Edible insects: a food security solution or a food safety concern?

Simone Belluco,*† Carmen Losasso,* Michela Maggioletti,‡ Cristiana Alonzi,‡ Antonia Ricci*, and Maurizio G. Paoletti§

* Risk Analysis Division, Food Safety Department, Istituto Zooprofilattico Sperimentale delle Venezie, Viale dell'Università 10, 35020 Legnaro (PD), Italy
† Department of Animal Medicine, Production and Health, University of Padova, Viale dell'Università 16, 35020 Legnaro (PD) Italy
‡ UCSC-Allergy Unit, Complesso Integrato Columbus, Via G. Moscati 31, 00168 Rome, Italy
§ Biology Department, via Bassi 58 b, Padova University 35100 Padova, Italy

Implications

- Insect species intended for human consumption should be selected, managed, and prepared by taking into account traditional knowledge acquired in countries where insect consumption is customary.
- Existing evidence indicates that edible insects reared under controlled conditions are expected to pose no additional hazards compared with traditional animal products.
- Food safety research and regulatory issues should be implemented by addressing the insect food chain, taking into account species features, insect origins, farm management, and environmental conditions.

Key words: allergy, entomophagy, food security, novel food

Introduction

Insect consumption is practiced worldwide and has recently been proposed as a potential solution to fight food shortages and famine. Whether realistic or not, insect consumption could make important contributions to human nutritional requirements, in countries were malnutrition is a major issue..

On one hand, insects have been traditionally eaten throughout human history by a noticeable part of the worldwide population. On the other hand, insects are commonly considered as pests in most Western countries, and their presence in foods is unwanted and avoided as a potential source of contamination. However, Western attitudes are important to guarantee scientific interest, research, and development.

Insects suitably fulfill some human nutritional requirements due to their high protein value. In fact, their essential amino acid score (the essential amino acid requirement expressed as percentage in an ideal protein) ranges from 46 to 96% (Ramos-Elorduy et al., 1997), although the majority of insects have limited levels of either tryptophan or lysine (Ramos-Elorduy et al., 1997; Bukkens, 2005). Moreover, insect proteins are highly digestible (between 77 and 98%) (Ramos-Elorduy et al., 1997), with some exceptions among insects with less digestible chitin exoskeletons.

Insects vary widely in fat content, and thus, in energy. Depending on insect diet and insect species, the fat content can range from 7 to 77 g/100 g dry weight and the caloric value between 293 and 762 kcal/100 g dry weight (Ramos-Elorduy et al., 1997). A high PUFA/SFA ratio can occur; that of toasted chrysalis (*Bombyx mori*) is about 0.99, with the recommended level for a healthy diet being 0.45 (Pereira et al., 2003).

Cricket (*Acheta domestica*) based lollipops made by Giulia Tacchini.

Giulia Tacchini.

---

doi:10.2527/af.2015-0016

Insects also contain high concentrations of vitamins (B_1, B_2, and B_3) (Oliveira et al., 1976; Kodondi et al., 1987) and minerals (iron and zinc) (Malaisse and Parent, 1980). This is of particular interest for women's and children's diets, particularly in developing countries.

Although the commonly accepted definition of food is associated with nourishment, from a legislative point of view, nutritional evaluation alone is insufficient to justify categorizing items as food. In contrast, food safety has a central role in guiding judgment about the suitability of foods for human consumption, and thus, addressing this topic is considered a fundamental step to instigate the inclusion of edible insects in Western diets.

Food safety hazards represent a daily challenge for food producers, food safety authorities, and consumers. Foodborne hazards are thoroughly studied, and stakeholders have been dealing with commonly found microorganisms and chemical contaminants in traditional foods for many years. Moreover, legislators and food safety authorities take advantage of the great body of knowledge, which exists regarding food and its associated hazards to achieve a high level of consumer protection through everyday control activities. In this context, insects as foodstuffs are under-researched.

The small but growing amount of research in this field focuses on nutritional values, sustainability of production, economics, and description of insect consumption by different ethnic groups. However, very few studies have focused on food safety aspects of insect consumption. Moreover, insects are likely to escape comparisons with most Western foods, as they belong to groups phylogenetically far removed from mammals and birds and encompassing, as similar food animals, only some aquatic species including crustaceans. Insects' cold blood, their behaviors, habitats, and body compositions are expected to contribute huge differences in terms of microbiological, chemical, allergological, and parasitological risks when drawing comparison with food animals traditionally eaten in Western countries.

