and Pruetz 2011; Van Itterbeeck and van Huis 2012) and is still traditional in many countries (Paoletti and others 2000; Meyer Rochow 2005; Onore 2005; Paoletti 2005; Paoletti and Dreon 2005) especially where food is in short supply (Tchibozo and others 2005; Christensen and others 2006) but also where food security is not a major concern (Cunningham and Marcason 2001). Historically, however, Western diets had similar elements. In Roman times, for example, consumption of cossus (*Lucanus cervus* or *Prionus corioranus*) larvae, fattened in wine and flour, were popular among epicureans, as described by Plinius in his "Naturalis Historia" (Holt 2007). Among the historical factors that diverted humans from this food source was the Neolithic revolution. The passage from nomadism to geographical stability brought major agricultural development, instead of wild harvesting, and insects began to be considered agricultural pests rather than food (Tommaseo-Ponzetta 2005; Perlès 2006). Today, in most developed countries, few food products of insect origin are commonly consumed (honey, royal jelly), while insects are only unintentionally ingested.

In industrialized countries, where the problem of food security is not of major concern, food-related health challenges refer principally to nutritional value and food safety; in this context, insect consumption has to meet these main factors.

The nutritional value of insects is repeatedly stated in the scientific literature and, as described elsewhere, is comparable to that of common sources of animal proteins. Insects can be compared to other foods of animal origin, such as crustaceans, fish, and meat, which commonly form the Western diet. Insects have a high quality protein content due to the presence of all the essential amino acids in the recommended ratios (Collavo and others 2005). This renders insects a suitable food for all age groups. Insects'; additional value is represented by their fatty acid composition since the ratio between the 3 fat categories (SFA, MUFA, and PUFA) remains within the suggested range for health purposes. Moreover, compared with other food of animal origin, insects have an important fiber content making them a nutritionally balanced foodstuff.

The nutritional value of insects has been widely recognized. WHO has considered insects as a suitable food to meet the protein needs of starving individuals, including HIV-positive subjects who require higher quality nutrition to counteract immunological impairment (WHO and FAO 2002).

Concerning hazards (summarized in Table 3), insects, like other common foods, may cause allergic symptoms, even after the 1st exposure. Moreover, involuntary ingestion is quite frequent considering that insects (or parts of them) are common food contaminants (FDA 1995).

It has also been demonstrated that some allergens are common to different kinds of food leading to cross-reactivity phenomena. This is the case, for example, of insects and crustaceans. For these reasons, insect consumption should take into account the real possibility of adverse reactions and appropriate indications in food labeling should be required.

From a microbiological point of view it has been widely demonstrated that insects can harbor different kinds of food pathogen bacteria. Nevertheless, research has been generally limited to farm pests like darkling beetle and flies and designed to evaluate their potential role in livestock contamination. Some authors have also described how bacteria are unable to survive after insect contamination for days (Templeton and others 2006; Hazeleger and others 2008). This suggests that a properly managed insect farm could remain free from pathogens by avoiding contact with wild insects and other sources of contamination. However, since microbiological concerns are well known and widely diffused in animal farming and in the derived food chain, they cannot be considered as hazards sufficient to justify insect limitation or exclusion from the food market.

The possibility for insects to harbor parasites has also been described, but, in the light of common animal husbandry practices, this risk can be reduced, since parasites are strictly connected to environmental features that maintain the parasitic life cycle.

On the basis of current knowledge, to reduce parasitic and other biological risks that could be connected with insect consumption by humans, simple hygienic measures (as appropriate cooking and/or freezing) should be applied during food processing, as suggested for poultry, pork, and fish.

Following a few preventive measures can reduce chemical risks connected with insect consumption. In order to avoid the toxic effects of insects due to the synthesis of poisons, an accurate selection of species should be envisaged before farming and appropriate regulations have to be settled to ban species recognized to be dangerous for humans on a case by case basis. To counteract chemical bioaccumulation, a controlled feed program needs to be considered, focusing particularly on feed composition and feed contamination by chemicals.

"Food Defect Action Levels" is the official U.S. FDA regulation concerning insect parts in food products (FDA 1995) and pertains to "Levels of natural or unavoidable defects in foods that present no health hazards for humans." It established the maximum permitted level of insects or parts thereof in food by considering them from an aesthetic (offensive to the senses) point of view rather than as a biological hazard. Likewise, the EU classifies the presence of visible insects larvae in food as "foreign bodies," as reported in the RASFF (Rapid Alert System for Food and Feed) database, otherwise only the presence of viable larvae is classified as microbiological hazard. Evidently, if insects were considered as food, the foreign body classification would consequently be lost.

Since nutritional and food safety considerations justify insect presence in the Western diet, the greatest obstacle to insect

Table 3–Insect species described in the article and relative hazards.

