



Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Review

Transforming insect biomass into consumer wellness foods: A review

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ARTICLE INFO

Article history:

Received 2 August 2016

Received in revised form 28 September 2016

Accepted 2 October 2016

Available online xxxx

Keywords:

Alternative protein sources

Consumer perception

Edible insects

Human wellbeing

Nutrients and bioactives

Processing

ABSTRACT

Potential food shortages, human health challenges and environmental concerns, all thematically linked to growing and aging global populations, drive the search for alternative and sustainable food sources. Insects, which have been part of the human diet since antiquity though not currently widely consumed in Western societies, are rich in high quality proteins and nutrients and bioactives. Accordingly, insects could make a significant contribution to the global food supply chain in the future. This review explores the potential of entomophagy in an integrated global food network and focuses on practical approaches for transforming insect biomass into consumer food products. Carefully regulated breeding, rearing, harvesting and processing of insect bioresources are critical for realising the concept of “edible insects for human well-being”.

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1. Introduction

The discovery of new and sustainable approaches for growing foods and efficiently utilizing biomass resources is a global priority, with the

human population on Earth predicted to reach 9 billion in 2050. To achieve this, more sustainable farming practices need to be developed for food production, together with conservation of ocean, water and energy resources. Growing consumer awareness of diet-disease relationships and longer life spans suggest that we need to address potential food shortage challenges as well as human preferences for foods that are both nutritious and palatable. Moreover, there is a currently significant change occurring in consumer purchasing behavior worldwide.

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Foods that are perceived as healthy or marketed health-promoting are attracting increasing demand (Ali, Alam, & Ali, 2015).

Insects in nature form a significant biomass resource distributed across aquatic, forest and agricultural ecosystems (New, 2009). Insects are important for all terrestrial ecosystems and livelihoods, due to their fast reproduction rates and many benefits in human/animal food and nutrition, medicines, therapies and organic matter recycling (often the roles of insects in our everyday lives are overlooked or underestimated). Insects produce dyes, silk and wax as well as food products with broad spectrum nutritional and functional benefits such as bee honey, propolis and royal jelly. Insects are able to convert plant proteins to insect proteins very efficiently (with a much higher yield than other animals, especially mammals) (Deroy, Reade, & Spence, 2015). For example, the conversion of plant biomass to animal biomass by caterpillars was 10 times greater than that of cattle, requiring much less land and with a smaller environmental footprint (Schabel, 2010). Livestock accounts for approximately 8–18% of anthropogenic greenhouse gas emissions (Herrero et al., 2015). To achieve the same protein yield, crickets require one twelfth and a quarter the feed of cattle and sheep, respectively, and around one half the feed of pigs or chickens (Deroy et al., 2015). Further, insects can be raised efficiently using various bio-waste streams. On average, every two kilograms of biomass can yield one kilogram of cricket biomass (Collavo et al., 2005). This allows the transformation of under- or non-utilised biowaste and organic side streams into high value human foods or animal feeds (Veldkamp et al., 2012). Thus, mass production of insects is economically viable and may satisfy rising demand for nutritious, protein rich alternatives to conventional staple meat sources such as beef, chicken, pork and fish (Finke, 2002; Kinyuru, Kenji, & Njoroge, 2009). Directly or indirectly (as livestock feed), insect proteins could complement animal proteins to address the food challenge of feeding 9 billion people in 2050.

Edible insects have been a part of the human diet, especially in tropical countries, for thousands of years (Bodenheimer, 1951). Insects commonly consumed include ants, bees, beetles, cicadas, corn borer, cotton bollworm, crickets, flies, grasshoppers, grubs, holcocerus, sorghum borer strip and tabaniformis, although the consumption of these is now uncommon in Western societies. Insect proteins possess nutritional advantages in total protein level and/or essential amino acid profiles over plant proteins such as cereal, legumes, beans, lentils or soybean (Rumpold & Schlüter, 2014; Bukkens, 2005). Insects may also possess advantages over animal meats because of their high levels of quality proteins (~50–85%) and significant amounts of other nutrients such as lipids, vitamins and minerals including n-3 and n-6 fatty acids in favourable ratios (e.g. 1:17) (Makkar, Tran, Heuzé, & Ankers, 2014; Rumpold & Schlüter, 2014; Tzompa-Sosa, Yi, van Valenberg, van Boekel, & Lakemond, 2014; Bukkens, 2005). Accordingly, edible insects are anticipated to emerge as potential value-added functional ingredients/materials in the fast growing wellness food sector. Besides safety, pleasure and sensation are factors that influence significantly consumer acceptance and preference. Consumer preference fuels technological innovation in the food sector and drives global development of associated legislative frameworks.

This review aims to showcase the potential of edible insects in the food value chain as sustainable resources for consumer daily foods and value-added wellness foods. This review focuses on addressing current knowledge gaps in relation to the biological, ecological and nutritional characteristics of edible insects, the barriers related to consumer acceptance and food choice, as well as the role of innovative technologies in rearing and processing insects into human wellness foods. The need to stimulate and create consumer demand for edible insects as natural foods or food ingredients is emphasized. The design of insect-based foods and associated processing should maximize the retention of the nutrients and bioactives in the edible insects while eliminating the human perceived “disgusting” factors and potential allergens, through employing efficient insect rearing and processing technologies supported by appropriate labeling and marketing of insect-based foods.

2. Advantages and disadvantages of edible insects as food sources

2.1. Biology and ecology characteristics

There are about 1500–2000 insect species and other invertebrates that are consumed by humans across 3000 ethnic groups and 113 countries in Asia, Australia, and Central and South America (but not consumed in significant quantities in Europe and North America) (Jongema, 2015). Entomophagy is heavily influenced by cultural, social and religious factors (more details available in Section 3). Insects are consumed at different life stages including eggs, larvae, pupae or adults. The insect species consumed the most worldwide are beetles (Coleoptera, 31%), butterflies and moths (Lepidoptera, 18%), bees, wasps and ants (Hymenoptera, 14%), grasshoppers, locusts and crickets (Orthoptera, 13%), cicadas, aphids, honeyants, leafhoppers, plant hoppers, scale insects and true bugs (Hemiptera, 10%), termites (Isoptera, 3%), dragonflies (Odonata, 3%) and flies (Diptera, 2%) (Jongema, 2015). Lepidoptera, Coleoptera and Diptera are commonly consumed in the larval stage, while Orthoptera, Hymenoptera, Hemiptera and Isoptera are mainly consumed in the adult stage (Hanboonsong, Jamjanya, & Durst, 2013). Table 1 provides some examples of edible insects.

Coleoptera (beetles): There are many kinds of edible beetles, including 78 edible aquatic beetles from the Dytiscidae, Gyrinidae and Hydrophilidae families (Ramou, Pino, & Martinez, 2009). Beetles can easily be raised using a wide range of plant materials including cereals (e.g. wheat, oats and maize), fruits and vegetables (e.g. carrots, potatoes and lettuce), and animal and microbial products (e.g. meat waste, feathers and yeast) (Ramos-Elorduy, Gonzalez, Hernandez, & Pino, 2002; Veldkamp et al., 2012). Mealworms, the larvae of beetles, are an excellent protein source. The development of mealworm larva typically requires three months. Mature larvae weigh 130–160 mg and have a light yellow-brown colour and a body length of 20–32 mm.

Lepidoptera (caterpillars): Approximately 27 caterpillar species are consumed in Chiapas, Mexico (Makkar et al., 2014). The mopane caterpillar (*Imbrasia belina*) is one of the most economically important and commonly harvested caterpillars in Southern Africa (FAO, 2003; Ghazoul, 2006), and the bamboo caterpillar (*Omphisa fuscidentalis*: *Pyrallidae*) is widely consumed in Asia (Yhoung-Aree & Viwatpanich, 2005). Under suitable conditions such as 29–31 °C, 50–70% humidity, and appropriate diets (e.g. organic waste) and adequate oxygen, these caterpillars grow rapidly (e.g. at a rate of 25–500 mg fresh weight per day) (Hardouin & Mahoux, 2003; van Huis et al., 2013).

Hymenoptera (wasps, bees and ants): Hymenoptera species differ vastly in size, from 0.2 mm (the family *Trichogrammatidae*) to larger than 5 cm (the Asian giant hornet). Bees have a size from 2 mm to 39 mm (females of the largest species *Megachile pluto*), while ants range in size from 0.75 to 60 mm (the queen of largest species, the prehistoric *Titanomyrma giganteum*) (Shattuck, 1999; Schaal, 2006). These insects can survive under a broad spectrum of environmental conditions. Important rearing conditions include diet, temperature and relative humidity, and vary with species and growing stages. Diets include freshly killed or live insects, fallen fruit, seeds or nectar (Stabentheiner, Kovac, & Brodschneider, 2010). Hymenoptera are consumed in many countries. The State Food and Drug Administration (FDA) and State Health Ministry of China have approved >30 ant-containing health products since 1996. In some regions of Japan, the larvae of yellow jacket wasps (*Vespula* and *Dolichovespula* spp.; hebo) are consumed as a popular delicacy.

Orthoptera (locusts, grasshoppers and crickets): There are over 27,000 Orthoptera species worldwide. They exhibit large variations between species in size, food preference, habitat types, reproduction rates and behaviours. Their body lengths may be as small as 2 mm (ant-inquiline crickets, *Myrmecophilidae*) or as big as 567 mm (the longest phasmid *Phobaeticus chani*). Most Orthoptera eat plants including grasses, except for the Sand Grouper (Family *Cylindrachetidae*) as an occasional pest of wheat crops (Vickery & Kevan, 1985; Hoell, Doyen, &

Table 1

Some insects and their characteristics.

Insect	Available month*	Protein content (%)	Lipid content (%)	Specific lipids in total fat	Other distinct nutrients	Reference
Weaver ant	Mar–May	26–48.5 dry wt	10–25% fresh wt	Cholesterol 4.4–11.7% of total fat	P, Mg, Na, Zn, Ca, Fe; Vit B1, B2, B3; Fibre.	Borgohain et al. (2014), Mu et al. (2011), Rumpold and Schlüter (2014), Van Huis et al. (2013), Sribandit, Wiwatwitaya, Suksard, and Offenberger (2008)
Melon bug	Mid-June–early Nov	27.0 dry wt	45% dry wt	Cholesterol 1.4 & sterol 17 mg/100 g oil; 46.5% oleic acid, 3.4% linoleic acid, 44.2% palmitic acid and trace linolenic acid	Tocopherol 0.3 mg/100 g oil	Mustafa et al. (2008), Van Huis et al. (2013), Mariod (2013)
Stink bug	Feb, Apr.–June	33–36 dry wt	50–63 dry wt	Oleic acid, (Z)-9-hexadecenoic acid, linoleic acid, (Z)-9-octadecanoic acid, octadecanoic acid, (Z,Z)-9,12-octadecadienoic acid, myristoleate	P, K, Ca, Na, Mg, Fe, apeginin, quercitin, luteolin, rutin; neutral and acid detergent fibres	Teffo (2006), Van Huis et al. (2013), Musundire et al. (2016)
Palm weevil beetle	March–Dec., esp. Apr.–July	7–36 fresh wt; Some 40 dry wt	54 dry wt delicious due to elevated fat	Palmitoleic acid 38%, linoleic acid 45%	Vit E	FAO (2012), Fasaranti and Ajiboye (1993), Cerda et al. (2001), Womeni et al. (2009), Bukkens (2005), Van Huis et al. (2013)
Mealworm larvae of beetles	Jan–Dec	14–25 fresh wt; 47–64 dry wt; High glutamic acid; methionine limited	31–43 dry wt	Oleic acid 38%, linoleic acid 27%, palmitic acid 21%.	Zn, Fe, Cu, Mn, K, P, Vit B12; retinol & β -carotene (Vit A); Neutral detergent fibre 12%, acid detergent fibre 6.5%	Bukkens (2005), Barker, Fitzpatrick, and Dierenfeld (1998), Finke (2002), Jones, Cooper, and Harding (1972), Klasing, Thacker, Lopez, and Calvert (2000), Martin, Rivers, and Cowgill (1976), Li et al. (2008), Van Huis et al. (2013)
Mopane caterpillar	Nov–Jan., Mar.–May	48–80 dry wt.	16–20 (maybe fresh wt)	40% (maybe fresh wt)	Fe, Ca, Zn, K, P, Mg	Glew et al. (1999), Headings and Rahnama (2002), Bukkens (2005), Van Huis et al. (2013)
Ground cricket	May–Dec	48–67 dry wt; low in Lys, Met, Cys; high glutamic acid	<5–> 20 depending on species type	Palmitoleic acid 20–25%, linoleic acid 36–40%, stearic acid 9–32%, with some having palmitic acid 50%	Vitamin B12; fibre 8.7–18%; risk of lead contamination; Fe, Zn, Cu	FAO (2012), Bukkens (2005), Barker et al. (1998), Finke (2002), Van Huis et al. (2013), Chakravorty et al. (2014)
Grasshopper	Jan, Apr.–Oct	13–28 fresh wt or 57–69 dry wt; low Lys & Met; High glutamic acid & glutamine	3–67 dry wt	Palmitoleic acid 28%, linoleic acid 16–46%, linolenic acid 16–25%, oleic acid 21%, palmitic acid 17.2%, stearic acid 12.4%	Crude fibre 8.5–12.5%, neutral detergent fibre 22%, acid detergent fibre 10%; Zn, Fe, Mn, Cu, Ca, P.	FAO (2012), Womeni et al. (2009), Adeyemo, Longe, and Lawal (2008), Alegbeleye et al. (2012), Anand, Ganguly, and Haldar (2008), Ojewola, Okoye, and Ukoha (2005), Van Huis et al. (2013), Chakravorty et al. (2014), Ghosh et al. (2016)
Black soldier fly	Jan–Dec., esp. warm July	40–44 dry wt; lysine rich	15–49 dry wt. depending on diet	Lauric acid 21–43%, palmitic acid 11–16%, oleic acid 12–32%, omega-3 fatty acids 0.2–3%	Mn, Zn, Ca, P; Crude fibre 7% dry wt	Arango Gutierrez et al. (2004), Newton et al. (1977), Newton et al. (2005), St-Hilaire et al. (2007)a,b, Van Huis et al. (2013)
Termites	Jan–Dec. esp. Mar.–June	32–38 dried, some 64 (fresh wt, rich in Trp; 13–28 fresh wt	49 dry wt	Palmitic acid 30%, oleic acid 48%, stearic acid 9%, linoleic acid 34–43% fresh wt	Fe, Ca	Nkouka (1987), Santos Oliveira, Passos de Carvalho, Bruno de Sousa, and Madalena Simao (1976), FAO (2012), Womeni et al. (2009), Van Huis et al. (2013), Chakravorty et al. (2013)
Silkworms	Jan–Dec	10–17 fresh wt; or 52–76% dry wt. High in Lys, Met and Cys	37	High polyunsaturated fatty acids, esp. linolenic acid (18:3) 11–45%	Vit E; Acid detergent fibre 6–12% dry wt, low Ca	FAO (2012), Tong et al. (2011), Finke (2002), Rao (1994), Ioselevich, Steingäß, Rajamurodov, and Drochner (2004), Usub et al. (2008), Coll et al. (1992), Göhl (1982), Fagoonsee (1983a, b), Gowda Ramana et al. (2004), Hossain, Islam, and Alim (1993), Hossain, Nahar, and Kamal (1997), Jintataporn (2012), Longvah, Mangthya, and Ramulu (2011), Narang and Lal (1985), Van Huis et al. (2013)

Note: *Availability varies considerably with country, region, climate, type and life stage of species.

Purcell, 1998). Many cricket species are commercially available (Weissman, Gray, Pham, & Tijssen, 2012), and they can survive over a wide temperature range with 32–35 °C generally preferred (Kvassay, 2014). Locusts can be easily reared with any green produce, grass and wheat bran in terrariums (preferably in large wire enclosures with sufficient air flow, low humidity (<30%) and warm temperatures between 31 and 35 °C). Orthoptera species are part of human diets in South America (e.g. different regions of Mexico), Asia (e.g. Thailand, North and South Korea) and Africa (e.g. Niger), although attention should be paid to potential contaminants such as lead (Yhoung-Aree & Viwatpanich, 2005; Handley et al., 2007; Cohen, Sánchez, & Montiel-ishinoet, 2009; Alegbeleye, Obasa, Olude, Otubu, & Jimoh, 2012; Meyer-Rochow, 2013).

There are many more edible insects reared for dietary purposes such as red palm weevils (*Rhynchophorus ferrugineus*, which are consumed all over the tropical world), Homoptera (cicadas, leafhoppers, planthoppers and scale insects, which are for direct intake or processed into food products e.g. the E120 carmine dye and crystallized secretion lerpape) (Yen, 2005). Hemiptera are popular foods and provide oil for cooking in sub-Saharan Africa and Mexico (van Huis & Motte-Florac, 2003; Ramos-Elorduy, 2006). Isoptera (termites) are consumed all over the world as a delicacy as a main or side dish, and their oils are used for food processing in many countries (Costermans, 1955; Kinyuru et al., 2009). A typical example of flies (Diptera) is the black soldier fly (*H. illucens* Linnaeus 1758), which is not consumed directly by humans but is instead used as an animal feed (Hardouin & Mahoux, 2003; Diclaro & Kaufman, 2009).