The aim of this article, based on a previously published paper (Belluco et al., 2013) and updated with recent literature, is to give an overview about known hazards associated with insect consumption and to highlight data gaps and requirements for further studies.

Summary of Foodborne Hazards for Edible Insects

Allergies

Food allergy is defined as an adverse health effect arising from a specific immune response that occurs reproducibly after exposure to a given food. The clinical picture of food allergy is pleomorphic and can range from mild symptoms, such as urticaria, to severe reactions including anaphylaxis, "a serious allergic reaction that is rapid in onset and may cause death."

Naturally, food allergy risks vary according to differences in geographical food traditions. Caterpillars, as well as termites, are commonly eaten insects in sub-Saharan Africa where they can provide an important amount of protein in the daily diet. Among these are mopane caterpillars (*Imbrasia belina*), which are usually sun-dried after harvest to increase shelf life. Only a few cases of anaphylactic shock have been described following consumption. Okezie and others (2010) reported the case of a 36-yr-old female who had two different episodes of anaphylactic shock after mopane caterpillar ingestion (the patient had previously eaten this mopane worm 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, which can be eaten fried in oil, boiled in water, or powdered. It is estimated that each year in China, more than 1,000 patients experience anaphylactic reactions after consuming silkworm pupa, and 50 of them present a severe reaction requiring emergency room admittance (Ji et al., 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 first 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. Arginine kinase and tropomyosin were identified as major cross reactive allergens in yellow mealworm, representing a risk for people with crustacean and house dust mite allergy (Verhoeckx et al., 2014).

Food allergy to insects, including locusts and grasshoppers was reviewed by Pener in 2014, who reported some cases of severe allergic reactions: seven cases of anaphylaxis after the ingestion of fried grasshoppers and crickets during a 2-yr period in a Thai hospital emergency department. Additionally, 27 cases of anaphylactic shock caused by consumption of grasshoppers and 27 cases caused by consumption of locusts were described in the Chinese literature between 1980 and 2007 (Pener, 2014).

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 eye shadow and lipstick (DiCello et al., 1999). A number of cases of allergic reactions to cochineal, including anaphylaxis, have been reported (Kagi et al., 1994; DiCello et al., 1999).

Infestation of lentils with lentil pests, mainly *Bruchus lentis,* is a very common event in Spain (Armentia et al., 2006). Sixteen patients with allergic symptoms to lentils all reacted to infested lentils and to *B. lentis* in a skin-prick test. In an oral food challenge with boiled infested lentils, six out of seven patients proved positive. The authors concluded that *B. lentis* proteins can be a cause of IgE-mediated anaphylaxis.

The majority of people eating edible insects will probably have a low to absent risk of manifesting allergic reactions, especially if they have no history of allergy. However, because sensitivity can be induced by repeated exposure to an allergen, insects should be eaten with caution when introduced in diet. Moreover, cross-reactivity between related and taxonomically scattered groups of insects is demonstrated. There is evidence for cross-reactivity between distantly related members of the phylum Arthropoda*,* suggesting the existence of common allergens. Further studies are needed to evaluate the risks of edible insect food allergy.

Microbial risks

Data regarding microbiology of insects and their potential for carrying pathogens are mainly available in studies considering insects as pests rather than food animals. In these cases, insects were investigated for their potential to act as vectors for foodborne pathogens in farming conditions. Such data are of limited value in the context of farms rearing insects fit for human consumption; however, they do provide some qualitative information.

Campylobacter, an important cause of foodborne illness worldwide, can be easily isolated from arthropods in contact with affected poultry flocks,

Cricket (*Acheta domestica*) salads served during a lunch at the Insects to Feed the World International Conference held in Wageningen in May 2014.

especially from flies that have been described as a vector for infecting *Campylobacter*-negative poultry flocks (Wales et al., 2010). Buffalo worm (*Alphitobius diaperinus*), both larvae and adults, was shown to act as vector maintaining *Campylobacter* during the fallow period between batches in a broiler farm (Templeton et al., 2006). The maximum survival time of *Campylobacter* in this insect varied from 72 h (Templeton et al., 2006) to 1 wk (Hazeleger et al., 2008). *Escherichia coli* O157:H7, responsible for severe foodborne illnesses, proliferated in houseflies for at least 3 d after ingestion (Kobayashi et al., 1999), suggesting a potential dissemination mechanism.