Order	Family	Genus	Species	Common name	Hazard category	Potential hazard	Reference
Coleoptera	Tenebrionidae	Tenebrio	*Tenebrio molitor*	Mealworm	Microbial	High bacterial count	Giaccone and others (2005)
		Zophobas	*Zophobas morio*	Superworm, zophobas	Microbial	High bacterial count	Giaccone and others (2005)
		Alphitobius	*Alphitobius diaperinus*	Lesser mealworm, Buffalo worm	Microbial	High bacterial count	Templeton (2006); Goodwin (1996); Agabou (2010)
		Tribolium	*Tribolium confusum*	Confused flour beetle	Chemical	Benzoquinons	Lis (2011)
			Tribolium castaneum	Red flour beetle	Chemical	Benzoquinons	Lis (2011)
		Ulmoides (Palembus o martianus)	*Ulmoides (Martianus o Palembus) dermesetoides*	nd	Chemical	Benzoquinons	Crespo (2011)
	Dytiscidae	nd	*nd*	Beetle	Chemical	Ormones	Blum (1994)
	nd	nd	*nd*	nd	Chemical	Cyanogenetic substances	Blum (1994)
	Zygaenidae	Zygaena o Sintomis	*nd*	nd	Chemical	Cyanogenetic substances	Zagrobelny (2009)
	Cerambycidae	Syllitus	*nd*	Longhorn beetles	Chemical	Toluene	Blum (1994)
	Meloidae	Lytta	*Lytta vescicatoria*	Spanish fly	Chemical	Cantharidine	Blum (1994)
	Chrysomelidae	Bruchus	*Bruchus lentis*	Lentil wevil	Allergic		Armentia (2006)
Odonata	nd	nd	*nd*	Dragonfly	Parasitical	Phaneropsolus bonnei	Chai (2009)
	nd	nd	*nd*	Damselfly	Parasitical	Phaneropsolus bonnei	Chai (2009)
Diptera	Muscidae	Musca	*Musca domestica*	Houseflies	Microbial	High bacterial count	Nelson (2006)
	Phoridae	Megaselia	*Megaselia scalaris*	Humpbacked/ Coffin/Scuttle fly	Parasitical	Miasis	Sehgal and others (2002)
	Dryomizidae	Dryomiza	*Dryomiza formosa*	nd	Parasitical	Miasis	Sehgal and others (2002)
	Syrphidae	Eristalis	*Eristalis tenax*	Drone fly	Parasitical	Miasis	Sehgal and others (2002)
	Stratiomyidae	Hermetia	*Hermetia illucens*	Black soldier fly	Parasitical	Miasis	Sehgal and others (2002)
	Sarcophagidae	Sarcophaga	*Sarcophaga peregrina*	nd	Parasitical	Miasis	Sehgal and others (2002)
			Sarcophaga crassipalpis	nd	Parasitical	Miasis	Sehgal and others (2002)
	Calliphoridae	Phormia	*Phormia regina*	Black blow fly	Parasitical	Miasis	Sehgal and others (2002)
Orthoptera	Gryllidae	Acheta	*Acheta domesticus*	House cricket	Microbial	High bacterial count	Giaccone and others (2005)
		Sphenarium	*nd*	Grashopper (chapulines)	Chemical	Lead	Handley and others (2007)
Hemiptera	Reduvidae	Triatoma	*nd*	nd	Parasitical	Chagas disease	WHO (2010); Pereira and others (2010)
Lepidoptera	Arctidae	Lophocampa	*Lophocampa caryae*	Hickory tussock moths	Allergic		Pitetti and others (1999)
	Saturnidae	Gomimbrasia	*Imbrasia belina*	Mopane worm	Allergic		Okezie and others (2010)
	Bombycidae	Bombyx	*Bombyx mori*	Silkworm	Allergic		Ji and others (2008)
	Pyralidae	Piraliini	*Galleria mellonella*	Honeycomb moth	Microbial	High bacterial count	Giaccone and others (2005)
	nd	nd	*nd*	nd	Chemical	Cyanogenetic substances	Blum and others (1994)
	Notodontidae	Anaphe	*Anaphe venata*	nd	Chemical	Thiaminase	Nishimune and others (2000)
	Noctuidae	Agrotis	*Agrotis infusa*	Bogong moth	Chemical	Arsenic	Green and others (2001)
Blattaria	Blattoidae	Periplaneta	*Periplaneta americana*	Waterbug	Parasitical	Protozoa	Graczyk and others (2005)
		Blatella	*Blatella germanica*	German coackroach	Parasitical	Protozoa	Graczyk and others (2005)

consumption remains the repulsion felt by Western people. However, people should become aware of the impact that food choices can have on malnutrition and environmental and animal welfare policies (Beckett and Oltjen 1993; Reijnders and Soret 2003; Fiala 2009).

The global food security challenge could be the 1st reason driving humans toward insect consumption. Hundreds of millions of hungry people are living in the world. FAO considers food scarcity to be dangerous for peace and political stability. The United Nations'; Dept. of Economic and Social Affairs, Population Div., calculates that an increase in the global population will bring the total number to 9.3 billion (8.1 to 10.6) in 2050, over one billion of whom will be suffering famine. Changing diet is not only a healthy idea for Western inhabitants, but also a feasible way to produce greater amounts of food in a more sustainable way (Paoletti and others 2011; Schosler and others 2012).