2.2. Nutrients and bioactives

Increasing pressures on food supply chains worldwide necessitate large scale production of proteins and oils. Insects are efficient producers of protein, unsaturated fat and other important bioactive substances such as carbohydrates, minerals, antioxidants and vitamins (Table 1). For example, by weight yellow mealworm larvae (*Tenebrio molitor*, L.) have significantly higher contents of linoleic acid, isoleucine, leucine, valine, tyrosine, alanine and vitamins (except for vitamin B12)

compared with beef (Finke, 2002; Finke & Oonincx, 2014). Further, the nutritional and bioactive profiles of edible insects are highly variable and affected by factors such as insect species, castes of the same species, metamorphosis phase/stage, season, habitat (including host plant and geographic location), insect diet, as well as preparation, processing and handling methods applied prior to consumption. All these enable the tailored use and manipulation of insect foods for human well-being.

Insects generally have higher protein contents (up to about 50–80% dry weight) than most plants or many animal products such as eggs and meat. Typical protein contents are 26% for Ephemeroptera larva, 40–65% for Odonata larva, 40–57% for Homoptera larva and eggs, 42–73% for Hemiptera, 23–66% for Coleoptera larva and 20–70% for Lepidoptera (Table 1) (Comby, 1990; Ramos-Elorduy & Pino, 1990; DeFoliart, 1992; Yang, 1998; Chen, Feng, & Chen, 2009; Makkar et al., 2014). In particular, Orthoptera species such as *Melanoplusfemurrubrum*, *Sphenariumhistrio* and *Melanoplusmexicanus* contain up to 60–80% protein (Ramos-Elorduy, Pino-M, & Correa, 1998; Julieta et al., 2007). The proteins in edible insects are considered superior because of their high digestability (up to 75–98%), relative to other protein sources (e.g. cereal proteins are low in lysine and sometimes lack tryptophan and threonine) and compliance with human needs (e.g. containing 46–96% essential amino acids including tryptophan and lysine) (Table 1, Fig. 1) (Finke, Defoliart, & Benevenga, 1989; Ramos-Elorduy et al., 1997; Bukkens, 2005; Verkerk, Tramper, van Trijp, & Martens, 2007; Finke, 2008; Cerritos, 2009; Agbidye, Ofuya, & Akindele, 2009; Schabel, 2010; Mitsuhashi, 2010; Wei & Liu, 2001; Chakravorty, Ghosh, Jung, & Meyer-Rochow, 2014). Nine essential amino acids were found in the edible stink bug *Encosternum delegorguei* including lysine, tryptophan and methionine (which are often missing in cereal/legume-based diets) (Musundire, Osuga, Cheseto, Irungu, & Torto, 2016). Therefore, edible insects can serve as a meat substitute in regions lacking reliable protein sources (e.g. in some Asia and Africa countries) and as food supplements for certain populations who require specific proteins and amino acids (e.g. histidine and arginine for children) (Ladron de Guevara, Padilla, Garcia, Pino, & Ramos-Elorduy, 1995; Tan et al., 2015; Ghosh, Haldar, & Mandal, 2016).

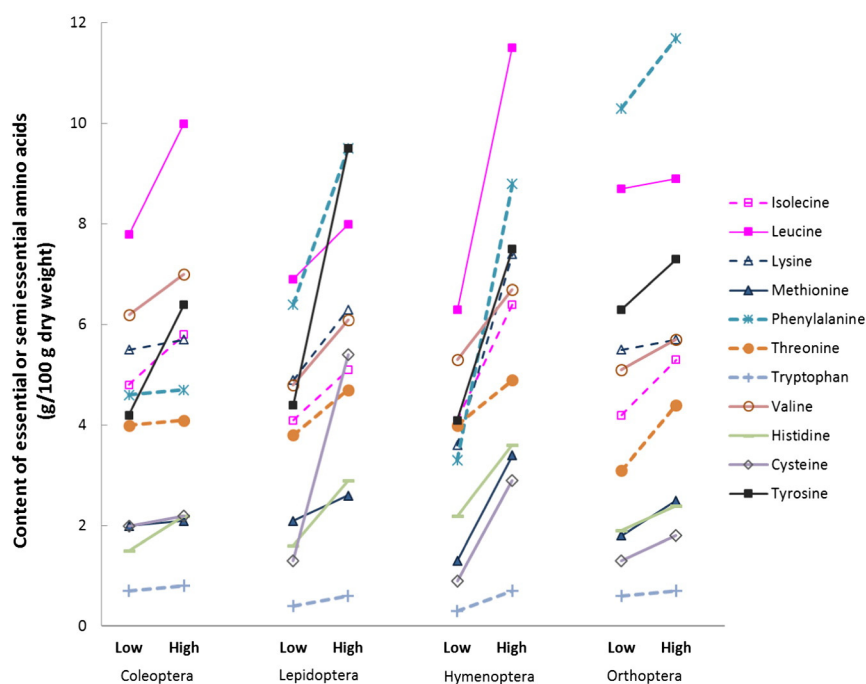


Fig. 1. Comparison of the content of essential amino acids (g/100 g dry weight) among four groups of edible insects: Coleoptera (beetles), Lepidoptera (butterflies and moths), Hymenoptera (bees, wasps and ants), and Orthoptera (grasshoppers, locusts). Cysteine (derived from methionine) and tyrosine (derived from phenylalanine) are “semi essential amino acids” (after Ladron de Guevara et al., 1995; Ramos-Elorduy et al., 1997).

Fat accounts for the second largest portion (~10–50%) of the nutrients contained in edible insects, with an average ratio of saturated to unsaturated fatty acids ranging from 0.43–0.79 (Table 1) (Chen & Feng, 1999; Durst, Leslie, & Shono, 2008). The larvae of *P. triangularis* (Lepidoptera) have a very high fat content (up to 77%) (Ramos-Elorduy et al., 1998). The edible stink bug *Encosternum delegorguei* contains unsaturated fatty acid derivatives including oleic acid, hexadecenoic acid, linoleic acid, 9-octadecenoic acid, octadecanoic acid, 9,12-octadecadienoic acid and myristoleic acid (Musundire et al., 2016). Some species such as the desert locust *Schistocerca gregaria* (Orthoptera: Acrididae) contain important phytosterols including β -sitosterol, campesterol and stigmasterol (Cheseto et al., 2015; Ramos-Buen, González Fernández, Sánchez Muros Lozano, García Barroso, & Guil Guerrero, 2016). The total amount and individual concentrations of fats in insects are affected by factors such as developmental stages, caste and season. Using *Oecophylla smaragdina* (the weaver ant) as an example (Borghain, Borkotoki, & Mahanta, 2014), the total lipid content is 10–25% for queen larva, 10–23% for queen pupa and 10–20% for queen adults. The cholesterol level is relatively high in the pupal stage (15.22 mg/g for worker pupa and 10.95 mg/g for queen pupa). The triglyceride level of worker pupa is generally low (47.75 mg/g) in January. Moreover, diet can alter the lipid profile of insects. Feeding insects with a diet rich in specific omega-3 fatty acids can increase the concentrations of these fatty acids in the insect products. For example, the fat content of black soldier fly larvae is diet-dependent i.e. feeding with cow manure alone or a combination of 50% fish offal and 50% cow manure led to 21 and 43% lauric acid, 16 and 11% palmitic acid, 32 and 12% oleic acid, and 0.2 and 3% omega-3 fatty acids, respectively (Arango Gutierrez, Vergara Ruiz, & Mejia Velez, 2004; St-Hilaire et al., 2007).

Carbohydrates occur at a relatively low level (typically 1–18%) in edible insects, with black ants from China *Polyrhachis vicina* and the moth larvae of *Latebraria amphipyrioides* having very high carbohydrate contents (~29%) (Ramos-Elorduy et al., 1997; Bhulaidok, Sihamala, Shen, & Li, 2010). The amount and type of carbohydrates vary with species and stage of insect development. Insects contain significant amounts of fibre (mostly in the form of chitin) i.e. 2.7–49.8 mg/kg fresh weight or 1.6–137.2 mg/kg dry weight (Muzzarelli, Terbojevich, Muzzarelli, Miliani, & Francescangeli, 2001; Finke, 2007). Some bioactive carbohydrates in insects such as polysaccharides like chitin were recently found to exhibit immunity-enhancing, wound-healing and defense effects on parasitic infections or allergy (He, Tong, Huang, & Zhou, 1999; Sun et al., 2007).

Edible insects have significant amounts of desired micronutrients and antioxidants such as vitamins A, B1, B2, B5, B6, B7, B9, C, D, E and K, carotenoids and flavonoids, although these substances vary considerably with insect species and feed (Table 1). One hundred grams of ground and freeze-dried silkworm moth (*Bombyx mori* L.) larvae fed on mulberry leaves and stem lettuce leaves contained almost 10 mg vitamin E (Tong, Yu, & Lui, 2011). Edible stink bug *Encosternum delegorguei* has significant amounts of flavonoid antioxidants such as aepiginin, quercetin, luteolin and rutin (Musundire et al., 2016). A wide range of nutritive elements such as potassium, sodium, calcium, copper, iron, zinc, manganese and phosphorus naturally occur at significant levels in edible insects (Chen & Feng, 1999; Gowda Ramana, Prasad, & Khub Singh, 2004; FAO, 2012). The mopane caterpillar and locusts (*Locustamigratoria*) have 31–77 and 8–20 mg iron per 100 g dry weight, respectively, and the palm weevil larvae (*Rhynchophorus phoenicis*) have 26.5 mg zinc per 100 g dry weight, in comparison with beef (~6 mg Fe and 12.5 mg Zn in 100 g of dried beef) (Bukkens, 2005; Oonincx et al., 2010).

Recently, the bioactive components in insect-based products and their potential as therapeutic agents to provide desired health functionalities have been in the spotlight. Traditionally, insect secretions, certain parts/tissues and ground-up bodies have been used in various medicinal applications including the prevention or treatment of Acquired Immune Deficiency Syndrome (AIDS), cancer, inflammation

and infectious diseases (Pemberton, 1999; Feng, Zhao, He, Chen, & Sun, 2009; Dossey, 2010; Gomes et al., 2011; Chakravorty, Ghosh, & Meyer-Rochow, 2013). *Aspongopus chinensis* from Southern China exhibits desired efficacies in pain relief, nephropathy treatment and potent anti-tumor and anti-bacterial activities (which have been associated with its protein, fat and chitin contents) (Liu & Yu, 2008; Li, 2010; Ratcliffe, Mello, Garcia, Butt, & Azambuja, 2011; Chakravorty, Ghosh, & Meyer-Rochow, 2011). Bioactive proteins and peptides derived from insects such as silkworm and bumblebee exhibit significant antioxidant capacity (Guo, Zhang, Guimei, & Liu, 2011; Yang et al., 2013), angiotensin-I converting enzyme (ACE) inhibitory activity (Dai, Ma, Luo, & Yin, 2013; Wu, Jia, Yan, Du, & Gui, 2015), antimicrobial or antibacterial functions (Rees, Moniatte, & Bulet, 1997; Vonkavaara et al., 2012; Hu et al., 2013; Yi, Chowdhury, Huang, & Yu, 2014; Rahnamaeian et al., 2015) and mineral bioabsorption-enhancing effects (Sasaki, Yamada, & Kato, 2000). Bioactive lipids from insects were also found beneficial to human health, e.g. the therapeutic potential of the fatty acids in mealworm larvae for Alzheimer's disease (Youn et al., 2014), and the sterols and derivatives in the desert locust (*Schistocerca gregaria*) and the sericin from silkworm for high blood cholesterol and cardiovascular diseases (Limpeanchob et al., 2010; Cheseto et al., 2015).

2.3. Potential safety hazards including food allergenicity, intolerance and toxicity

Not all insects are safe to eat. Microbial, chemical, physical, allergenic, parasitological and toxicological risks should be considered when insects are selected for human consumption. Minimizing such risks must remain an imperative throughout the whole process from processing, handling and eventually consumption. As with other substances for human intake, monitoring potential microbial contamination is the first concern for edible insects, given the nature of their habitats and rapid reproduction rates (Klunder, Wolkers-Rooijackers, Korpela, & Nout, 2012; Opara, Sanyigba, Ogbuewu, & Okoli, 2012). Only a few investigations have been reported to date addressing the microbiological safety of edible insects and these studies provide some recommendations on hygiene management during insect handling and processing (Klunder et al., 2012). For example, *Allomyrina dichotoma*, a beetle species well-known in East Asia for its therapeutic effects on diabetes mellitus and liver disease, has a NOAEL (No Observed Adverse Effect Level) of 2500 mg powder (freeze-dried)/kg/day or more in both sexes of Sprague-Dawley rats (Noh et al., 2015). Besides the microbial threat, parasitological hazards such as dipterous larvae, flukes, hydatid cysts, nematodes, protozoa and trypanosomes, deserve high attention (otherwise, serious infection or even death could occur) (Wilson, Lorente, Allen, & Eberhard, 2001; Sehgal et al., 2003; Graczyk & Knight, 2005; Molavi, Massoud, & Gutierrez, 2006; Chai, Shin, Lee, & Rim, 2009; Pereira et al., 2010).

Intrinsic toxicity or allergenicity, detrimental interference (by substances such as some proteins, hormones and enzymes), and external contamination are other factors that require critical consideration prior to insect consumption. Physical hazards such as glass, stones, plastic and metal fragments may be present in insects. Chemical hazards include those naturally occurring (e.g. scombrototoxin, ciguatera toxin, tetrodotoxin, mycotoxins, patulin, phytohaemagglutinin, pyrrolizidine alkaloids, and paralytic, diarrhetic, neurotoxin and amnesic shellfish toxins), those synthesized and accumulated by insects, or those added, imparted or leached during food processing (e.g. allergens, sulfiting agents, nitrites/nitrates, niacin, pesticides, fungicides, fertilizers, insecticides, antibiotics, growth hormones, lubricants, cleaners, sanitizers, paints, mercury, copper and lead). The Code of Federal Regulations (CFR) provides guidance on naturally occurring poisonous or deleterious substances (e.g. Title 21 CFR Parts 109 Unavoidable Contaminants in Food for Human Consumption and Food Packaging Material, and 184 Direct Food Substances Affirmed as Generally Recognized as Safe). Some insects have repellants or toxic chemicals (DeFoliart, 1992),

while some contain cross-reactive allergens that might induce allergic responses somewhat similar to those associated with shellfish or mollusks (Auerswald & Lopata, 2005; Yen, 2010; Barre et al., 2014). Prawn-allergic patients likely exhibit allergic reactions to edible insects such as field crickets (*Gryllus bimaculatus*), as insects may contain their own specific allergens (e.g. hexamerin1B (HEX1B)) as well as the allergens commonly found in crustaceans (e.g. Arginine kinase (AK)) (Srinroch, Srisomsap, Chokchaichamnankit, Punyarit, & Phiriyangkul, 2015). Insects can produce poisons including anti-nutritional substances, enzymes, phenolics and steroids (as part of their defense mechanisms against enemies), and accumulate heavy metals at different levels from their environment (Nishimune, Watanabe, Okazaki, & Akai, 2000; Brown, Doyen, Moore, & Lawrence, 2007; Handley et al., 2007; Zagrobelny et al., 2009). Insects may contain nutrient absorption-interfering substances including enzymes such as thiaminase e.g. consumption of the African silkworm pupae would cause thiamine deficiency or even seasonal ataxic syndrome (Nishimune et al., 2000). There may be different forms of pollutants or contaminants in insects e.g. the carcinogen aflatoxin might contaminate edible stink bugs if the insects were stored in traditional wooden dung smeared baskets or gunny bags previously used to store cereals (Adamolekun, McCandless, & Butterworth, 1997; Musundire et al., 2016). The genotoxic and oxidative potentials of edible insects should be assessed, along with analyses of the allergenic and toxicogenic substances, heavy elements and other chemical species (Türkez, İncekara, & Erman, 2010; Koç, İncekara, & Türkez, 2014).