The study of survival time of foodborne pathogens in edible insects is of particular interest because it could give some insight into infection dynamics in insect farms. A farm committed to the rearing of insects should carefully avoid the presence of other animals, meaning relevant pathogen contamination could exist only if the farming conditions allow bacterial entrance and/or growth.

To our knowledge, two studies have investigated foodborne hazards in insect species suitable for human consumption. In the first study, four commercial species of insects were analyzed (*Zoophobas morio, Tenebrio molitor, Galleria mellonella*, and *Acheta domesticus*). They displayed a high total microbial load (10^5 to 10^6 cfu/g), mainly composed of Gram-positive bacteria, as well as fecal and total coliforms. The Gram-positive population was mostly *Micrococcus* spp., *Lactobacillus* spp. (10^5 cfu/g), and *Staphylococcus* spp. (approximately 10^3 cfu/g). *Salmonella* spp. and *Listeria monocytogenes* were not detected in the tested samples. These insects originated from a closed-cycle insect farm not produced for human consumption (Giaccone, 2005). The second study was carried out by Klunder and others (2012) to evaluate the microbiological content of edible insects (*Tenebrio molitor, Acheta domesticus* and *Brachytrupes* sp.), analyzing them as fresh, boiled, or roasted, as well as after storage at refrigeration and room temperatures. Enterobacteriaceae and boil-resistant (5 min) spore-forming bacteria were isolated from fresh insects. Storage of fresh insects at refrigeration temperature (4 to 6°C) did not prevent spoilage. In contrast, boiled insects stored for more than 2 wk at refrigeration temperature did not spoil. Roasting alone did not kill all *Enterobacteriaceae*; therefore, boiling for several minutes before roasting was advised. The authors also showed that lactic acid fermentation was able to inactivate Enterobacteriaceae and keep remaining spore-forming bacteria at acceptable levels (Klunder et al., 2012).

Recently, a study of volumetric and surface decontamination techniques for processing mealworm larvae (*Tenebrio molitor*) suggested that innovative techniques such as indirect plasma treatment could be effective for surface decontamination (Rumpold et al., 2014). Indirect plasma treatment consists in the input of ionized gases (which contain free charged particles like ions and electrons) in the reaction chamber containing the target specimen. However, high hydrostatic pressure (600 MPa) and thermal treatment (90°) would produce lower total bacterial counts than plasma treatments (Rumpold et al., 2014).

Scientific evidence addressing the microbiological safety of edible insects is weak, sporadic, and rarely originates from studies designed *ad hoc*. Thus, knowledge of edible insect microbiology in the food context should be addressed by specific, targeted research; particular attention should be paid to potential pathogens, to the impact of handling and correct storage, and to effective decontamination treatments able to guarantee consumer protection.

Parasitological risks

Parasites represent a potential hazard in relation to insect consumption. Their presence was well documented in a review about foodborne intestinal flukes in Southeast Asia where the isolation of six different species from insects was discussed. Evidence from human autopsies and insect analysis suggested the possible foodborne transmission of parasites belonging to Lecithodendriid and Plagiorchid because insects are commonly eaten in these countries (Chai et al., 2009).

Other reports, summarized by Wilson et al. (2001), described larva migrans syndrome due to *Gongylonema pulchrum* infection in the upper digestive tract of humans reporting insect ingestion (Wilson et al., 2001). *Dicrocoelium dendriticum* is another parasitic zoonotic agent potentially infecting humans through insect consumption. The infection is due to the ingestion of ants containing metacercariae whereas pseudo-infections (presence of *D. dendriticum* eggs in stool in the absence of adult worms) are due to the consumption of infected animal liver. The prevalence in children (2 to 15 yr old) was 8.0% in a pan-urban area of Kyrgyzstan, although the diagnostic test did not distinguish between infection and pseudo-infection (Jeandron et al., 2011).

The potential of insect consumption in the transmission of trypanosomiasis, overlooked for a long time, should not be neglected (Pereira et al., 2010); nor should the presence of protozoa including *Entamoeba* *histolytica*, *Giardia lamblia, Toxoplasma* spp., and *Sarcocystis* spp., anecdotally described in cockroaches and flies (Graczyk et al., 2005).