FAO recently published an extensive report on the actual role of insects as food, worldwide (FAO 2010) and asked institutions to develop research programs on this topic to promote insects as a source of protein and to evaluate the possibility of farming them.

Insect use as food also addresses the environmental sustainability challenge because traditional farming is a leading cause of pollution, while some insect species have a lower environmental impact (Oonincx and others 2010). For example, Oonincx and De Boer (2012) recently demonstrated that mealworms (*Tenebrio molitor*) are more sustainable in comparison with farm animals in particular considering land use and Global Warming Potential (sum of CO_2, CH_4, and NO_2 emissions expressed in CO_2-eq). However, carbon dioxide (CO_2) is not the worst problem because methane (CH_4) and nitrogen dioxide (NO_2) have considerably greater global warming potential than CO_2. Based on a life cycle analysis (LCA) that examines the entire production process, the global contribution by the food-producing animal sector is: 9% for CO_2 (fertilizer production for food crops, farm energy expenditures, feed transport, animal product processing, animal transport and land use changes), 35% to 40% for CH_4 (enteric fermentation in ruminants and from farm animal manure), and 65% for NO_2 (farm manure and urine) (Steinfeld and others 2006; Fiala 2009). Farming is considered the 2nd source of greenhouse gas emissions after energy production and before transport. A 220-g beef steak costs, in terms of CO_2 emission, the same as driving 16 km with an 11 km/L gasoline car (Fiala 2009). Moreover, water footprint is also of great concern. The amount of water needed to produce 1 kg of boneless meat, estimated in the United States was approximately 3682 L, due mainly to feed irrigation practices (Beckett and Oltjen 1993) whereas values ranging between 22000 and 43000 L/kg are reported by van Huis (2012). The values of water use are hardly comparable probably because those for complete LCA are lacking. In addition, these data are highly influenced by from farm location and characteristics.

Nitrate production resulting from high-protein feeding is an environmental threat causing the well-known phenomenon of eutrophication, which is dangerous for water organisms and ecological homeostasis. Land is mainly dedicated to livestock production (including feed crops) as 70% of the world's agricultural land and 30% of whole of the earth's land surface is used for this "protein consuming" production system (Premalatha and others 2011).

In 2003 the United States livestock population consumed more than 7 times as much grain as was consumed directly by the entire American population and for every kilogram of high-quality animal protein produced 6 kg of plant protein are consumed (Pimentel and Pimentel 2003).

Avoiding meat as a protein source could lead to the abandonment of up to 2700 Mha of pasture and 100 Mha of cropland, resulting in a large carbon uptake from vegetation regrowth. Additionally, methane and nitrous oxide emissions would be reduced substantially. Global transition to a reduced meat diet, as recommended, would reduce the mitigation costs to achieve a 450 ppm CO2-eq. stabilization target by about 50% in 2050 compared to a reference and mitigation scenario without these dietary changes. Hence, dietary choices are not only able to create substantial benefits for human health and global land use, but can also play an important role in future climate change mitigation policies (Stehfest and others 2009).

Moreover, the poikilothermic nature of insects helps them achieve energy balance more efficiently and consequently their feed conversion ratio (FCR) is lower than that of common livestock (Nakagaki and DeFoliart 1991). For example, FCR calculated for mealworm (*Tenebrio molitor*) was calculated in 2.2 kg/kg of live weight (Oonincx and de Boer 2012). Farm animals display values ranging from 2.5 and 10, respectively, for chicken and beef as reported by van Huis (2012).

Insects constitute an enormous available biomass with a number of species that reach 80% of the entire animal kingdom. Their fecundity is high and their life cycle short; they reach adulthood within a matter of days compared to the months taken by fowl and the years by ruminants. In addition, the percentage of edible weight is 100% for larva and around 80% if considering adult cricket without legs and exoskeleton (indigestible) (Nakagaki and DeFoliart 1991).

In Mexico, harvesting grasshoppers to preserve plant crops has been considered an alternative to pesticide use in pest management practice, with 3 resulting objectives: to obtain a secondary profitable product, to save money due to the reduction in pesticide use, and to decrease chemical contamination of soil and water (Cerritos and Cano-Santana 2008).

The production pressure on the small amount of farmed species ought to decrease and this can be achieved by the introduction of insects. Insect farming is practiced everywhere for uses other than food supply and small scale farming for human consumption is a historical habit (Van Itterbeeck and van Huis 2012) that currently exists in several countries as previously stated. Silkworm is the most studied among the potential candidates, probably on account of the age-old tradition of silk farming (Liu and others 2010).

This review demonstrates not the safety of insects as a whole food category, but rather the possibility for humans to consume some species with no additional hazards in comparison with usually eaten animal products.

On the basis of these considerations, insects can be regarded as safe, if properly managed and consumed. Moreover, in order to reduce exposure to contaminants and achieve a high-quality diet, their consumption should follow commonly accepted dietary recommendations, such as diet variation and portion control.

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