Food allergens as food safety hazards always draw special attention because of the increasing number of food allergy sufferers (e.g. over 17 million in Europe). Up to 2.5% of the general population suffer shellfish allergies, and the incidence depends on factors such as degree of consumption, species, age and geographic location (i.e. much lower in children than in adults, and lower in Western countries than in Asian countries) (Woods et al., 2001; Sicherer, Munoz Furlong, & Sampson, 2004; Chiang et al., 2007). Allergic reactions can be grouped into two kinds of responses that may or may not be mediated by

immunoglobulin E (IgE) (Fig. 2). Food allergies refer to an abnormal immune response to food and are divided into IgE- and IgG- (or non IgE mediated) reactions. IgE is synthesized against antigens in which the release of mast cell mediators is triggered when food allergen binds to IgE antibodies already bound to the mast cell (Olivier, 2013). Food intolerance (non-immune-mediated and non-allergic food hypersensitivity) can mimic allergic inflammation and refers to any abnormal response, often delayed, to one or more specific food(s), food additive pharmacological compounds, enzymatic deficiency (i.e. lactose intolerance), or food substances that produce symptoms in one or more body organs and systems without involving immunologic mechanisms. Typical symptoms of food allergy may include skin itchiness, tongue swelling, vomiting, diarrhea, hives, breathing difficulty and/or low blood pressure. Foods such as cow milk, eggs, some fruits, maize, rice, peanuts, shellfish, soy, spices, tree nuts, some seeds (e.g. sesame and poppy seeds), wheat, buckwheat and some vegetables have been found closely associated with food allergies (Leung et al., 1998; Yu, Lin, Chiang, & Chow, 2003; Sicherer & Sampson, 2010; Han, Kim, & Ahn, 2012). The risk of allergies caused by edible insects varies considerably due to the vast differences in their biological and ecological characteristics as well as individual farming and processing practices. Substances causing allergic reactions are some intrinsic proteins (like tropomyosin), carbohydrates (like chitin) and other yet to be identified components (Rop, Mlcek, & Jurikova, 2009).

Allergenicity of edible insects might resemble that of shellfish, and the potential allergenicity of insects could be associated with the so-called arthropods and invertebrates allergy (which is caused by body components such as the haemolymph and cuticle, as well as body parts including exuviae, hairs, setae and scales) (Santos et al., 1999; Pérez-Pérez et al., 2000). Edible insects are somewhat similar to certain seafoods and nuts in composition, rich in proteins, unsaturated fatty acids, fibre, vitamins, minerals and sterols. Accordingly, the co-occurrence of allergenic proteins in significant amounts (with hydrophobic fractions) and certain interactive components (e.g. lipid fraction and ions like Cu^{2+}) might trigger an allergic response in humans

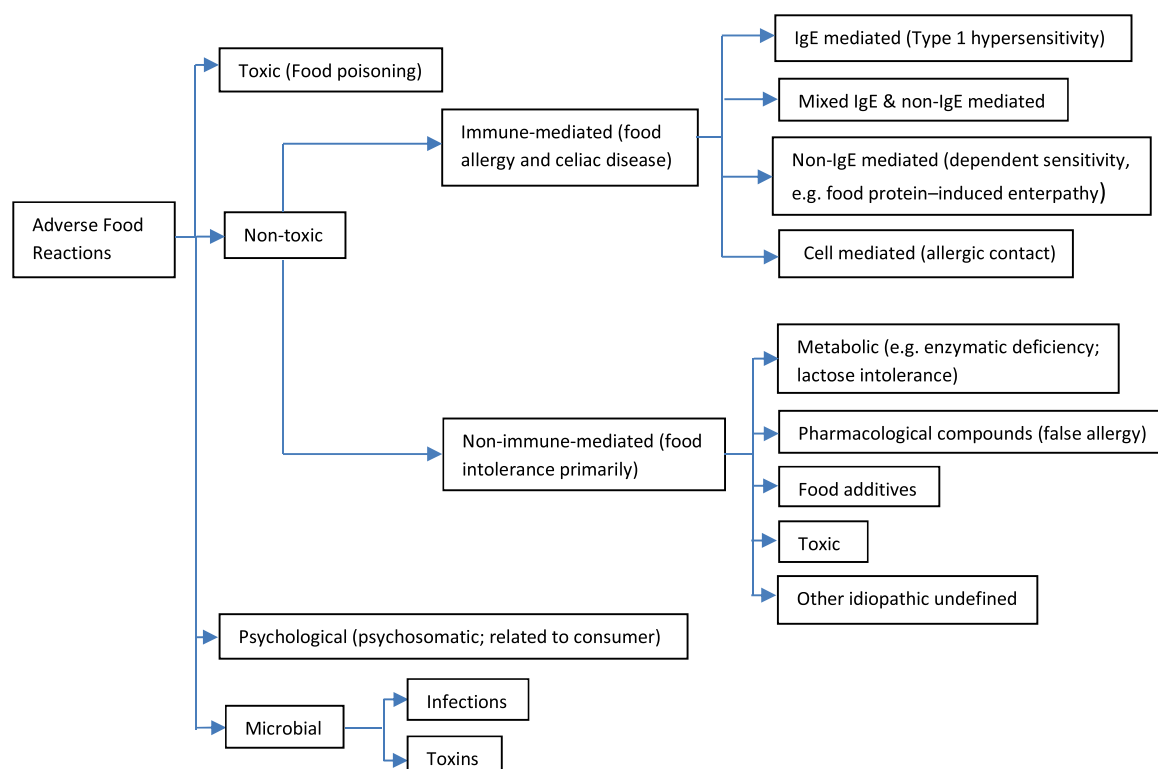


Fig. 2. Potential adverse reactions developed through food ingestion (after Bruijnzeel-Koomen et al., 1995; Boyce et al., 2010).

(Rundqvist et al., 2012; Vadivel, Kunyanga, & Biesalski, 2012; Van Bilsen et al., 2013; Broekman et al., 2015). The protein-type food allergens include enzymes (e.g. proteases and pectate lyases), albumins, tropomyosins, bexpansins, profilins, ligand-binding proteins, calcium-binding proteins, pathogenesis-related proteins, trypsin inhibitors, lipid transfer proteins and storage proteins (Chapman, Pome's, Breiteneder, & Ferreira, 2007). Proteins possessing higher thermal stability, resistance to proteolysis, binding capacity and interactive potential with lipids and/or ions like Cu^{2+} (especially high stability under the acidic and proteolytic conditions in the digestive tract), typically exhibit greater allergenicity (Breiteneder & Mills, 2005). Tropomyosin and paramyosin have been identified as major protein panallergens or allergens in shellfish, while subtle structural differences of tropomyosin between shellfish species are responsible for discrepancies between in vitro cross-antigenicity and clinical cross-allergenicity studies (Leung et al., 1996). Arginine kinase, myosin heavy chain, myosin light chain kinase, haemocyanin, amylase and sarcoplasmic calcium binding protein are other allergens that may be present in certain insect species (Yu et al., 2003; Garcia-Orozco, Aispuro-Hernandez, Yepiz-Plascencia, Calderon-de-la-Barca, & Sotelo-Mundo, 2007; Taylor, 2008; Ayuso et al., 2008 and 2009).

Different responses to allergens, especially shellfish allergens, have been found between Western and Eastern consumers, between the populations in developed and developing countries (even between urban and rural areas in the same country), and between the children and adults (Sicherer & Sampson, 2014). The underlying cause of higher prevalence of food allergy in developed countries or urban regions, compared to the developing countries or rural area, is complicated. It is postulated that increased exposure to pathogens in developing countries, especially helminths, might alter the intestinal microbes and stimulate the development of regulatory cells thereby improving the immune system to allergies (Boye, 2012). Age may lead to different responses to shellfish allergens, which is likely associated with the level of specific IgE antibody resulting in different extents of binding to food peptides and epitope diversity (Sampson, 2004; van Der Poel, Chen, & Penagos, 2009; Ayuso et al., 2010). It is recommended during food formulation to include food proteins that have low allergenicity and also to minimize the use of food additives and substances that induce allergic sensitivity such as sulfites, mono-sodium glutamate and tartrazine. Alternatively, one can include some specific enzymes (e.g. proteases), minerals and phytochemicals (which possess not only desirable health benefits but could also alter the allergenic status through imparting antioxidant and anti-inflammatory effects) (Philpott, Mackay, Ferguson, Forbes, & Skinner, 2007; Sun-Waterhouse et al., 2009). Section 4.2 provides detailed information about the feasibility of using appropriate processing technologies to alter insect food protein allergenicity.

Consumers with food allergies rely heavily on information contained on food labels to avoid food allergens. This means that the identification, characterization and management of the potential allergens in insect-based foods “from farm to fork” is a critically important part of the Legislation Framework for insect products. Legislative rules resembling the Food Allergen Labeling and Consumer Protection Act and the Code of

Practices are needed to guide the establishment of allergen-free insect-based foods. Mandatory labeling is also expected to indicate the presence of allergenic ingredients in insect-based foods or the potential of cross-contact between the insect foods and extrinsic allergenic substances during processing and handling. Legislative authorities and societies should continuously update the list of food allergens that need to be disclosed on food packaging. Worldwide harmonised guidelines and strategies for the prevention, diagnosis, treatment and management of food allergies caused by eating insects are required to avoid potentially life-threatening allergic reactions like anaphylaxis. Section 5 provides more information on this topic.

2.4. Environmental, economic and ecological impacts

The benefits of switching to insect-based foods lay not only the nutritional value of insects, but also the positive environmental, economic and ecological impacts. Compared with conventional livestock farming approaches, farming insects has many other advantages including increased feed-conversion efficiency, decreased greenhouse gas emission (by up to 100 times), reduced water pollution, and smaller area land use with low environmental contamination (Fig. 3). Among insect species, only cockroaches, termites and scarab beetles produce methane (CH_4 results from bacterial fermentation by *Methanobacteriaceae* in the hindgut) (Hackstein & Stumm, 1994; Egert, Wagner, Lemke, Brune, & Friedrich, 2003). Insects' widespread distribution, high reproductive rates and short reproduction cycles are further advantages that underpin their economic potential (Schabel, 2010). Insect production is advantageous as it does not require a large area. The land area required to yield the same quantity of protein is about 1 ha for mealworm, 2–3.5 ha for pig or chicken, and 10 ha for cattle (Oonincx & de Boer, 2012). Insects can be raised on a wide range of foods, including agricultural biowastes and even human wastes, abattoir blood and food wastes (Katayama et al., 2008), thus representing an economically attractive protein source.

Insects can be raised to provide an indirect food source for humans (i.e. in the form of feeds for animals such as pigs, poultry and fish) or to support the growth of some valuable health foods such as *Ophiocordyceps sinensis* (a medicinal mushroom also called “caterpillar fungus” that parasitizes larvae of ghost moths through germinating in the living larva and then killing and mummifying it) (Halpern & Miller, 2002; Shrestha, Weimin, Yongjie, & Xingzhong, 2010; Wang & Yao, 2011). Compared to the direct use of insects as human foods, such indirect approaches may be less efficient in terms of energy and mass conversion but are likely to be more widely accepted (Parent & Thoen, 1977; Farina, Demey, & Hardouin, 1991; van Huis, 1996). Insects such as black soldier flies, common house fly larvae, silkworms, yellow mealworms, grasshoppers and termites are promising alternatives to traditional protein-rich animal feeds like soy or fishmeal.

It is worth noting the impact of commercial development on the preference for edible insects and the sale price of insect-based products (Césard, Komatsu, & Iwata, 2015). Some insects such as bees, beetle larvae, flies, ants and termites play positive roles in plant reproduction,

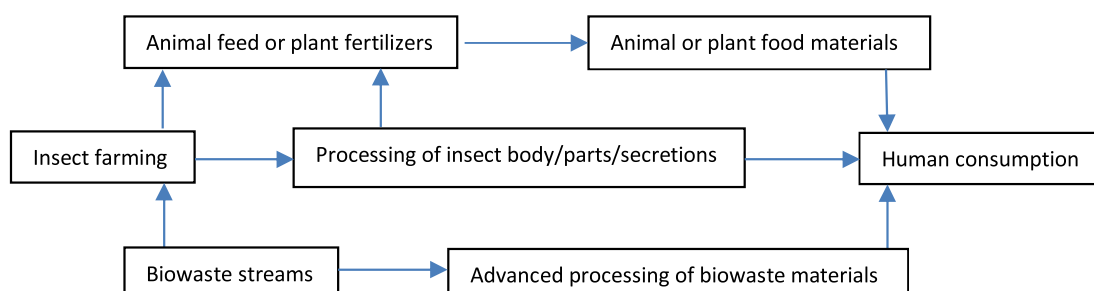


Fig. 3. Edible insects and the animal feed and human food value chains.

waste biodegradation and the human food supply chain. Other insects are considered pests and can cause considerable damage to plants (e.g. preventing rice grain formation), animals and humans (e.g. transmitting diseases), especially when the number of these insects grossly outnumber that of their natural predators or if the insects predate on other beneficial species. Accordingly, consumption of pest insects should be advocated from both an environmental and nutritional perspective (i.e. reducing the pressure of pest control, whole produce damage and pesticide usage while increasing human intake of high quality protein along with desired minerals and lipids) (Akinnawo & Ketiku, 2000). Market surveys revealed that the wholesale or retail price of some edible insects could exceed traditional animal meat products if edible insects are solely collected from the wild (e.g. grasshoppers in Uganda are marketed at prices 40% higher than beef) (Agea, Biryomumaishe, Buyinza, & Nabanoga, 2008). Therefore, industrial-scale insect production aided by sustainable insect breeding, farming and processing technologies could alleviate the constraints of insect availability while decreasing the sale price of edible insects.

3. Consumer perception and cultural and metabolic differences in human populations

Despite the nutritional, environmental and economical benefits of insect consumption, the growth potential of insects as everyday foods for humans in all parts of the world is still not clear (Srivastava, Babu, & Pandey, 2009). Widespread consumer acceptance of insects as an alternative food resource remains a concern. Consumer perception towards the inherent unsanitariness of insects represents the biggest barrier. An increasing number of studies are appearing based on the concept “the use of insects for foods”, however, only a few have been aimed at consumer acceptance and product preference for insect-based foods. The development and globalisation of the insect-based foods would face stiff barriers due to the current very low consumer demand compared with the normal (non-insect) foods (the development of the latter is highly consumer-driven). Recognition of the interplay between individual preferences, cultural and/or social influences, and promotion of the existing positive role of entomophagy in indigenous communities will be critical for overcoming prejudices and adoption of the concept. Perhaps the biggest push towards widespread consumption of edible insects will be economic, driven by the urgent need for westernized societies to reduce their environmental footprint (caused by high protein consumption from livestock).

3.1. Cultural and traditional taboos

Entomophagy clearly exhibits cultural, traditional and regional characteristics (Nonaka, 2009). Different ethnic groups, populations, regions and nations tend to have completely different attitudes towards insect-based food products. The spectrum covers “daily intake” versus “totally reluctant”, and “consumed as part of healthy diet/delicacy/favourite foods” versus “consumed only as an emergency or non-conventional food of low prestige”. Some species, which are eaten in one nation, region or society, are not consumed in other countries, regions or societies due to reasons like traditional taboos (e.g. grasshoppers and locusts are not eaten in Australia, whereas are commonly consumed elsewhere) (Henrikson, Yohe, Newman, & Druss, 1998; Yen, 2005; Meyer-Rochow, 2009). Even in the insect-eating continents such as Africa, Asia and America, opposing attitudes exist among the residents i.e. “sustainable traditional use” versus “complete movement away from insect eating” (Ramos-Elorduy, 2005). Further, there are huge differences in perception, acceptance and willingness to experiment with new foods between Western and Eastern countries, and also between the rural and urban societies. Rural regions (subsistence farmers) and Eastern societies have traditionally utilised insects as foods thereby recognising the nutritional, ecological and economical benefits of entomophagy (Yen, Hanboonsong, & van Huis, 2013). In comparison, there

exists public aversion towards consuming insects in Western societies where insect intake is not deeply rooted in their traditional diet and insects are generally perceived as “unclean”, “mere pests”, “disgusting nuisances” or “disease-transmitters” (Pimentel, 1991; Kellert, 1993; Looy, Dunkel, & Wood, 2014). A study exploring options for meat substitution in the Netherlands found the lowest ratings in “attractiveness” and “likelihood of preparation” for meals containing locusts or fried mealworms (Schösler, de Boer, & Boersema, 2012). A very recent study on a traditional meat-eating Western society revealed that younger males with a more open mind to novel foods, a weak attachment to meat and a strong interest in environmental impact associated with food choices were the most likely and earliest adopters of insects as a sustainable protein source (Verbeke, 2015). The same study also revealed that Western meat lovers would be very unlikely eat insects. A cross-cultural comparison (German adults ($n = 502$) and Chinese adults ($n = 443$)), based on the willingness to consume insect-based processed foods (cookies made from cricket flour) and unprocessed foods (crickets), showed that Chinese adults adopted more favourable attitudes towards the consumption of insects (especially processed insects). Food neophobia, however, influenced the willingness of insect consumption equally for all the participants of both countries, while the insect-based foods with insects incorporated into familiar food formats tended to succeed easier in Western societies (Hartmann, Shi, Giusto, & Siegrist, 2015).