Evidence of potentially dangerous parasites in edible insects is sporadic in the scientific literature. However, a properly managed closed farm environment would lack all the hosts necessary for the completion of parasite life cycles. In every case, and particularly with harvested rather than farmed insects, proper management before consumption, relying on freezing and cooking, could minimize risks.

Chemical hazards

Chemical hazards are a concern for insect consumption. Toxic substances in insects can result from different origins; they can be the result of contamination from natural or artificial sources or they can be produced by insect metabolism.

Two studies described the consumption of insects contaminated by pesticides in Thailand (DeFoliart, 1999) and in Kuwait in 1988–1989 after the spraying of locusts with organophosphorus pesticides (Sumithion and malathion) (Saeed et al., 1993), with risks for human health.

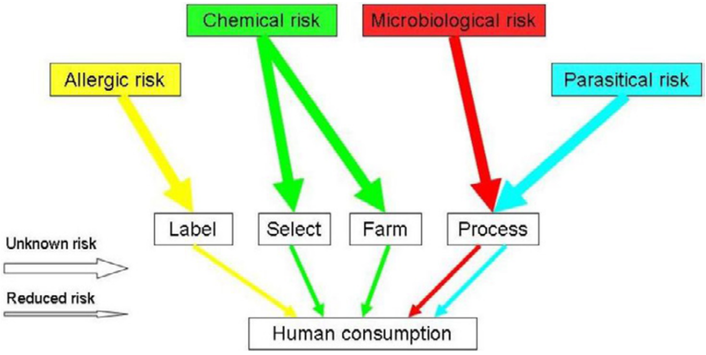
The concentrations of heavy metals accumulated in four species of grasshoppers were, in order, Pb > Cd > Hg with the mean concentration of Pb about 55 and 20 times the concentrations of Hg and Cd, respectively. However, grasshoppers tended to accumulate more Cd from grass than from other plants (Devkota and Schmidt, 2000). More recently, Handley and others (2007) found a high Pb content in chapulines (dried grasshopper) produced for human consumption and originating from Oaxaca (Mexico). This was associated with elevated blood Pb levels in Californian children and pregnant women consuming insects, even if their diets included other sources of Pb (Handley et al., 2007).

Other insect-related chemical hazards are metabolic steroids (including testosterone and dihydrotestosterone) found in beetles (*Dytiscidae*) and potentially causing growth retardation, hypofertility, masculinization in females, edema, jaundice, and liver cancer. Cyanogenic substances can be present in Coleoptera and Lepidoptera, causing inhibition of enzymes including succinate dehydrogenase and carbonic anhydrase, and inhibiting metabolic pathways like oxidative phosphorylation. Longhorn beetles (genera *Stenocentrus* and *Syllitus*) can contain toluene, a nervous system depressant toxic for the brain, kidneys, and liver, while *Lytta vescicatoria* (Coleoptera) contains cantharidin, causing bladder and urethral irritation, and occasionally priapism. This substance can be lethal if it enters the blood stream (Blum, 1994).

Benzoquinones have been detected in Tenebrionidae (*Ulomoides dermestoides*) (Crespo et al., 2011) and in flour beetles, *Tribolium confusum* and *Tribolium castaneum* (Lis et al., 2011). The carcinogenicity of 1,4-benzoquinone, however, is not known (IARC and WHO, 1999).

Silkworm pupae are among new food sources approved by the Chinese Ministry of Health. Zhou and Han (2006) evaluated the safety of PSP (silkworm protein). They performed acute toxicity and mutagenicity tests (Ames test, mouse bone marrow cell micronucleus test, and mouse sperm abnormality test). After a 30-d feeding study, they concluded that 1.50 g/kg body weight of PSP daily could be considered as safe (Zhou and Han, 2006). Freeze-dried powdered larval mealworm, *Tenebrio molitor,* was assessed as non-genotoxic, and oral administration of up to 3,000 mg/kg/d for 4 wk produced no adverse effects in rats (Han et al., 2014).

Chemical hazards in insects are highly dependent on insect species, habitat, natural environment or farming conditions, and feed. All these factors should be controlled in order to reduce potential risks; this can be more effectively achieved by farming selected and known insect species and controlling farming and dietary conditions.



Approaches to reduce risks potentially arising from insect consumption.

Directions for Future Research

Edible insects for human consumption must be considered in the context of safety requirements for foods and food products. Thus, evaluation of hazards commonly considered in the food chain is useful and necessary to collect existing evidence, evaluate data gaps, and pinpoint future research. Insect consumption has been extensively practiced worldwide over centuries, so this history of use can be easily proven. However, fundamental scientific data on potential foodborne hazards in edible insects are lacking; searching the literature reveals the weakness of evidence and the scarcity of data, as this overview highlights.

The sporadic evidence available indicates that edible insects reared under controlled conditions seem unlikely to pose additional hazards compared with traditional animal products; however, data are lacking, so no conclusion can be drawn. The adoption of insect species for food production should consider existing knowledge derived from traditional consumption in countries where insect consumption is customary and which has been described in scientific literature (Paoletti et al., 2000; Malaisse et al., 2015). Traditional knowledge is important since history of safe consumption can indicate species unlikely to pose safety concerns to potential human consumers. However, history of safe consumption should take into account not only species but also traditional methods of collection, transportation, and cooking in order to avoid unexpected hazards (Cerda et al., 2001).

Future research on edible insects should assess their safety in all relevant disciplines. Previous allergological studies made complicated efforts to interpret sporadic reactions following insect ingestion in the context of foodborne risks (Ji et al., 2008; Belluco et al., 2013). In contrast, recently published studies have targeted precise genera (Pener, 2014) and species (Verhoeckx et al., 2014) of edible insects. These studies give initial, valuable information on the allergic cross-reaction potentially following insect ingestion. This focused strategy, targeting precise insect genera/species, should be used by other disciplines to implement and/or improve the body of knowledge about edible insects, starting from the more popular ones and widening to others. Clearly, attempts to address the safety of the whole insect class, accounting for millions of species, is extremely unlikely to provide useful data. Researchers wishing to investigate food safety aspects of edible insects should focus on relevant species chosen on the basis of food chain interest. Later on, using a bottom-up approach, studies could move to higher taxonomical groups of edible insects sharing the same features.

Microbiological research on edible insects is also scarce, and largely addresses human bacterial pathogens in insects' products. This is a useful, ready-to-use strategy in the implementation of food safety criteria. However, it must be coupled with fundamental knowledge of microbiota of the insects themselves–and this data is severely lacking. The microbiology of insects is significantly different from that of conventional food animals and their products and deserves to be studied, taking advantage of next generation sequencing techniques and other valuable innovative tools. Studying the presence of parasites in harvested insects is very relevant where the risk of harboring specific parasitic life stages is high; however, a very different situation exists under controlled farm conditions, where the parasitic life cycle is expected to be unsustainable. Clearly, identified parasitic hazards are totally different in harvested and farmed insects purely due to this break in parasite life cycles. Scientific study of farmed edible insects is necessary from the food safety perspective, and knowledge of parasitic hazards cannot be transferred from harvest to farm conditions.

Finally, the wide plethora of chemical hazards in edible insects needs to be addressed via multi-factorial controls. In particular, insect species should be selected for their established chemical safety, and environmental and farming conditions should be managed to minimize contamination and/or accumulation of contaminants.

It is time to rehabilitate insects, remove them from indiscriminate classification as pests, and change Western attitudes toward them because only with this will edible insects come into the mainstream and attract the scientific attention they deserve (DeFoliart, 1999).

Acknowledgements

The authors wish to acknowledge Dr. Sheryl Avery (absees.editorial@gmail.com; http://absees-editorial.com), who edited the English language of this text.

Literature Cited

Armentia, A., M. Lombardero, C. Blanco, S. Fernandez, A. Fernandez, and R. Sanchez-Monge. 2006. Allergic hypersensitivity to the lentil pest bruchus lentis. Allergy 61:1112–1116.

Belluco, S., C. Losasso, M. Maggioletti, C.C. Alonzi, M.G. Paoletti, and A. Ricci. 2013. Edible insects in a food safety and nutritional perspective: A critical review. Compr. Rev. Food Sci. Food Saf. 12:296–313.

Blum, M. 1994. The limits of entomophagy: A discretionary gourmand in a world of toxic insects. The Food Insects Newsletter. 7(1)

Bukkens, S. 2005. Insects in the human diet: nutritional aspects. p. 545–577, In: M.G., Paoletti, editor, Ecological implications of minilivestock: role of rodents, frogs, snails and insects for sustainable development. Science publisher, Enfield NH.