The Fertile Crescent's original agriculture and subsequent domestication of plant and animal production in Europe imparted a long-lasting influence on the food sources of European consumers, causing the dominance of plants and domesticated animals in the diet and the persistent perception of insects as a nuisance or threat to food production in Western societies (DeFoliart, 1999; Diamond, 2005). Insects, however, are valued as important and delicacy foods in Eastern countries because of the recognition of insects' nutritional and health properties and low availability of conventional meat sources (including beef, fish and chicken). Further, urbanization is more extensive in Western countries, and has led to the wider consumption of bulk processed foods thereby increasing the “shock factor” of entomophagy (DeFoliart, 1999; Amar, 2003; UN, 2012). Increasing urbanization over time also leads to a reduction in the number of edible insects for consumption due to the habitat reduction and damage. As a result, insect's food potential is lower in Western and urban societies compared with Eastern and rural communities.

Many insect species are traditionally eaten as foods. In Thailand, edible insects such as wasps, bamboo caterpillars, crickets and locusts are eaten by the rural people (Yhoong Aree, Puwastien, & Attig, 1997) and served as premium dishes or snacks to local people and foreign tourists (Bristowe, 1932; Durst et al., 2008; Yen, 2015). In China, eating insects such as ants, bamboo insects, bee larva, silkworm chrysalis and wasp larvae dates back >3000 years and there are over 1000 species served in restaurants or used for Chinese medicines (Zhou, 1982; Chen et al., 2009). In Japan, >117 insect species are traditionally consumed as food (Mitsuhashi, 1997, 2008), considered as “nostalgic” or “homeland foods” (kyoudo-shoku) and marketed as souvenirs (e.g. zazamushi) by local people mainly to domestic tourists (Mitsuhashi, 1997; Césard et al., 2015). Insects are sold year-round packed in cans, glass bottles or punnets in boutiques that specialize in regional products (meibutsu). Exceptions to the persistent perception of insects as a nuisance or threat can be found in some Western countries. In France the palm worm (*Rhynchophorus palmarum*) was once considered as the highlight of a luxurious meal (Smeathman, 1781).

Western societies should be taking the lead advocacy role given their general phobias and abhorrence to eating insects. Western societies are proven front runners for globalisation of universal cultural systems related to customs and habits (DeFoliart, 1999), thus, other cultures will soon follow if Western societies practice entomophagy. Indeed, there has been a recent increasing interest in entomophagy in Western societies because of the growing awareness of insects'

Table 2

Consumer studies on insect-based foods and food ingredients.

Target	Research method	Consumer or population variables	Factor influencing acceptance	Experience of entomophagy	Consumer attitude	Reference
Insect/entomophagy	Questionnaire	363 Norwegians (67.5% women, 32.5% men; 37.5% 18–35 yr, 39.9% 35–55 yr, 22.6% > 55 yr; > 64.5% married; 57.3% higher education)	Nutrition; Ease of preparation & cooking; Environmental friendliness	/	Positive	Neves (2015)
Insect/entomophagy	Questionnaire	303 Portuguese (59.4% women, 40.6% men; 46.5% 18–35 yr, 29.4% 35–55 yr, 24.1% > 55 yr; 56.1% married; 47.9% higher education)	Nutrition; Ease of preparation & cooking; Environmental friendliness	/	Positive	Neves (2015)
Mealworms (<i>Tenebrio molitor</i> L.) and house crickets (<i>Acheta domesticus</i>)	Questionnaire	189 Belgian (55.6% men, 44.4% women; 9.5% < 13 yr, 30.2% 13–18 yr, 16.9% 19–25 yr, 26.5% 26–45 yr, 16.9% > 45 yr);	Age; Gender; Preparation; Legislation; Traditional cognition	Knowledge on entomophagy increases with age; few < 18 yr informed about entomophagy	61.9% respondents knew entomophagy, 46.6% negative; 77.7% willing to eat insects	Caparros Megido et al. (2014)
Insect/entomophagy	Email questionnaire	Total 209 people completed survey incl. 75 Australian and 134 Dutch participants	Price & quality, health benefits, naturalness, consumer need & convenience; attitude & culture	73 participants had eaten insects before and 134 had not.	Before survey, neither agree nor disagree; After survey, positive	Lensvelt and Steenbekkers (2014)
Insects (meat substitute): deep fried silkworm/cricket, cricket cookies, cricket cookies choco chip, silkworm drink	Questionnaire	502 Germany and 443 Chinese (most 20–69 yr; half men, half women; > 60% Germany are middle educated, 80% Chinese highly educated)	Gender, age, education, consume insects before, food neophobia, nutritional value, familiarity, taste, social acceptance	13.3% Germany and 67.7% Chinese had eaten insects before.	Germany negative and Chinese relatively positive	Hartmann et al. (2015)
Edible insect (almost 200 species consumed in Thailand)	Interviews + collection of published research articles & reports	26 Provinces in northern, northeastern, central & southern Thailand (60 farmers + 12 farmer groups from 17 northeast provinces; 7 farmers from 4 south provinces about palm weevil farming; 20 collectors from north + northeast, 12 edible insect entrepreneurs/distributors in Kalasin, Rong Kluea, Klong Toey, Jatujak & Talad Thai markets)	/	/	Positive	Hanboonsong et al. (2013)
Insects: Ant larva, bigbutt ant, grasshopper, giant water bug, bambooworm, mealworm, mopane worm, witchetty grub	Focus group interview	8 Focus groups (each 6–8 participants of similar insect-eating experience but varied gender, age, education & occupation) — 4 Wageningen/Netherlands, and 4 in Sakon Nakhon, Thailand; 54 participants (19 men, 35 women, 20–65 yrs., mean 38 yr)	Experiences & knowledge of insects as food; Species; Interest & concerns; Product properties & expectation; Preparation appropriateness; Insect visibility; Product sensoryliking	For Dutch insects available for consumption in specialty shops & events but not recognized as food; Insect consumption is part of local culture for Thai	Dutch participants, positive in trying new food incl. Insect; Thai, positive in consuming insects	Tan et al. (2015)
Insect	Web-based survey	368 meat consumers in Flanders, Belgium during Dec. 2013 (61% female, age 18–79 yr, mean age 42 yr)	Age, convenience, familiarity, food neophobia, gender, meat-related attitude, environmental food choice motive, future meat intake intention	/	Younger males, more open to trying insect as food	Verbeke (2015)
Insect	Questionnaire	1100 consumers in 11 small-to-large cities (incl. Beijing & Shanghai, along China's eastern coast); 1005 usable sample data collected (Beijing 200, Shanghai, 200, Shandong 200, Jiansu 205, Zhejiang 200)	Gender, age, education, household size, monthly per capita disposable income, residing city, occupation, Role of food shopping, awareness of biotech foods, health condition	Two-thirds of respondents had heard of biotech foods	Relatively positive & neutral	Lin, Somwaru, Tuan, Huang, and Bai (2007)

Note: “/” indicates information unavailable.

nutritional and environmental advantages. It is worth noting that the consumption of insects is not always driven by nutritional and environmental benefits but by taste and sensation (as with any kind of food, poor flavour and texture result in rejection) (Meyer-Rochow & Changkija, 1997). This implies that consumer acceptance could be increased if the sensory characteristics of insect-based products please consumers and consumers understand the intrinsic nutrients and bioactives contained in insect foods or ingredients. Appropriate food formulations and processes could facilitate insect incorporation into normal consumer foods e.g. masking the presence of insects in foods, or creating insect food ingredients with particular flavour/texture for specific dishes or processed foods (Ahn, Ahnert, Bagrow, & Barabási, 2011) (more discussion on this aspect is provided in Section 4.2).

3.2. Consumer perception, acceptance and preference

Consumers' attitudes towards novel foods vary considerably and are driven by factors such as gender, age, food familiarity, food neophobia, convenience, environment and food choice motives (Dovey, Staples, Gibson, & Halford, 2008). Consumers' initial perceptions and societal perceptions of a new food dictate their willingness to consume (Martins & Pliner, 2005). The challenge of convincing an insect phobic culture to recognize the value of insects in sustainable ecosystems and sustainable food supply chains is not just about raising, processing and transporting edible insects but also about creating consumer demand and increasing acceptance of such "minilivestock" (Bharucha & Pretty, 2010; van Huis, 2013). It is difficult to overcome consumer aversions towards insects (aversions seeded and propagated by contemporary media, proverbs and even scientific publications on insect pests and their unhygienicness or disease transfer) (Meyer-Rochow, Okui, Henshall, & Brook, 2000). In particular, the United States has a history of public, political and scholarly resistance to entomophagy (DeFoliart, 1999 and 2012). Examination of the attitudes of different populations towards insect-based foods is a must. Through education consumers will slowly appreciate the short term (good nutrition and food supply security) and longer term (environmental conservation) benefits of consuming insects.

To our knowledge, only a limited number of studies have been conducted on the general willingness of insect consumption and product likeability of insect-based foods. Very few studies have quantified the evolution and interplay of consumer perception, demand, acceptance and preference of edible insects as foods using systematic methods such as random utility theory, stated choice experiments or latent class model (Table 2). A recent study on Belgian populations consisting of five age groups (0–12, 13–17, 18–25, 26–45, 45+ years) indicated an opportunity to introduce entomophagy in the form of mealworm and house cricket processed foods into Western European diets, based on participants' overall acceptance and willingness (Caparros Megido et al., 2014). A Kenyan study conducted between December 2014 and January 2015 via face-to-face interviews, used photo representations of two insect food formats (i.e. fried and salted whole or processed termite powder) and engaged 611 consumers with different levels of education (from minimal to tertiary education) and from five counties of Kenya (Kisumu, Siaya, Kakamega, Machakos and Nairobi). This study revealed that most consumers adopted a pro entomophagy attitude with less food neophobic traits, and generally preferred termite-based food products due to their high nutritional value, high food safety control and high official recommendation. There were no stark differences in taste preference for the Kenya consumers between the two formats of insect foods (though the potential uncertainty or distrust with processors caused some food safety concerns) (Alemua, Olsena, Vedela, Pambob, & Owinoc, 2015). A comparative study between the adults in China and Germany implied that elicitors of rejection could vary with insect species especially for the Chinese consumers, while the westerners might treat all insects as one single category of 'bugs' carrying threats (Looy et al., 2014; Hartmann et al., 2015). A cross-cultural

qualitative study involving eight focus groups (i.e. 4 in Thailand where entomophagy is part of local food culture; 4 in the Netherlands where insects are generally not recognized as foods) was carried out via stage-wise group discussions using images with descriptions of insect-based products (e.g. sweet vs savoury; insect visible, covered vs invisible), to explore consumer rationales behind the acceptance and rejection of insects as foods. Results revealed that consumers would likely make judgments based on their expectations (which vary with their cultural background and individual experience) and their perception varies with their knowledge, and that Dutch consumers might be willing to try an insect product but not accept it as a food if the product does not meet expectations (Tan et al., 2015). Much work remains to be done to fill knowledge gaps on the major acceptance determinants, impact of a specific determinant such as a sweet or savoury flavour on willingness-to-eat insect-based foods, the relationship(s) between hedonic scores and emotional responses to insect-based foods, difference in willingness to consume a whole meal with insects or to consume insects as an independent dietary component (e.g. a snack), or difference in the impact on insect consumption brought by the selling point of "possessing potent biological effect on a prevalent health problem" as compared to the selling point of "possessing a high protein content".

Many factors influence consumer food choice including 1) biological factors such as hunger, satiety and palatability; 2) economic factors such as cost, accessibility/availability, income, education and knowledge; 3) physical factors such as access and skills (e.g. cooking) and time; 4) social determinants such as culture, family, peers, social and family norms, context or setting; 5) psychological determinants such as mood, stress, guilt, family and history influences; 6) meal attributes such as meal patterns, convenience and familiarity; 7) attitudes, beliefs, tendency of optimistic bias, previous experiences, knowledge about food, dietary preferences and restrictions (Steiner, 1977; Dewberry & Ussher, 1994; Stubbs, van Wyk, Johnstone, & Harbron, 1996; De Almeida, Graca, Lappalainen, & Kearney, 1997; Anderson et al., 1998; Clarke, 1998; Feunekes, de Graaf, Meyboom, & van Staveren, 1998; Oliver & Wardle, 1999; De Irala-Estevez et al., 2000; Donkin, Dowler, Stevenson, & Turner, 2000; Kearney, Jearney, Dunne, & Gibney, 2000; Faugier, Lancaster, Pickles, & Dobson, 2001; Dibsdall, Lambert, Bobbin, & Frewer, 2003; Devine, Connors, Sobal, & Bisogni, 2003; Wardle, Steptoe, Oliver, & Lipsey, 2000; Sun-Waterhouse, 2011; Sun-Waterhouse & Wadhwa, 2013). All these factors will determine insect-based food acceptance and consumer choice, with the sensory properties being one of the most important determinants. The connections between these factors could further make food choices more complex, thus, multiple interventions (rather than one type of intervention) would likely modify the food choices of all populations.

There exists a motivational difference between trying and regularly eating a food, especially for unfamiliar foods including insect-based foods (Martins & Pliner, 2005; Tan et al., 2015). Unfamiliar foods (for example, an unfamiliar animal or insect-based product) tend to gain low initial acceptance or even complete rejection due to perceptions of disgust, distastefulness, riskiness or unsafeness (Fallon & Rozin, 1983). Social environment plays a key role in food preference (Larson & Story, 2009). Consumers learn the characteristics of various food sources from their very early years of childhood through food ingestion. Subsequently, perceived characteristics of a food from childhood remain deeply entrenched in their minds. This explains the unease of many adults, who disliked or rejected the association of insects with foods, to accept entomophagy.

Dietary change is difficult. Overcoming intrinsic human perceptions such as optimistic bias and reluctance to make dietary change and consume unfamiliar foods, is the main challenge for any novel food. Insect-based foods are not an exception. Accepting insects as human food will likely present additional barriers compared to other novel noninsect foods. Unusual products (Pliner & Hobden, 1992), products created using new technologies (Cox & Evans, 2008), food neophobia and food

technology neophobia could all impact the degree of readiness of consumers to adopt insects (Caparros Megido et al., 2014). Adding familiarity to an insect-based food would lift the acceptance e.g. incorporating insects into popular or conventional consumer foods (Hoek et al., 2011). However, the way in which insects are included in a food, as well as how the insect-based food is presented and advertised, will also influence consumer response. Visual appearance and certain texture or mouthfeel of insects may trigger a disgust-based food rejection response (e.g. seeing an entire insect or body part, or something slimy on the tongue) (Rozin & Fallon, 1987), especially for those with minimal experience with insects as food (Shan et al., 2015).

A perceived need by consumers to make dietary changes is a fundamental pre-requisite for achieving dietary change. Such changes can be achieved after education on short- and long-term impacts on an individual's or population's health (Paisley, Lloyd, Sparks, & Mela, 1995; Kearney et al., 1997; Dibsdall et al., 2003). The change in consumer attitudes to dietary fat (i.e. from sole reduction of total fat intake to moderation of total fat intake plus optimisation of the saturated to unsaturated fat ratios) is a good example. Thus, food neophobia or non-acceptance of insect-based foods is deeply rooted by the influence of our predecessors and their perceptions of inherent unsanitariness and “disgust” could be overcome or even eliminated in a generation. Keeping an open mind and increasing appreciation for cultural diversity are key steps in accepting insects as food, and rapid development of food safety policies and legislative frameworks would aid this goal. Proven nutritional quality and health benefits, alongside desirable taste, would increase acceptance and willingness-to-eat or purchase insect-based foods (Barrena & Sánchez, 2013). Recognising the importance of lifestyle and life status, different strategies will be required to facilitate dietary changes including education on the nutritional and environmental benefits of entomophagy, demonstrations of processing on palatability and cost-effectiveness of insect foods (Anderson & Cox, 2000). Interventions in various settings (e.g. supermarkets, schools or workplaces) and through multimedia tools would be helpful for raising awareness about the unsustainability of traditional animal breeding, and help lessen human bias against insects as food (Patterson et al., 1997; Lowe, Horne, Tapper, Bowdery, & Egerton, 2004). In the short term, insect-based foods will attract consumers who often search for new food choice options with novel and adventurous taste experiences (De Boer, Schöslér, & Boersema, 2013), especially the younger generation who enjoy distinct food experiences (Verbeke, 2015).