Cerda, H., R. Martinez, N. Briceno, L. Pizzoferrato, P. Manzi, M. Tommaseo Ponzetta, O. Marin, and M.G. Paoletti. 2001. Palm worm (Insecta, Coleoptera, Curculionidae: *Rhynchophorus palmarum*) traditional food in Amazonas, Venezuela: Nutritional composition, small scale production and tourist palatability. Ecol. Food Nutr. 40:13–32.

Chai, J.Y., E.H. Shin, S.H. Lee, and H.J. Rim. 2009. Foodborne intestinal flukes in southeast asia. Korean J. Parasitol. 47(Suppl):S69–S102.

Crespo, R., M.L. Villaverde, J.R. Girotti, A. Guerci, M.P. Juarez, and M.G. de Bravo. 2011. Cytotoxic and genotoxic effects of defence secretion of ulomoides dermestoides on A549 cells. J. Ethnopharmacol. 136:204–209.

DeFoliart, G.R. 1999. Insects as food: Why the Western attitude is important. Annu. Rev. Entomol. 44:21–50.

Devkota, B., and G.H. Schmidt. 2000. Accumulation of heavy metals in food plants and grasshoppers from the taigetos mountains, greece. Agric. Ecosyst. Environ. 78:85–91.

DiCello, M.C., A. Myc, J.R. Baker, Jr., and J.L. Baldwin. 1999. Anaphylaxis after ingestion of carmine colored foods: Two case reports and a review of the literature. Allergy Asthma Proc. 20:377–382.

Giaccone, V. 2005. Hygiene and health features of minilivestock. p. 579–598. In: M.G., Paoletti, editor, Ecological implications of minilivestock: role of rodents, frogs, snails and insects for sustainable development. Science Publisher, Enfield NH.

Graczyk, T.K., R. Knight, and L. Tamang. 2005. Mechanical transmission of human protozoan parasites by insects. Clin. Microbiol. Rev. 18:128–132.

Han, S., E. Yun, J. Kim, J.S. Hwang, E.J. Jeong, and K. Moon. 2014. Evaluation of genotoxicity and 28-day oral dose toxicity on freeze-dried powder of tenebrio molitor larvae (yellow mealworm). Toxicol. Rev. 30:121–130.

Handley, M.A., C. Hall, E. Sanford, E. Diaz, E. Gonzalez-Mendez, K. Drace, R. Wilson, M. Villalobos, and M. Croughan. 2007. Globalization, binational communities, and imported food risks: Results of an outbreak investigation of lead poisoning in Monterey County, California. Am. J. Public Health 97:900–906.

Hazeleger, W.C., N.M. Bolder, R.R. Beumer, and W.F. Jacobs-Reitsma. 2008. Darkling beetles (*Alphitobius diaperinus*) and their larvae as potential vectors for the transfer of *Campylobacter jejuni* and *Salmonella enterica* Serovar Paratyphi B Variant Java between successive broiler flocks. Appl. Environ. Microbiol. 74:6887–6891.

IARC and WHO. 1999. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Defect Levels Handbook. 71(8/9). International Agency for Research on Cancer (IARC), Lyon, France, and World Health Organization, Geneva, Switzerland.

Jeandron, A., L. Rinaldi, G. Abdyldaieva, J. Usubalieva, P. Steinmann, G. Cringoli, and J. Utzinger. 2011. Human infections with *Dicrocoelium dendriticum* in Kyrgyzstan: The tip of the iceberg? J. Parasitol. 97:1170–1172.

Ji, K.M., Z.K. Zhan, J.J. Chen, and Z.G. Liu. 2008. Anaphylactic shock caused by silkworm pupa consumption in china. Allergy 63:1407–1408.

Kagi, M.K., B. Wuthrich, and S.G. Johansson. 1994. Campari-orange anaphylaxis due to carmine allergy. Lancet 344:60–61.

Klunder, H.C., J. Wolkers-Rooijackers, J.M. Korpela, and M.J.R. Nout. 2012. Microbiological aspects of processing and storage of edible insects. Food Contr. 26:628–631.

Kobayashi, M., T. Sasaki, N. Saito, K. Tamura, K. Suzuki, H. Watanabe, and N. Agui. 1999. Houseflies: Not simple mechanical vectors of enterohemorrhagic escherichia coli O157:H7. Am. J. Trop. Med. Hyg. 61:625–629.

Kodondi, K.K., M. Leclercq, and F. Gaudin-Harding. 1987. Vitamin estimations of three edible species of Attacidae caterpillars from aire. Int. J. Vitam. Nutr. Res. 57:333–334.

Kung, S.J., B. Fenemore, and P.C. Potter. 2011. Anaphylaxis to mopane worms (*Imbrasia belina*). Ann. Allergy Asthma Immunol. 106:538–540.

Lis, L.B., T. Bakula, M. Baranowski, and A. Czarnewicz. 2011. The carcinogenic effects of benzoquinones produced by the flour beetle. Pol. J. Vet. Sci. 14:159–164.

Liu, Z., L. Xia, Y. Wu, Q. Xia, J. Chen, and K.H. Roux. 2009. Identification and characterization of an arginine kinase as a major allergen from silkworm (*Bombyx mori*) larvae. Int. Arch. Allergy Immunol. 150:8–14.

Malaisse, F., and G. Parent. 1980. Les chenilles comestibles du shaba meridional (Zaire). Naturalistes Belges. 61:2–24.

Malaisse, F., P. Roulon-Doko, G. Lognay, and M.G. Paoletti. 2015. Chenilles et papillons dans l'alimentation humaine. In: E. Motte-Florac and P. Le Gall, editors, Les insectes et la santè. A book in the collection Table des Hommes. In press.

Okezie, O.A., K.K. Kgomotso, and M.M. Letswiti. 2010. Mopane worm allergy in a 36-year-old woman: A case report. J. Med. Case Reports 4:42.

Oliveira, J.F.S., J.P. de Carvalho, R.F.X.B. de Sousa, and M.M. Simao. 1976. The nutritional value of four species of insects consumed in angola. Ecol. Food Nutr. 5:91–97.

Paoletti, M.G., D.L. Dufour, H. Cerda, F. Torres, L. Pizzoferrato, and D. Pimentel. 2000. The importance of leaf- and litter-feeding invertebrates as sources of animal protein for the amazonian amerindians. Proc. Biol. Sci. 267:2247–2252.

Pener, M.P. 2014. Allergy to locusts and acridid grasshoppers: A review. J. Orthoptera Res. 23:59–67.

Pereira, K.S., F.L. Schmidt, R.L. Barbosa, A.M. Guaraldo, R.M. Franco, V.L. Dias, and L.A. Passos. 2010. Transmission of chagas disease (American trypanosomiasis) by food. Adv. Food Nutr. Res. 59:63–85.

Pereira, N.R., O. Ferrarese-Filho, M. Matsushita, and N.E. de Souza. 2003. Proximate composition and fatty acid profile of *Bombyx mori* L. chrysalis toast. J. Food Compos. Anal. 16:451–457.

About the Authors

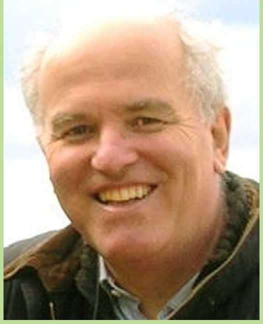
Simone Belluco graduated in Veterinary medicine at University of Padua in 2009 and obtained his specialisation in Inspection of Food of Animal Origins in 2012. He is a PhD student with a research project focusing on the food safety aspects of Toxoplasmosis; his research position is based at Istituto Zooprofilattico Sperimentale delle Venezie, a public health institute involved in food safety and animal health. His past and present research activities have focused on novel foods, such as nanoparticles and edible insects, and systematic review methodology.

Carmen Losasso graduated in Biology and defended her Ph.D. in Biochemistry at the University of Rome "La Sapienza" in Italy. Then she specialised in Food Science at the University of Padua, Italy. Currently she works at the Istituto Zooprofilattico Sperimentale delle Venezie, Italy, as Researcher. Her research interests encompass fields including: epidemiology of human nutrition, food safety, gut microbial ecology, antimicrobial resistance and new strategies for consumer education on food safety and nutrition. She is the co-author of about 40 scientific papers in these fields.

Michela Maggioletti studied medicine at Catholic University of the Sacred Heart of Rome. She developed a particular interest in the diagnosis and treatment of allergies. After obtaining her degree, she started her training in Allergy and Clinical Immunology in the Allergy Unit of the Columbus Integrated Centre, Catholic University of the Sacred Heart of Rome. She has developed her diagnostic and therapeutic skills as regards respiratory allergy, food allergy, anaphylaxis, drug allergy, severe drugs reactions, hymenoptera venom allergy and contact dermatitis. Currently, she is involved with research on the food allergic reactions, their treatment and future therapeutic strategies.