Examining the latent variables underlying disgust reactions is as equally important as studying on factors influencing consumer acceptance in the case of insect-based foods. The general latent variables underlying disgust response to food products include 1) aversive textural properties (e.g. squishy, slimy, slippery, mushy and fatty characteristics, and associated odours, off flavours or colours), and 2) reminders of livingness/animalness (extent of association with living animals, bloodiness, viscera, organs, body parts, unhygienicness, moldiness, etc.). Disgust is one of the six or seven “core” emotions and an important motivation for rejection of novel foods especially for unfamiliar foods of animal origin (Pliner & Pelchat, 1991). The causes of the disgust perception are primarily the offensiveness of the object, origin or social history of a food, along with their perceived capacity to contaminate other food items. Nausea, as the physiological concomitant of disgust, could take place in the absence of ingestion thus preventing consumption of a perceived “disgusting” item. Spoilage and decay's theory provides explanations for the mechanisms underlying disgust reactions. Negative responses to the actual or perceived textural characteristics of foods are the dominant factor of disgust reactions. Such responses are generally weaker for novel nonanimal foods than foods of animal origin (familiar or novel) (Martins & Pliner, 2005). Insect-based foods will likely be affected by all these aspects and would be rejected on the basis of perceived danger or capacity to contaminate other foods (although other standard sensory characteristics such taste, smell, texture, or appearance also contribute) (Fallon & Rozin, 1983; Pliner, Pelchat, & Grabski, 1993). Further, understanding the type of ‘values’ and ‘costs’ that influence overall consumer value perceptions is a pre-requisite for satisfying consumer demand and increasing consumer acceptance and preference (Fig. 4). Consumers with different general attitudes towards a product created by a specific process likely differ in the number and type of value–cost dimensions that lead to their value perception trade-offs (Perrea, Grunert, & Krystallis, 2015). Future consumer studies on edible insects and derived food products can fully utilize the existing knowledge about the motivations for rejecting novel animal and nonanimal foods, and should be directed towards the creation of psychographic and socio-demographic profiles of various populations for insect-based foods. As a result, the dimensions of functional value (perceived utility acquired from a product's capacity for physical performance), social value (perceived utility acquired from the association of a person's product choice with the expected choice of a specific social group), hedonic value (perceived utility acquired when a product is able

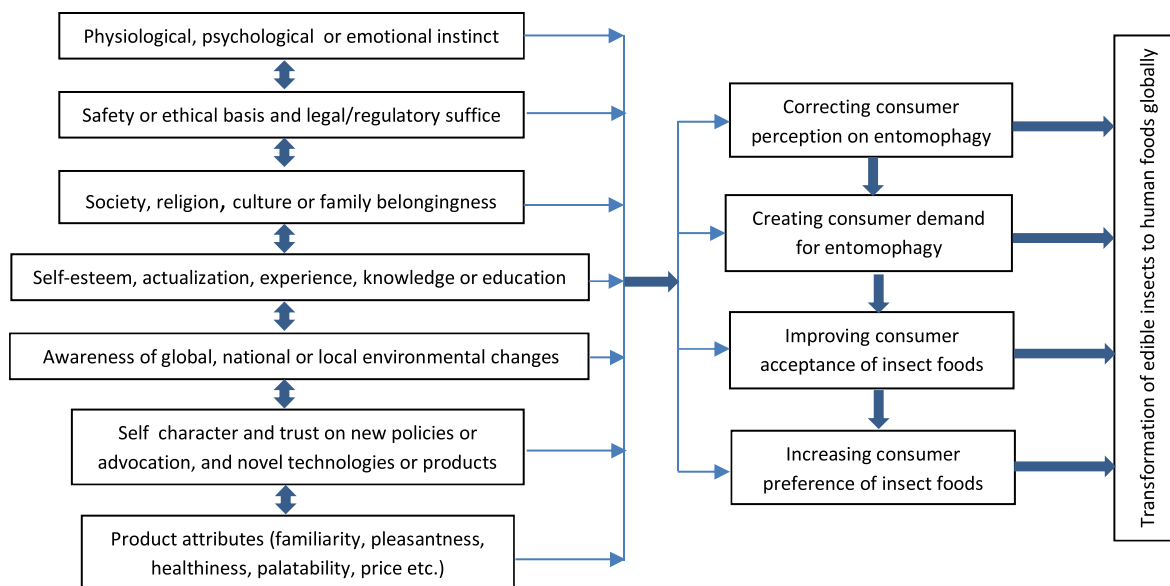


Fig. 4. Factors contributing to consumer perception, demand, acceptance and preference for edible insects to be naturally integrated into human daily diets.

Table 3

Bioactive proteins and polysaccharides generated from insects through processing.

Insect name	Life stage	Methods/technologies for producing protein/polysaccharide products	Functionality	Reference
<i>Tenebrio molitor</i> (L.)	Larva	Protein hydrolyzed by Alcalase (1%, pH 8.5, 4 °C)	ACE inhibitory activity	Dai et al. (2013)
Termite (heterometabole insect, Isoptera)	Adult	Termicin & spinigerin peptides obtained via extraction using 0.1% TFA (pH 3, with protease inhibitor aprotinin & phenylthiourea) + fractionation of supernatant by Sep.-Pak C18 cartridge + HPLC purification [C8 column, (with/without Ultraspherogel SEC 3000 and SEC 2000 columns), Aquapore OD-300 column, C ₁₈ RP column]	Antimicrobial/antifungal	Lamberty et al. (2001)
Scorpion	Different stages	The peptide produced via purification of the supernatant of the acidified scorpion hemolymph by Sep.-Pak C18 cartridge, followed by separation by RP HPLC (C18 column and then C8 column)	Antibacterial	Cociancich et al. (1993)
Hemiptera (Pyrrhocoris apterus)	Adult	Cell-free hemolymph was acidified for Sep.-Pak pre-purification (C18 cartridge), size-exclusion chromatography (Beckman SEC 3000 + SEC 2000 columns), purification (Aquapore OD300 C18 column), digestion (arginyl endopeptidase & endoproteinase Glu-C), separated (Aquapore RP300 C8 column)	Antibacterial	Cociancich et al. (1994)
Cricket (<i>Gryllobates sigillatus</i>)	Adult	Protein extraction: enzymatic hydrolysis by α -amylase and pepsin	High protein; well-balanced nutrients; rich micronutrients; skin fibroblast-stimulating	Zielińska, Baraniak, Karaś, Rybczyńska, and Jakubczyk (2015)
Mealworm (<i>Tenebrio molitor</i>)	Larvae			
Locust (<i>Schistocerca gregaria</i>)	Adult			
<i>Chondracris rosea</i> (Acrididae)	Adult	Protein hydrolysis: Ground samples hydrolyzed in 6 N HCl (18 h, 120 °C under N ₂), concentrated, reconstituted with 20 mM HCl, and derivatized with a Borate buffer	Replacement of vertebrate protein; linolenic acid rich	Chakravorty et al. (2014)
<i>Brachytrupes orientalis</i> (Gryllidae)	Adult			
<i>Clanis bilineata</i> (Lepidoptera)	Larvae	Chitoooligosaccharide extraction: chitosan dissolved in 1% aqueous acetic acid (to 1% w/v), pH to 5.5 (NaOH), α -amylase (40 mg) added to 500 mL chitosan solution, kept at 55 °C (4 h), heated to 95 °C (15 min, to stop reaction)	Inhibit body mass increase, reduce plasma TC, TG & LDL-C, raise HDL-C in rats fed high fat diet	Xia, Chen, and Wu (2013)
<i>Encosternum delegorguei</i> Spinola	Adult	Protein extraction via precipitation with 45–80% (NH ₄) ₂ SO ₄ , centrifugation (21,000 rpm, 30 min, 4 °C), protein pellets desalted in HEPES–NaOH (pH 8 containing DTT) by Sephadex G-25 gel filtration chromatography (PD-10 columns) yielding 80.2 and 77.9 mg proteins from processed and unprocessed insect samples, respectively	A nutrient- and antioxidant- rich food source	Musundire et al. (2016)
<i>Pachymerus nucleorum</i>	Larvae	Larvae lipids extracted by the Bligh & Dyer method; The antioxidant extract was prepared from two extraction 1) mixing lipid and 50% hydromethanol solution followed by resting (60 min) and centrifugation to yield 1st extract 2) pellets for second extraction with acetone (70%) and centrifugation; then combine supernatants.	High protein, good lipids (oleic acid 44% & linoleic acid 4%), high antioxidant activity.	Alves, Sanjinez Argandoña, Linzmeier, Cardoso, and Macedo (2016)
<i>Allomyrina dichotoma</i>	Larvae	Larvae extraction using water, ethanol, methanol, ethyl-acetate, chloroform or hexane	Antioxidant & antibesity effects (against CCl ₄ induced hepatotoxicity, streptozotocin-induced oxidative cytotoxicity & DNA damage)	Suh, Kim, Lee, Park, and Kang (2010), Chung, Yoon, Hwang, Goo, and Yun (2014)
Barley pest (<i>Zophobus morio</i> L.)	Larva	Protein dissolved in water, acid, mellow and alkaline (the water-soluble protein accounted for 30.24% and showed the highest antioxidant activity)	Antioxidant activity	Guo et al. (2011)
Silkworm <i>Bombyx mori</i> L.	Pupa	Pupa powder extracted with alkaline solution, precipitated with acid solution, defatted with supercritical CO ₂	Antioxidant activity	Yang et al. (2013)
Silkworm <i>Bombyx mori</i> L.	Pupa	Pupa powder defatted with petroleum ether, extracted by alkaline solution, precipitated in acid solution	ACE inhibitory activity	Wu et al. (2015)
Silkworm <i>Bombyx mori</i> L. (5th-instar larvae)	Larvae	Protein extracted by Tris-HCl buffer (50 mM, pH 7.4)	ACE inhibitory activity	Vercruysse, Smagghe, Herregods, and Van Camp (2005)
<i>Spodoptera littoralis</i> (6th-instar larvae)	Larvae		Alcalase, gastrointestinal, alcalase	
<i>Schistocerca gregaria</i>	Adult		Gastrointestinal, alcalase, thermolysin	
<i>Bombus terrestris</i>	Adult		Gastrointestinal, alcalase, thermolysin	
Melon bug (<i>Coridius viduatus</i>)	Adult	Extraction of insect gelatin: After pretreatment, samples were mixed with 60 g distilled water (1: 3 w/w, total 80 g) and extracted (50 °C, 180 min) in an incubator.	Yield gelatin for icecream making	Mariod and Fadul (2015)
Sorghum bug (<i>Agonoscelis versicoloratus</i>)				

to trigger changes in consumers' emotional status or arouse their feelings through stimulating the senses) and ethical value (perceived utility acquired when a product enables consumer engagement in ethically desirable practices, such as “fair trade”) should all be considered when introducing insect-based foods.

4. Technologies or approaches for utilizing insects in normal foods and wellness food products

Assuming demand for edible insects as human foods will increase, then new approaches for smart breeding, sustainable rearing, harvest and post-harvest processing will be imperative. To transform insect resources into real consumer food products, it is critical to identify the most appropriate approaches and technologies at every stage of the transformation process (i.e. what and how the insects are fed, raised, harvested, handled, processed, incorporated into foods and packaged all need to be considered). Technological advancements drive new food development and production, and it is expected that a wide range of consumer foods could be developed from a single insect source.

4.1. Insect breeding and farming

Insect breeding and farming are not the focus of this review. This section only provides a modicum of related information, sufficient to allow readers to follow the discussion in the subsequent sections of this paper.

Marketing insects as a sustainable food source means the use of edible insects on a scale large enough to partially replace conventional foods in the human diet while preserving the resource and the natural environment. This implies a need to terminate excessive and uncontrolled harvesting from nature with the concomitant establishment of safe and cost-effective farming systems for edible insects. Uncertainty in the supply of edible insects could result from natural factors (rainfall, climate change or even natural disasters), unpredictable human activities (overcollecting, careless hazards like fires during gathering), or even direct competition between humans and wildlife for edible insects (Ghazoul, 2006; Cerritos, 2009). In Nature, some insects can be collected

throughout the year while other species are available only for a short period (on a seasonal basis). Unmonitored harvesting of insects would place enormous pressure on the insect species, and also impact other wild populations that use those species as a food source. Thus, the production of edible insects would need to shift towards semi-domestication of insects and well-planned and controlled farming with optimised diet, and living conditions (Yen et al., 2013; De Figueirêdo, Vasconcellos, Policarpo, & Alves, 2015).

Selecting a suitable edible insect species is the most important starting point. Edible insects should be selected based on their size, ability to live in high densities, high reproduction rate, abundance, population dynamics, life cycle, survival potential, low susceptibility to diseases or parasitism, high egg hatchability, short larval stage, biomass increase rate, low feed cost, social behavior, epidemic tendency, safety, nutrient and bioactive quality, high meat/protein yields versus feed, ease for storage, marketability, and possible ecological consequences (Rumpold & Schlüter, 2013). Increased knowledge of the biology and ecology of all potential edible insects will guide future industrial insect breeding and farming. High insect biomass could be economically produced through using appropriate breeding technologies and effective habitat management systems based on the biology and habitat characteristics of target insect species, including factors such as diet, temperature, light/illumination, humidity, ventilation, rearing container, water facilities (Tchuinkam et al., 2011). Insect rearing does not require a lot of space, for example, small cages ($50 \times 44 \times 20.5 \text{ cm}^3$) can be used to raise up to 6000 crickets per day (Parajulee, DeFoliart, & Hogg, 1993). Insects such as black soldier flies can be reared using organic wastes such as manure (wastes of pigs, poultry or cattle), rotting fruits and vegetables, coffee beanpulp, distillers grains, fish offal, food wastes and human excreta (Newton, Booram, Barker, & Hale, 1977; Sheppard, Newton, Thompson, & Savage, 1994; Newton, Sheppard, Watson, Burtle, & Dove, 2005; van Huis et al., 2013). Effective channelling manure and other organic wastes to insect rearing facilities can enable edible insect farming while sustainably solving environmental problems associated with organic waste disposal. Harvesting methods could be adapted to target insect species based on traditional or indigenous practices (e.g. the use of hunting tools or sophisticated traps). In 2012, some recommendations have been made at FAO headquarters in Rome on

Table 4

Lipids generated from insects through processing with/without protection.

Insect name	Life stage of insect	Methods/technologies for producing lipid products	References
Eri Silkworm	Pupae	Roasting pupae; Extraction and methylation for gas chromatography (GC) analysis	Shanker et al. (2006)
Silkworm	Pupae	Extracted by Soxhlet apparatus - evaporation - extraction by supercritical carbon dioxide	Wei, Liao, Zhang, Liu, and Jiang (2009)
Ants, termite and flesh fly	Adult	Washing insects with hexane to yield insect surface waxes for room or high temperature GC (HTGC) and HTGC-mass spectrometry analyses	Sutton et al. (2013)
<i>Tenebrio molitor</i> , <i>Zophobas morio</i> & <i>Alphitobius diaperinus</i> (larvae); <i>Acheta domesticus</i> & <i>Blaptica dubia</i> (adult)	Larvae or adult	Demineralized water, mixed with ascorbic acid beforehand	Yi et al. (2013)
Black soldier fly	Prepupae	Mechanical extraction with a lab Taby Press Type 20; Chemical extraction with a Soxhlet apparatus	Surendra, Olivier, Tomberlin, Jha, and Khanal (2016)
<i>Tenebrio molitor</i> , <i>Alphitobius diaperinus</i> , <i>Acheta domesticus</i> & <i>Blaptica dubia</i>	Adult	Soxhlet extraction; Folch extraction; Aqueous extraction	Tzompa-Sosa et al. (2014)
<i>Osmia lignaria</i> , <i>Megachile rotundata</i>	Adult	Use organic solvents (hexane, chloroform, petroleum ether)	Buckner et al. (2009)
<i>Dinoptera quadriceps</i> , <i>Bagrada hilaris</i> , <i>Coptotermes formosanus</i>	Adult	Solid phase microextraction (SPME)	De Pasquale, Guarino, Peri, Alonzo, and Colazza (2007), Ginzel, Moreira, Ray, Millar, and Hanks (2006)
Grasshopper	Nymph/adult	Petroleum ether	Chouhan and Poonar (2016)
<i>Hermetia illucens</i> , <i>Lucilia sericata</i> , <i>Tenebrio molitor</i> & <i>Zophoba morio</i> (larvae); <i>Locusta migratoria</i> , <i>Acheta domestica</i> & <i>Anacridium aegyptium</i> (nymph)	Larvae/nymph	Direct methylation; Using pure n-hexane; Using pure acetone; Using ethanol/water; Using hexane/ethanol; Direct saponification	Ramos-Bueno, González-Fernández, Sánchez-Muros-Lozano, García-Barroso, and Luis Guil-Guerrero (2016)
<i>Munduca sexta</i>	Larvae	Density gradient centrifugation for high density lipophorin-larval	Tsuchida and Wells (1990)

species collection, insect rearing, household production, industrial-scale farming, insect choice, feedstock reliability, safety, health and environmental issues.