Cristiana Alonzi is an allergist in the Allergy Unit of the Columbus Integrated Centre, Catholic University of the Sacred Heart, Rome. She started her training in Allergy and Clinical Immunology at Catholic University of the Sacred Heart in Rome in 2002. She also had the opportunity to work at the Jaffe Food Allergy Institute, Division of Pediatric Allergy, Mount Sinai Hospital, New York, led by Professor Sampson. In 2006 she obtained the specialization degree on the topic of food allergy oral desensitization. In 2010 she obtained her PhD at the Catholic University of the Sacred Heart – Rome. Her research interests have focused on food allergic disorders.

Antonia Ricci graduated in Veterinary Medicine at the University of Bologna in Italy, and specialised in Food Hygiene at the University of Turin. She is the Director of the Food Safety Department at Istituto Zooprofilattico Sperimentale delle Venezie, and she heads the National Reference Laboratory for Salmonella, which in 2007 has been appointed as OIE (World Organization for Animal Health) Reference Laboratory. She is member of the Biohaz Panel of EFSA, and is author or co-author of more than 200 papers, book chapters and conference contributions mainly on detection, epidemiology and control of Salmonella and other foodborne zoonoses.



Maurizio Guido Paoletti is ecology professor at the Department of Biology, University of Padua. Education: Degree in Natural Science (Padova, 1973); International Master in Human Ecology (Padova, 1979); Specialization in Biological Control (University of California, Berkeley,1983). Research Activities: Zoology, Ecology, Agroecology, Biodiversity assessment. He has spent one sabbatical at Cornell University, as visiting professor (1992); at Ohio State University (1987), at Colorado State University at Boulder (1999) and at La Trobve and Melbourne University, Australia (2005-2006). Has been visiting professor at the Fry University of Bruxelles and at the Universities of Helsinki, Sofia, Budapest and Beijing. He is author of 280 scientific papers and 22 edited books cited 3900 times. He has been a leader of European Commission research projects (TEMPUS, STD, AIR, ALFA). Fieldwork has been done especially in Amazon, China, Australia, Vietnam and Europe.

Ramos-Elorduy, J., J.M. Pino, E.E. Prado, M.A. Perez, J.L. Otero, and O.L. de Guevara. 1997. Nutritional value of edible insects from the state of oaxaca, mexico. J. Food Compos. Anal. 10:142–157.

Rumpold, B.A., A. Fröhling, K. Reineke, D. Knorr, S. Boguslawski, J. Ehlbeck, and O. Schlüter. 2014. Comparison of volumetric and surface decontamination techniques for innovative processing of mealworm larvae (*Tenebrio molitor*). Innov. Food Sci. Emerg. Technol. 26:232–241.

Saeed, T., F.A. Dagga, and M. Saraf. 1993. Analysis of residual pesticides present in edible locusts captured in kuwait. Arab Gulf J. Sci. Res. 11:1–5.

Templeton, J.M., A.J. De Jong, P.J. Blackall, and J.K. Miflin. 2006. Survival of campylobacter spp. in darkling beetles (*Alphitobius diaperinus*) and their larvae in australia. Appl. Environ. Microbiol. 72:7909–7911.

Verhoeckx, K.C.M., S. van Broekhoven, C.F. den Hartog-Jager, M. Gaspari, G.A.H. de Jong, H.J. Wichers, E. van Hoffen, G.F. Houben, and A.C. Knulst. 2014. House dust mite (der p 10) and crustacean allergic patients may react to food containing yellow mealworm proteins. Food Chem. Toxicol. 65:364–373.

Wales, A.D., J.J. Carrique-Mas, M. Rankin, B. Bell, B.B. Thind, and R.H. Davies. 2010. Review of the carriage of zoonotic bacteria by arthropods, with special reference to salmonella in mites, flies and litter beetles. Zoonoses Public Health 57:299–314.

Wilson, M.E., C.A. Lorente, J.E. Allen, and M.L. Eberhard. 2001. Gongylonema infection of the mouth in a resident of Cambridge, MA. Clin. Infect. Dis. 32:1378–1380.

Zhou, J., and D. Han. 2006. Safety evaluation of protein of silkworm (*Antheraea pernyi*) pupae. Food Chem. Toxicol. 44:1123–1130.