4.2. Practical approaches and processing technologies for transforming insect biomass into desired consumer food products

Insects can be consumed whole (cooked or occasionally raw, including those added in alcoholic beverages like tequila), or as processed products in ground and paste forms or other less recognisable forms (e.g. extracts of protein, fat or chitin) for food applications such as chocolates, snacks, crackers, paste, breads, sausages or meat loaves as well as special dishes in restaurants (Ramos-Elorduy, 2009; Ayieko, Oriamo, & Nyambuga, 2010). Traditionally insects are killed via freeze-drying, sun-drying or boiling before further processing (e.g. degutting, removal of body parts like wings and legs and then cooking), although whole live frying is sometimes practiced. Depending on the dish, edible insects are cooked through baking, barbecuing, boiling, braising, deep-frying, frying, smoking, stewing, steaming or roasting with/without oil or salt. For example, palm weevil larvae are often dry fried without oil after washing (Fasoranti & Ajiboye, 1993; Chung, 2010). Caterpillars are usually degutted and then boiled in salted water or sun-dried (to be stored and consumed for extended periods) (Stack et al., 2003). Edible insects such as termites are eaten as main dishes and side dishes or as snack foods (Kinyuru et al., 2009). A spicy Mexican leguminous food consisting of chickpeas and mealworms has been well-received as a sustainable, healthy and exotic snack in restaurants and canteens (van Huis, van Gurp, & Dicke, 2012). Crikizz, a spicy and crunchy snack containing mealworms and cassava was awarded a culinary innovation prize at the national French contest Eco-trophéa, 2012. A fermented mixture of sorghum and nutritious flying termites was promoted as a porridge suitable for breakfast, lunch or dinner (Institute of Food Technologists, 2011). Grinding or milling is commonly used to processing edible insects into pastes or powders (e.g. giant waterbugs), and extraction of various nutrients and bioactives from edible insects for dietary purposes is an approach with relatively high consumer acceptance (e.g. protein and oil from insects) (Costermans, 1955). Processed edible insects are often consumed directly or used as food ingredients/additives, e.g. the red colourant carmine (E120) extracted from female cochineal insect, and the melon bugs in powder or extract form for culinary uses.

Appropriate processing and handling can make inedible insects edible via eliminating harmful substances including “poisons”, “toxins” and bacteria (Gardiner & Gardiner, 2003; Amadi, Ogbalu, Barimalaa, & Pius, 2005; Teffo, Toms, & Eloff, 2007). For examples, stink bugs can be eaten through washing repeatedly with warm water to release intrinsic pheromones, followed by boiling in water. Alternatively, removing the heads of live or dead stink bugs by squeezing (from back to front) to get rid of “poison” followed by sun-drying can make them edible (Toms & Thagwana, 2003). The armored ground cricket *Acanthopplus spiseri Brancsik* can be eaten after careful removal of its head and guts following extensive boiling (at least 5 h) before further cooking (e.g. frying in oil). Proper storage of insects after harvesting and thorough cleaning of insects prior to consumption could minimize potential contamination (e.g. human carcinogen mycotoxin as the contaminants in edible stink bugs) (Meyer-Rochow, 1975; Adamolekun, 1993; van Huis et al., 2012; van dijk & Meijerink, 2014; Musundire et al., 2016).

Engagement of appropriate processes and technologies can ensure high retention of nutrients and bioactives in insect foods (such as flavonoids in stink bugs) and optimisation of the health benefits of end insect-based products (Tables 3–4) (Kinyuru, Kenji, Njoroge, & Ayieko, 2010). Tailored chemical, physical or biological (enzymatic) treatments can facilitate the creation of protein-/polysaccharide-rich food products (Table 3) or lipid ingredients (Table 4) with desired processing and health functionalities (Guo et al., 2011; Steen et al., 2016). Proteins with high levels of essential amino acids and desired foaming, gelling or

rheological properties for food applications could easily be obtained from insects (e.g. *Tenebrio molitor*, *Zophobas morio*, *Alphitobius diaperinus*, *Acheta domesticus* and *Blaptica dubia*) through processes such as an ascorbic acid-containing aqueous protein extraction followed by sieving, centrifugation and freeze-drying (Yi et al., 2013). Manipulating the variables of conventional treatments (e.g. heating, mixing, pumping, centrifugation, filtration or sonication) can also alter the structure and properties of biopolymer nutrients in insects (Sun-Waterhouse & Waterhouse, 2016). Processing involving shear forces or high pressures could be used to induce unfolding or even formation of amyloid fibrils via pathways other than thermal unfolding (Torrent et al., 2004; Mangialardo, Piccirilli, Perucchi, Dore, & Postorino, 2012). Hydrolysis and fermentation processes such as proteolytic treatments can induce protein structural changes (Sun-Waterhouse, Zhao, & Waterhouse, 2014; Zheng et al., 2014). Dry-roasting, drying or smoking could enable increased protein contents (e.g. from 20% (raw) to 48%, 57% or 37%, respectively, for mopane caterpillar) (Bukkens, 1997; Ademolu, Idowu, & Olatunde, 2010). Processes such as 1) toasting (i.e. in a stainless steel cooking pan over an open flame for 5 min at ~150 °C), 2) toasting plus drying (i.e. toasting and cooling to room temperature before solar drying at ~30 °C and ~40% relative humidity on the wire mesh trays using a locally fabricated solar drier) and 3) solar drying only, were found causing little change in protein digestibility but significantly decreased the riboflavin or retinol content of winged termites (Kinyuru et al., 2010). For green and brown grasshoppers, all these processes significantly reduced the niacin content with toasting and drying processes causing a significantly decreased protein digestibility (Kinyuru et al., 2010). An extraction process involving aqueous NaOH and ethanol can produce, at an extraction efficiency of ~70%, essential amino acids-rich proteins with favourable rheological properties for food applications from yellow mealworm larvae (Zhao, Vázquez-Gutiérrez, Johansson, Landberg, & Langton, 2016). A hyperactive antifreeze protein rich in threonine and cysteine (which provides freeze resistance or ice crystal growth control in food applications) was successfully isolated from the yellow mealworm beetle, through the combined use of gel exclusion chromatography and reverse phase high-performance liquid chromatography (Graham, Liou, Walker, & Davies, 1997). Novel glutamine-rich proteins isolated from *Tenebrio molitor* larvae show desirable encapsulating functionality and cellular defense properties. The proteins react to encapsulate hemocytes and extracellular hemolymph components (Cho et al., 1999). Moreover, a number of healthy products including foods produced using silkworm pupae proteins have gained the approval from the Ministry of Health and State Food and Drug Administration of the People's Republic of China (Wei & Xu, 1999; Wang et al., 2002; Han, Zhou, Xu, Dong, & Chen, 2004; Zhou, 2004). Silkworm pupa (*Bombyx mori*) have long been used as ingredients for foods and medicines in countries such as China, Japan, Korea, India and Thailand (Zhou & Han, 2006), because of the diabetes-ameliorating, liver-protecting and immune-enhancing functions derived from intrinsic substances such as proteins, lipids and polysaccharides in the insect (Shi, Xie, Zhang, & Shen, 1990; Zang, Wan, He, & Xu, 1992; Yin & Peng, 1998; Ding et al., 2001; Liu, Tian, & Chen, 2001; Yang et al., 2002). Black weaver ant can be processed into various tonics or wellness foods (Shen, Li, Feng, & Ren, 2006), and large black ants showed significant protection and recovery of the immune system in mice (Wang et al., 2001). Hymenoptera and formicidae insects have been used in China to develop dietary products including liquid beverages, granules and powders, because of insects' anti-cancer, anti-rheumatic and anti-inflammatory functions (Cui, 2009). Proteins extracted from insects including water-, acid- or alkaline-soluble proteins from the barley pest (*Zophobas morio* L.), exhibit excellent antioxidant activities (Guo et al., 2011). Besides, peptides or proteins extracted from some insects and derived products (such as scorpion and bee venom) exhibited anti-vira, anti-bacteria, anti-inflammatory and pain-alleviating effects (Yu & Li, 2005; Lin & Li, 2008). *Tenebrio* larvae was found to promote the growth rate and brain development in

rats and also exhibit anti-fatigue, anti-oxidant and immune-enhancing effects (Li et al., 2007a). Hydrolysis using different commercial enzymes including proteases has been used to improve the physico-chemical characteristics and bioactivities of non insect-based products while reducing allergenicity (Sun-Waterhouse et al., 2014; Su, Zhao, Sun-Waterhouse, & Zhao, 2016). This approach is also applicable to insect-based foods, for example, the short chain peptides from silkworm exhibit high antioxidant activity, digestability and ACE inhibitory activity (Yang et al., 2013; Wu et al., 2015). A peptide from the gastrointestinal hydrolysate of cotton leaf worm showed significant ACE inhibitory activity (Vercruyse, Smagghe, Matsui, & Van Camp, 2008).

As indicated earlier, insects may present allergenicity risk in a way similar to shellfish and crustaceans with heat stable tropomyosin likely the major allergen (Leung et al., 1996). Food processing is able to reduce the potential allergenicity of insect proteins making them less allergenic (van Broekhoven, Bastiaan-Net, de Jong, & Wichers, 2016). Heating via roasting, boiling, steaming, blanching or autoclaving (with/without pH and ionic strength moderation) is one of the commonly used methods to improve digestibility and reduce allergenicity of proteins through mechanisms involving protein structure modification, protein aggregation, reduced affinity or damage of epitopes, decreased IgG-binding capacity via glycation (e.g. induced by the Maillard reaction) and reversible/irreversible protein denaturation (van Bostel, Koppelman, et al., 2008; van Bostel, van den Broek, et al., 2008; Bu, Lu, Zheng, & Luo, 2009; Taheri-Kafrani et al., 2009; Iwan et al., 2011; López et al., 2012; Cabanillas et al., 2014). Boiling shellfish such as shrimp was found to reduce allergens through inducing the Maillard reaction (glycation) (Carnes et al., 2007; Nowak-Węgrzyn & Fioocchi, 2009). Extrusion can lower the potential of allergenicity via decreasing the binding capacity of specific IgG (Ohishi et al., 1994). Fermentation can help alleviate the allergenicity of foods such as peanuts (Zhang et al., 2008; Yao, Xu, Luo, Shi, & Li, 2015). Fermentation using multiple mould strains and bacteria can reduce allergenicity of soybean seed products by 65–99% through decreasing the IgE-binding to human serum (Frias, Song, Martínez-Villaluenga, de Gonzalez, & Vidal-Valverde, 2008). Hydrolysis using acid, probiotic lactic acid bacteria and bifidobacteria and/or enzymes (e.g. Alcalase, cellulase, α -chymotrypsin, Flavourzyme, pepsin, peroxidase, or trypsin) can induce structural changes and partial deamidation of allergens, and reduce IgE-binding and/or cross-linking capacity of the end product (i.e. endoprotease is more effective than exoprotease in this regard) (Watanabe, Watanabe, Sonoyama, & Tanabe, 2000; Chung, Maleki, & Champagne, 2004; Rizzello, De Angelis, Coda, & Gobbetti, 2006; De Angelis et al., 2007; Hildebrandt et al., 2008; Yu, Ahmedna, Goktepe, Cheng, & Maleki, 2011; Cabanillas et al., 2012; Denery-Papini et al., 2012; Shi et al., 2013). Electron beam radiation, γ -irradiation, UV-C exposure or ultrasound treatment can chemically and physically change the native structure of proteins (including allergic tropomyosin) into a molten globule state or even denatured/degraded forms via cyclic generation and collapse of cavities, causing decreased IgG/IgE-binding capacity (Li, Lin, Cao, & Jameel, 2006; Li et al., 2007b; Lee, Seo, Kim, Lee, & Byun, 2007; Manzocco & Nicoli, 2012; Tammineedi, Choudhary, Perez-Alvarado, & Watson, 2013). An ultrasound treatment of sufficient intensity can decrease the binding of shrimp extract with the sera of shrimp allergic patients (Li et al., 2006). High pressure processing (pressure as a function of food type) can reduce or remove allergens like tropomyosin, decrease IgG-binding, induce protein denaturation or conformational changes, and promote enzymatic hydrolysis (to alter the sensitization of allergens) (Li, Zhu, Zhou, & Peng, 2012; Huang, Hsu, Yang, & Wang, 2014). Pulsed ultraviolet light can also decrease the level of allergens in proteins (Yang et al., 2010). Ultrafiltration helps reduce allergens, especially allergens with high heat stability (Brenna et al., 2000). Furthermore, the use of multiple treatment processes and techniques can increase the efficiency of each processing method (Zhou et al., 2016). For example, heating may inactivate certain structural epitopes but is unlikely to eliminate the allergenicity of certain food allergens. A combination of

heating (e.g. boiling or frying) and enzymatic hydrolysis (e.g. by pepsin, pancreatin, lipase and α -chymotrypsin) is effective for decreasing allergenicity through reducing IgE-binding capacity of glycinin (van Bostel, Koppelman, et al., 2008; van Bostel, van den Broek, et al., 2008) or tropomyosin IgE cross-reactivity in mealworm species (van Broekhoven et al., 2016). Genetic engineering, although not the focus of this study, can also reduce or eliminate allergens through various mechanisms (Nordlee, Taylor, Townsend, Thomas, & Bush, 1996).

4.3. Other useful technologies supporting the utilization of insects for food-related products

The association of insects with nanotechnology and biotechnologies (including biotechnologies related to marine/aquatic, agricultural, medical or industrial applications) mainly lies in the management of insect pests, animal/human diseases or infections and food contamination. The knowledge already accumulated in this field can be utilised to support the exploitation of insects for food-related applications. Modern biotechnologies including genomics, genetic manipulation, recombinant DNA technology, enzymatic and fermentation technologies can be applied to breeding, rearing and processing of appropriately selected insect species for human foods, medicinal treatments and associated diagnostic devices. Nanotechnology can be used to manipulate the structure of insect proteins or insect-based foods to achieve target health outcomes (e.g. increased recovery of insect-based nutrients or bioactives while minimizing diseases). Nanotechnology can manipulate the processing functionalities of insect-based food ingredients and materials, and improve the efficiency of delivery and bioabsorption of insect-derived nutrients and bioactives (Will et al., 1996; Bruce et al., 1997; Sonkaria, Ahn, & Khare, 2012). In fact, manipulating the structures of biopolymers through mimicking the protein or carbohydrate nanostructures in nature could impart special properties (e.g. strength, gloss, coloration and antimicrobial properties) to foods and food packaging (Igic et al., 2014; Yabutani et al., 2014; Fechey-Lippens et al., 2015). Colour can be produced through selective absorbance of light at particular wavelengths by pigments, by nanoscale structures that interact with light (structural colour) or by the combination of pigments and nanoscale structures (Bagnara, Fernandez, & Fujii, 2007; D'Alba, Kieffer, & Shawkey, 2012). Structural colours are perceived differently with angle of observation and relative to a fixed light source. The Waterhouse group in New Zealand has extended such investigations to some insect species such as *Chrysina aurigans* and *Chrysina chrysargyrea* beetles which show striking gold and silver colouration, respectively. The structural colour originates from chitin chirped multilayer sheets in the beetle cuticles (which prevent the propagation of right circularly polarized light). The co-existence of pigments and structural components enables a broad array of fascinating and adaptable colours (Chan, Mark, Sun-Waterhouse, & Waterhouse, 2014; Vandermeer, Chan, & Waterhouse, 2014). Thus, the protein and carbohydrate biopolymers in insects could be utilised not only as food nutrients but also as food materials that exhibit special and desirable visual appeal. The integration of nanotechnology and biotechnology through appropriate processing technologies will be key to the delivery of appealing insect food systems with optimised nutrient and bioactive profiles, potentially stimulating the next wave of R&D in the food sector.

5. Regulatory frameworks governing the safety of insect-based food products

As for any novel food, there is always an urgent need to establish and implement relevant regulatory frameworks, with a requirement for ongoing improvements of the implemented legislation. This is true for insects either harvested in the wild or raised on farms. When insects are utilised for finished foods and food ingredients, microbial, chemical, allergenic, parasitical and toxicological risks as well as potential food processing or handling hazards are anticipated over the entire process from

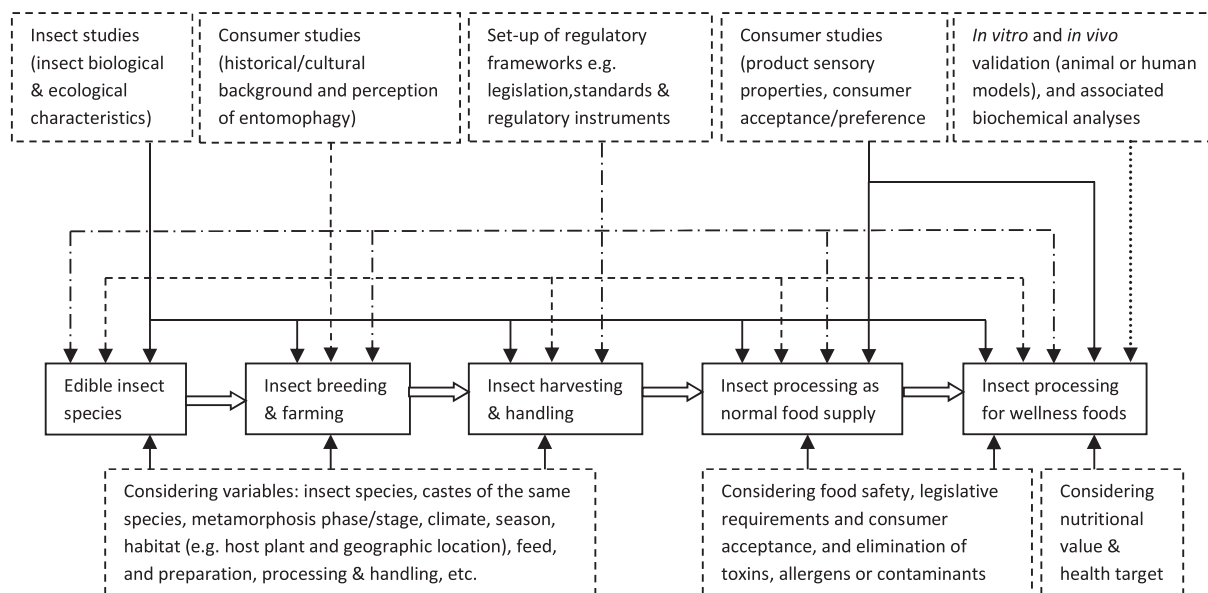


Fig. 5. A flow chart illustrating the development of insect-based food products.

insect selection and breeding, through insect farming and harvesting, to insect processing into foods (Fig. 5).

Although edible insects have been included in the human diet for millennia, care should be taken during the selection of edible insects (i.e. some insects like meloid beetles are outright dangerous, even lethal for humans). Insect production and trade for human consumption were seldom subjected to official management and assessment until January 2012 at the FAO Headquarters in Rome, Italy (<http://www.fao.org/edible-insects/86386/en/>). The lack of precise and insect-inclusive legislation, standards, labeling and other regulatory instruments remains a major barrier to globalised entomophagy, even though some good progress has achieved in this field. Food regulatory bodies including the European Food Safety Authority (EFSA), Food Standards Australia and New Zealand (FSANZ), US FDA and Health Canada have recently conducted extensive reviews and discussions on regulations and guidelines related to edible insects. In 2010, a proposal "Development of a Regional Standard for Edible Crickets and Their Products" (prepared by Lao PDR in the 17th session of FAO/WHO CCASIA) requested the set-up of standards for house crickets or other edible insect products for human consumption and food trade purposes (Laos, 2010). In late December 2013, ten insect species were authorized by the Belgian Food Safety Authority (FAVV, 2014). In July 2014, the European Commission asked EFSA to supply a scientific opinion on the risks of insect consumption, although some European researchers believed it unnecessary for insects to undergo pre-market safety assessment given their long history of safe use in non-EU countries. In October 2014, the Dutch Office for Risk Assessment & Research proposed, according to the General Food Law (Regulation 178/2002), to admit three insect species, *Tenebrio molitor*, *Alphitobius diaperinus* and *Locusta migratoria* (which are currently produced and sold in the Netherlands), in a report to the Inspector-General of the Netherlands Food and Consumer Product Safety Authority (in Dutch: 'NVWA') and the Dutch Ministers of Health Welfare and Sport and Agriculture.

In the EU, it has been suggested to use the Novel Food Regulation to monitor edible insect products (which requires a thorough safety assessment and final approval by food safety regulators prior to their launch in the market). In the US and Canada, a novel insect-derived product used as a food ingredient or additive (not wholesome insect) will be subject to petition for safety designation within the FDA and/or Health Canada regulatory framework (Health Canada, 2006; USFDA, 2009). In China, the Procedures for Toxicological Assessment of Food is applied to the assessment of the safety (along with the dose–response

relationship) of insect-based food products (as non-insect novel foods based on toxicity tests over various time lengths) (Zhou & Han, 2006). In terms of insect-based products for food services, there exists no legislation covering this segment, although the segment is feasible to be administered (at least in the initial stage through complying with the currently available regulations or practices). The federal law the Food Safety and Modernization Act of 2010 (S510/HR2751, 111th Congress) signed in January 2011 by President Barack Obama details voluntary management guidelines on food allergies and anaphylaxis especially for public kindergartens, elementary and secondary schools. Similarly, the EU Food Information for Consumers Regulation 1169/2011 established in December 2014 requires the inclusion of allergy information on food sold in unpackaged formats such as those commonly found in bakeries, catering outlets, deli counters and sandwich bars.

Regulatory frameworks including legislation, standards and associated regulatory bodies must be set up to guide, monitor, assure and govern the production, conservation, trade and use of edible insects as human food or animal feed. Insects are not perceived as a regular food. Specific codes of practice concerning biodiversity conservation, disease control, Integrated Pest Management (IPM), sanitation and pest eradication should be implemented to monitor insect breeding and farming, besides the standard food safety laws for the development of insect-based foods and ingredients. To date, well-established laws and regulations on biosecurity are available only for a few insects such as bee and silkworm. International standards such as the Codex Standards may facilitate compliance with food safety and trade rules for edible insect products although there are concerns on the lack of verifiable level of trade in insects. The Codex Alimentarius does not provide standards on fresh or processed insects for direct use as food and feed. But Codex standards, irrespective of their voluntary implementation, serve as reference legislation for the production and food application of insects through specifying "insects" as "dead or living filth" and "cause of abnormal flavours and odours" that may potentially harm human health at certain amounts. Legislative references that regulate the maximum permissible levels of insects as food impurities only fall into certain categories, e.g. the FDA's list of *Food Defect Action Levels* allows contamination of below 150 insect fragments per 100 g wheat flour, or 5 *Drosophila* and other fly eggs per 250 mL canned citrus fruit juice (FDA, 2011). In the recent years, there has been a push in the feed sector (including that in US and Europe) for the development of specific regulations and standards on using insects as feed and to a lesser degree as human food. Proposals have been made based on the concept of novel

foods to guide the development of legislation for insects as human food. In a few developed countries in Europe, the US and Canada, a premarket safety evaluation and authorization may be required for sale of some edible insects as a novel food or ingredient. Such efforts, however, have encountered barriers associated with the differences in the definition of a “novel food” between countries. While a substance (including an edible insect) may be novel in some countries, it may be part of a normal diet in other countries. Sometimes the differences in the description of novel foods reflect the extent of human ingestion and the degree of risk consideration, for example, a novel food is defined as “a food that does not have a history of human consumption in a region or country” by Australia and New Zealand (Australia New Zealand Food Standards Code – Standard 1.5.1), but “as a substance, including a microorganism, that does not have a history of safe use as food” by Canada (Canada's Food and Drug Regulations (C.R.C., c.870) – B.28.001).

Producing large quantities of suitable insects for human consumption will be challenging, while also widening regulatory frameworks of human foods globally. Establishing industrial-scale insect rearing farms and processing plants for human food and animal feed purposes won't be possible in the absence of appropriate globally agreed legislation. It is inevitable that existing legislation will need to be tweaked significantly, or a completely new array of legal frameworks covering scientifically-based and measurable guidelines will be required for insect breeding, sanitary regulations for mass-rearing of insects, quality standards and assurance guidelines on contaminants and nutritional compositions as well as assessments of product label and environmental impact. Knowledge of insect species consumed in human history will guide early legislative development. The potential risks (including out-of-control hazards) associated with insect production and release as a function of species or quantity, and the potential impact on health and biodiversity, should be carefully assessed during the development of regulatory frameworks. All legislative information including international standards should be accessible by insect producers, industry processors, users, distributors, traders and consumers through official publications or legal labels on product packaging. Failure in regulating the trade between countries of living insects as breeding stock could lead to global disasters impacting other food production or biodiversity of natural ecosystems. A preventive rather than reactive global legislative system containing dynamic and effective monitoring, verification, validation and corrective processes is desired. Global formalization of the edible insect sector and international harmonization of private or public standards and codes of practice should be the ultimate goal worldwide.

6. Conclusions

Edible insects represent a novel and sustainable protein source for humans and have enormous potential as ingredients for wellness foods. There is growing evidence to support the concept of “the use of insects for foods”. However, currently the demand for the development and commercialisation of insect-based foods remains very low. Therefore, conventional approaches for non-insect food product development are unlikely to work as straightforward solutions. Creating public demand and improving consumer acceptance and preference for insect-based foods will be critical for globalisation.

More consumer studies should be performed on the psychological and cultural barriers to eating insects. Eastern societies have traditionally been more accepting of edible insects than Western societies. Wider acceptance of insects or insect proteins in Western societies may help to pave the way towards realizing insects' full potential. Education and advocacy on the benefits of insect consumption, proper insect-based food processing for improved sensory properties and cost-effectiveness, regulatory rigor and openness to consumers, are the keys to successful globalisation of entomophagy.

Exploration and exploitation of edible insects as food sources will need ongoing R&D efforts. Industrial scale farming and processing

with successful integration of biotechnologies and processing technologies could fast track globalised entomophagy and create safe insect-based foods possessing high nutritional quality and bioactivities. Successful development of such insect-based foods will eventually overturn the negative perception or “unwelcome” attitudes of consumers towards insect foods. A new generation of chefs, farmers, sustainability experts and adventurous eaters will promote entomophagy, creating new consumers alongside conventional insect-eaters.

References

- Adamolekun, B. (1993). *Anaphe venata* entomophagy and seasonal ataxic syndrome in southwest Nigeria. *Lancet*, 341, 626.
- Adamolekun, B., McCandless, D. W., & Butterworth, R. F. (1997). Epidemic of seasonal ataxia in Nigeria following ingestion of the African silkworm *Anaphe venata*: role of thiamine deficiency? *Metabolic Brain Disease*, 12, 251–258.
- Ademolu, K. O., Idowu, A. B., & Olatunde, G. O. (2010). Nutritional value assessment of variegated grasshopper, *Zonocerus variegatus* (L.) (Acridoidea: Pygmoidea: Pygmoidea), during post-embryonic development. *African Entomology: Journal of the Entomological Society of Southern Africa*, 18(2), 360–364.
- Adeyemo, G. O., Longe, O. G., & Lawal, H. A. (2008). Effects of feeding desert locust meal (*Schistocerca gregaria*) on performance and haematology of broilers. *Hohenheim: Tropentag 2008*.
- Agbidiye, F. S., Ofuya, T. I., & Akindele, S. O. (2009). Marketability and nutritional qualities of some edible forest insects in Benue State, Nigeria. *Pakistan Journal of Nutrition*, 8, 917–922.
- Agea, J. G., Biryomumaisho, D., Buyinza, M., & Nabanoga, G. N. (2008). Commercialization of *Ruspolia nitidula* (Nsenene grasshoppers) in Central Uganda. *African Journal of Food Agriculture Nutrition and Development*, 8(3), 319–332.
- Ahn, Y.-Y., Ahnert, S. E., Bagrow, J. P., & Barabási, A.-L. (2011). Flavor network and the principles of food pairing. *Scientific Reports*, 1, 1–7.
- Akinlawo, O., & Ketiku, A. O. (2000). Chemical composition and fatty acid profile of edible larva of *Cirina forda* (Westwood). *African Journal of Biomedical Research*, 3, 93–96.
- Alegbeleye, W. O., Obasa, S. O., Olude, O. O., Otubu, K., & Jimoh, W. (2012). Preliminary evaluation of the nutritive value of the variegated grasshopper (*Zonocerus variegatus* L.) for African catfish *Clarias gariepinus* (Burchell, 1822) fingerlings. *Aquaculture Research*, 43, 412–420.
- Alemu, M. H., Olsen, S. B., Vedela, S. E., Pambob, K. O., & Owinoc, V. O. (2015). Consumer acceptance and willingness to pay for edible insects as food in Kenya: the case of white winged termites. IFRO Working Paper 2015/10; www.ifro.ku.dk/english/publications/foi_series/working_papers.
- Ali, T., Alam, A., & Ali, J. (2015). Market structure analysis of health and wellness food products in India. *British Food Journal*, 117(7), 1859–1871.
- Alves, A. V., Sanjinez Argandoña, E. J., Linzmeier, A. M., Cardoso, C. A., & Macedo, M. L. (2016). Chemical composition and food potential of *pachymerus nucleor* larvae parasitizing *acromia aculeata* kernels. *PLoS one*, 11(3), e0152125. PLoS: One. <http://dx.doi.org/10.1371/journal.pone.0152125>.
- Amadi, E. N., Ogbalu, O. K., Barimalaa, I. S., & Pius, M. (2005). Microbiology and nutritional composition of an edible larva (*Bunaea calcarata* Stoll) of the Niger Delta. *Journal of Food Safety*, 25, 193–197.
- Amar, Z. (2003). *The eating of locusts in Jewish tradition after the Talmudic period*. 11. (pp. 186–202). The Torah u-Madda J, 186–202.
- Anand, H., Ganguly, A., & Haldar, P. (2008). Potential value of acridids as high protein supplement for poultry feed. *International Journal of Poultry Science*, 7(7), 722–725.
- Anderson, A., & Cox, D. (2000). Five a day - challenges and achievements. *Journal of Nutrition & Food Sciences*, 30(1), 30–34.
- Anderson, A. S., Cox, D. N., McKellar, S., Reynolds, J., Lean, M. E. J., & Mela, D. J. (1998). Take five, a nutrition education intervention to increase fruit and vegetable intakes: Impact on attitudes towards dietary change. *The British Journal of Nutrition*, 80, 133–140.
- Arango Gutierrez, G. P., Vergara Ruiz, R. A., & Mejia Velez, H. (2004). Compositional, microbiological and protein digestibility analysis of larval meal of *Hermetia illucens* (Diptera: Stratiomyidae) at Angelópolis-Antioquia, Colombia. 57. (pp. 2491–2499). Rev. - Fac. Nacl. Agron. Med, 2491–2499.
- Auerswald, L., & Lopata, A. (2005). Insects - Diversity and allergy. *Current Allergy Reports*, 18, 58–60.
- Ayieko, M. A., Oriamo, V., & Nyambuga, I. A. (2010). Processed products of termites and lake flies: Improving entomophagy for food security within the Lake Victoria region. *African Journal of Food Agriculture Nutrition and Development*, 10(2), 2085–2098.
- Ayuso, R., Grishina, G., Bardina, L., Carrill, T., Blanco, C., Ibanez, M. D., ... Beyer, K. (2008). Myosin light chain is a novel shrimp allergen, Lit v3. *The Journal of Allergy and Clinical Immunology*, 122(4), 795–802.
- Ayuso, R., Grishina, G., Ibanez, M. D., Blanco, C., Carrillo, T., Bencharitwong, R., ... Sampson, H. A. (2009). Sarcoplasmic calcium-binding protein is an EF-hand-type protein identified as a new shrimp allergen. *The Journal of Allergy and Clinical Immunology*, 124(1), 114–120.
- Ayuso, R., Sanchez-Garcia, S., Lin, J., Fu, Z., Ibanez, M. D., Carrillo, T., ... Sampson, H. A. (2010). Greater epitope recognition of shrimp allergens by children than by adults suggests that shrimp sensitization decreases with age. *The Journal of Allergy and Clinical Immunology*, 125(6), 1286–1293.
- Bagnara, J. T., Fernandez, P. J., & Fujii, R. (2007). On the blue coloration of vertebrates. *Pigment Cell Research*, 20, 14–26.
- Barker, D., Fitzpatrick, M. P., & Dierenfeld, E. S. (1998). Nutrient composition of selected whole invertebrates. *Zoo Biology*, 17, 123–134.

- Barre, A., Caze-Subra, S., Gironde, C., Bienvenu, F., Bienvenu, J., & Rouge, P. (2014). Entomophagy and the risk of allergy. *Revue Française d'Allergologie*, 54(4), 315–321.
- Barrena, R., & Sánchez, M. (2013). Neophobia, personal consumer values and novel food acceptance. *Food Quality and Preference*, 27, 72–84.
- Bharucha, Z., & Pretty, J. (2010). The roles and values of wild foods in agricultural systems. *Philosophical Transactions of the Royal Society B*, 365, 2913–2926.
- Bhulaidok, S., Sihamala, O., Shen, L., & Li, D. (2010). Nutritional and fatty acid profiles of sun-dried edible black ants (*Polyrhachis vicina* Roger). *Maejo International Journal of Science and Technology*, 4, 101–112.
- Bodenheimer, F. S. (1951). *Insects as human food: A chapter of the ecology of man*. Dr. W. Junk, Publishers, the Hague, 352.
- Borgohain, M., Borkotoki, A., & Mahanta, R. (2014). Total lipid, triglyceride and cholesterol contents in *Oecophylla smaragdina*, Fabricius consumed in upper assam of north east India. *Journal of Scientific Research*, 4(7).
- Boyce, J. A., Assa'ad, A., Burks, A. W., Jones, S. M., Sampson, H. A., Wood, R. A., Plaut, M., Cooper, S. F., Fenton, M. J., Arshad, S. H., Bahna, S. L., Beck, L. A., Byrd-Bredbenner, C., Camargo, C. A., Eichenfield, L., Fu ruta, G. T., Hanifin, J. M., Jones, C., Kraft, M., Levy, B. D., Lieberman, P., Luccioli, S., McCall, K. M., Schneider, L. C., Simon, R. A., Simons, F. E., Teach, S. J., Yawn, B. P., & Schwaninger, J. M. (2010). Guidelines for the diagnosis and management of food allergy in the United States: Report of the NIAID-sponsored expert panel. *The Journal of Allergy and Clinical Immunology*, 126, S1–S58.
- Boye, J. I. (2012). Food allergies in developing and emerging economies: Need for comprehensive data on prevalence rates. *Clinical and Translational Allergy*, 2, 25. <http://dx.doi.org/10.1186/2045-7022-2-25>.
- Breiteneder, H., & Mills, E. N. (2005). Molecular properties of food allergen. *The Journal of Allergy and Clinical Immunology*, 115, 14–23.
- Brenna, O., Pompei, C., Ortolani, C., Pravettoni, V., Fariolo, L., & Pastorello, E. A. (2000). Technological processes to decrease the allergenicity of peach juice and nectar. *Journal of Agricultural and Food Chemistry*, 48, 493–497.
- Bristowe, W. S. (1932). Insects and other invertebrates for human consumption in Siam. *Trans. R. Entomol. Soc. Lon.*, 80(2), 387–404.
- Broekman, H., Knulst, A., Jager, S. D. H., Gaspari, M., Jong, G. D., Houben, G., & Verhoeckx, K. (2015). Shrimp allergic patients are at risk when eating mealworm proteins. *Clinical and Translational Allergy*, 5(Suppl 3), P77.
- Brown, W. V., Doyen, J. T., Moore, B. P., & Lawrence, J. F. (2007). Chemical composition and taxonomic significance of defensive secretions of some Australian Tenebrionidae (Coleoptera). *Australian Journal of Entomology*, 31(1), 79–89.
- Bruce, M. E., Will, R. G., Ironside, J. W., McConnell, I., Drummond, D., Suttie, A., ... Bostock, C. J. (1997). Transmissions to mice indicate that "new variant" CJD is caused by the BSE agent. *Nature*, 389(6650), 498–501.
- Bruijnzeel-Koomen, C., Ortolani, C., Aas, K., Bindslev-Jensen, C., Bjorksten, B., Moneret-Vautrin, D., & Wüthrich, B. (1995). Adverse reactions to food. *EAAI Allergy*, 50, 623.
- Bu, G., Lu, J., Zheng, Z., & Luo, Y. (2009). Influence of Maillard reaction conditions on the antigenicity of bovine α -lactalbumin using response surface methodology. *Journal of the Science of Food and Agriculture*, 89, 2428–2434.
- Buckner, J. S., Pitts-Singer, T. L., Guédot, C., Hagen, M. M., Fatland, C. L., & Kemp, W. P. (2009). Cuticular lipids of female solitary bees, *Osmia lignaria* Say and *Megachile rotundata* (F.) (Hymenoptera: Megachilidae). *Comparative Biochemistry and Physiology. Part B, Biochemistry & Molecular Biology*, 153(2), 200–205.
- Bukkens, S. G. F. (1997). The nutritional value of edible insects. *Ecology of Food and Nutrition*, 36, 287–319.
- Bukkens, S. G. F. (2005). Insects in the human diet: Nutritional aspects. In M. G. Paoletti (Ed.), *Ecological implications of minilivestock: role of rodents, frogs, snails, and Insects for sustainable development* (pp. 545–577). New Hampshire: Science Publishers.
- Cabanillas, B., Pedrosa, M. M., Rodríguez, J., Muzquiz, M., Maleki, S. J., Cuadrado, C., ... Crespo, J. F. (2012). Influence of enzymatic hydrolysis on the allergenicity of roasted peanut protein extract. *International Archives of Allergy and Immunology*, 157, 41–50.
- Cabanillas, B., Maleki, S. J., Rodríguez, J., Cheng, H., Teuber, S. S., Wallowitz, M. L., ... Crespo, J. F. (2014). Allergenic properties and differential response of walnut subjected to processing treatments. *Food Chemistry*, 157, 141–147.
- Canada, H. (2006). Food additives permitted for use in Canada. (Available at) http://www.hc-sc.gc.ca/fn-an/securit/addit/diction/dict_food-alim_add-eng.php (Accessed April, 2016)
- Caparros Megido, R., Sablon, L., Geuens, M., Brostaux, Y., Alabi, T., Blecker, C., ... Francis, F. (2014). Edible insects acceptance by Belgian consumers: Promising attitude for entomophagy development. *Journal of Sensory Studies*, 29, 14–20.
- Carnes, J., Ferrer, A., Huertas, A. J., Andreu, C., Larramendi, C. H., & Fernandez-Caldas, E. (2007). The use of raw or boiled crustacean extracts for the diagnosis of seafood allergic individuals. *Annals of Allergy, Asthma & Immunology*, 98(4), 349–354.
- Cerritos, R. (2009). Insects as food: An ecological, social and economical approach. CAB reviews: Perspectives in agriculture. *Veterinary Science. Nutr. Nat. Resour.*, 4(27), 1–10.
- Césard, N., Komatsu, S., & Iwata, A. (2015). Processing insect abundance: Trading and fishing of *zazamushi* in Central Japan (Nagano Prefecture, Honshū Island). *Journal of Ethnobiology and Ethnomedicine*, 11, 78. <http://dx.doi.org/10.1186/s13002-015-0066-7>.
- Chai, J. Y., Shin, E. H., Lee, S. H., & Rim, H. J. (2009). Foodborne intestinal flukes in southeast Asia. *The Korean Journal of Parasitology*, 47(Suppl.), S69–S102.
- Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. B. (2011). Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes of the state of Arunachal Pradesh (North-East India). *Journal of Ethnobiology and Ethnomedicine*, 7, 5.
- Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. B. (2013). Comparative survey of entomophagy and Entomotherapeutic practices in six tribes of Eastern Arunachal Pradesh (India). *Journal of Ethnobiology and Ethnomedicine*, 9, 50.
- Chakravorty, J., Ghosh, S., Jung, C., & Meyer-Rochow, V. B. (2014). Nutritional composition of *Chondracis rosea* and *Brachytrupes orientalis*: Two common insects used as food by tribes of Arunachal Pradesh, India. *Journal of Asia-Pacific Entomology*, 17(3), 407–415.
- Chan, A., Mark, C., Sun-Waterhouse, D., & Waterhouse, G. (2014). Now you see me...now you don't. *The 2014 University of Auckland research showcase*. New Zealand: Auckland.
- Chapman, M. D., Pome's, A., Breiteneder, H., & Ferreira, F. (2007). Nomenclature and structural biology of allergens. *The Journal of Allergy and Clinical Immunology*, 119(2), 414–420.
- Chen, X. M., & Feng, Y. (1999). *The edible insects of China* (1st ed.). Beijing, China: Science and Technology Publishing House.
- Chen, X., Feng, Y., & Chen, Z. (2009). Common edible insects and their utilization in China. *Entomological Research*, 39, 299–303.
- Cheseto, X., Kuate, S. P., Tchouassi, D. P., Ndung'u, M., Teal, P. E. A., & Torto, B. (2015). Potential of the desert locust *Schistocerca gregaria* (Orthoptera: Acrididae) as an unconventional source of dietary and therapeutic sterols. *PLoS One*, 10(5), e0127171. <http://dx.doi.org/10.1371/journal.pone.0127171>.
- Chiang, W. C., Kidon, M. I., Liew, W. K., Goh, A., Tang, J. P., & Chay, O. M. (2007). The changing face of food hypersensitivity in an Asian community. *Clinical and Experimental Allergy*, 37(7), 1055–1061.
- Cho, M. Y., Choi, H. W., Moon, G. Y., Kim, M. H., Kwon, T. H., Homma, K., ... Lee, B. L. (1999). An 86 kDa diapause protein 1-like protein is a component of early staged encapsulation-related proteins in coleopteran insect *Tenebrio molitor* larvae. *FEBS Letters*, 451(3), 303–307.
- Chouhan, B., & Poonar, N. (2016). Nutritional role of lipids in different dietary regimes of the surface grasshopper, *Chrotogonus trachyporus* blanch (Orthoptera: Acrididae) during nymphal and adult development. *Remarking, Vol-II, Issue-VIII, January*, 35–37.
- Chung, A. Y. C. (2010). Edible insects and entomophagy in Borneo. Edible insects in Lao market economy. *Forestinsects As Food: Humans Bite Back. Proceedings of A Workshop on Asia-Pacific Resources and Their Potential for Development*. (pp. 131–140).
- Chung, S. Y., Maleki, S. J., & Champagne, E. T. (2004). Allergenic properties of roasted peanut allergens may be reduced by peroxidase. *Journal of Agricultural and Food Chemistry*, 52, 4541–4545.
- Chung, M. Y., Yoon, Y. I., Hwang, J. S., Goo, T. W., & Yun, E. Y. (2014). Anti-obesity effect of *Allomyrina dichotoma* (Arthropoda: Insecta) larvae ethanol extract on 3T3-L1 adipocyte differentiation. *Entomological Research*, 44, 9–16.
- Clarke, J. E. (1998). Taste and flavour: Their importance in food choice and acceptance. *The Proceedings of the Nutrition Society*, 57, 639–643.
- Cociancich, S., Goyffon, M., Bontems, F., Bulet, P., Bouet, F., Menez, A., & Hoffmann, J. (1993). Purification and characterization of a scorpion defensin, a 4kDa antibacterial peptide presenting structural similarities with insect defensins and scorpion toxins. *Biochemical and Biophysical Research Communications*, 194(1), 17–22.
- Cociancich, S., Dupont, A., Hegy, G., Lanot, R., Holder, F., Hetru, C., ... Bulet, P. (1994). Novel inducible antibacterial peptide from a hemipteran insect, the sap sucking-bug *pyrrhocoris apterus*. *The Biochemical Journal*, 300(Part 2), 567–575.
- Cohen, J. H., Sánchez, N. D. M., & Montiel-Isinoet, F. D. (2009). Chapulines and food choices in rural Oaxaca. *Gastronomica*, 9(1), 61–65.
- Coll, J. F. C., Crespi, M. P. A. L., Itagiba, M. G. O. R., Souza, J. C. D., Gomes, A. V. C., & Donatti, F. C. (1992). Utilization of silkworm pupae meal (*Bombyx mori* L.) as a source of protein in the diet of growing-finishing pigs. *Revista da Sociedade Brasileira de Zootecnia*, 21, 378–383.
- Collavo, A., Glew, R. H., Huang, Y. S., Chuang, L. T., Bosse, R., & Paoletti, M. G. (2005). House cricket small-scale farming. In M. G. Paoletti (Ed.), *Ecological implications of minilivestock: Potential of insects, rodents, frogs and snails* (pp. 519–544). New Hampshire: Science Publishers.
- Comby, B. (1990). *Délicieux insectes*. In *Les Protéines Du Futur* (1st ed.). Geneve, Switzerland: Editions Jouvence, 105–119.
- Costermans, J. B. (1955). Het termieten-stoken bij de Logo-Avokaya (vervolg). *Aequatoria*, 18(2), 50–55.
- Cox, D. N., & Evans, G. (2008). Construction and validation of a psychometric scale to measure consumers' fears of novel food technologies: The food technology neophobia scale. *Food Quality and Preference*, 19, 704–710.
- Cui, Y. J. (2009). Research and development of ant products. *Food Nutr. China*, 4, 18–20.
- Dai, C., Ma, H., Luo, L., & Yin, X. (2013). Angiotensin I-converting enzyme (ACE) inhibitory peptide derived from *Tenebrio molitor* (L.) larva protein hydrolysate. *European Food Research and Technology*, 236, 681–689.
- D'Alba, L., Kieffer, L., & Shawkey, M. D. (2012). Relative contributions of pigments and biophotonic nanostructures to natural color production: A case study in budgerigar (*Melopsittacus undulatus*) feathers. *The Journal of Experimental Biology*, 215, 1272–1277.
- De Almeida, M. D. V., Graca, P., Lappalainen, R., & Kearney, J. M. (1997). Sources used and trusted by nationally-representative adults in the European Union for information on healthy eating. *European Journal of Clinical Nutrition*, 51(Suppl.2), S16–S22.
- De Angelis, M., Rizzello, C. G., Scala, E., De Simone, C., Farris, G. A., Turroni, F., & Gobbetti, M. (2007). Probiotic preparation has the capacity to hydrolyze proteins responsible for wheat allergy. *Journal of Food Protection*, 70, 135–144.
- De Boer, J., Schöslér, H., & Boersema, J. J. (2013). Motivational differences in food orientation and the choice of snacks made from lentils, locusts, seaweed or "hybrid" meat. *Food Quality and Preference*, 28, 32–35.
- De Figueiredo, R. E. C. R., Vasconcellos, A., Policarpo, I. S., & Alves, R. R. N. (2015). Edible and medicinal termites: A global overview. *Journal of Ethnobiology and Ethnomedicine*, 11(1), 29. <http://dx.doi.org/10.1186/s13002-015-0016-4>.
- De Irala-Estevez, J., Groth, M., Johansson, L., Oltersdorf, U., Prattala, R., & Martinez-Gonzalez, M. A. (2000). A systematic review of socioeconomic differences in food habits in Europe: Consumption of fruit and vegetables. *European Journal of Clinical Nutrition*, 54, 706–714.
- De Pasquale, C., Guarino, S., Peri, E., Alonzo, G., & Colazza, S. (2007). Investigation of cuticular hydrocarbons from *Bagrada hilaris* genders by SPME/GC–MS. *Analytical and Bioanalytical Chemistry*, 389(4), 1259–1265.

- DeFoliart, G. R. (1992). Insects as human food. *Crop Protection*, 11, 395–399.
- DeFoliart, G. R. (1999). Insects as food: Why the western attitude is important. *Annual Review of Entomology*, 44, 21–50.
- DeFoliart, G. R. (2012). Insects as a global food resource: The history of talking about it at the University of Wisconsin. <http://labs.russell.wisc.edu/insectasfood/files/2012/09/Manuscript.pdf> (Accessed 6 April 2016)
- Denery-Papini, S., Bodinier, M., Larré, C., Brossard, C., Pineau, F., Triballeau, S., ... Moneret-Vautrin, D. A. (2012). Allergy to deamidated gluten in patients tolerant to wheat: Specific epitopes linked to deamidation. *Allergy*, 67, 1023–1032.
- Deroy, O., Reade, B., & Spence, C. (2015). The insectivore's dilemma, and how to take the West out of it. *Food Quality and Preference*, 44, 44–55.
- Devine, C. M., Connors, M. M., Sobal, J., & Bisogni, C. A. (2003). Sandwiching it in: Spillover of work onto food choices and family roles in low- and moderate-income urban households. *Social Science & Medicine*, 56, 617–630.
- Dewberry, C., & Ussher, J. M. (1994). Restraint and perception of body weight among British adults. *The Journal of Social Psychology*, 134(5), 609–619.
- Diamond, J. M. (2005). *Guns, germs and steel: A short history of everybody for the last 13000 years*. London, UK: Vintage.
- Dibsdall, L. A., Lambert, N., Bobbin, R. F., & Frewer, L. J. (2003). Low-income consumers' attitudes and behaviour towards access, availability and motivation to eat fruit and vegetables. *Public Health Nutrition*, 6(2), 159–168.
- Diclaro, J. W., II, & Kaufman, P. E. (2009). *Black soldier fly Hermetia illucens Linnaeus (Insecta: Diptera: Stratiomyidae)*. EENY-461, Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
- Ding, H., Zhang, X. M., Wei, X. B., Zhu, Q. F., Deng, S. H., & Wu, B. J. (2001). The effect of PUFAs in silkworm pupa oil on serum lipids, EPA and DHA levels in rats. *Acta Academiae Medicinae Shandong*, 39(5), 455–459.
- Donkin, A. J., Dowler, E. A., Stevenson, S. J., & Turner, S. A. (2000). Mapping access to food in a deprived area: The development of price and availability indices. *Public Health Nutrition*, 3(1), 31–38.
- Dossey, A. T. (2010). Insects and their chemical weaponry: New potential for drug discovery. *Natural Product Reports*, 27(12), 1737–1757.
- Dovey, T. M., Staples, P. A., Gibson, E. L., & Halford, J. C. (2008). Food neophobia and "picky/fussy" eating in children: A review. *Appetite*, 50(2–3), 181–193.
- Durst, P. B., Leslie, R. N., & Shono, K. (2008). *Forest Insect as Food: Humans Bite Back*. Chiang Mai: FAO. Regional Office for Asia and the Pacific.
- Egert, M., Wagner, B., Lemke, T., Brune, A., & Friedrich, M. W. (2003). Microbial community structure in midgut and hindgut of the humus-feeding larva of *Pachnoda ephippiata* (Coleoptera: Scarabaeidae). *Applied and Environmental Microbiology*, 69(11), 6659–6668.
- Fagoonée, I. (1983a). Inclusion of silkworm pupae in poultry rations. *Tropical Veterinarian Journal*, 1, 91–96.
- Fagoonée, I. (1983b). Possible growth factors for chickens in silkworm pupae meal. *British Poultry Science*, 24, 295–300.
- Fallon, A. E., & Rozin, P. (1983). The psychological bases of food rejections by humans. *Ecology of Food and Nutrition*, 13(1), 15–26.
- FAO (2003). *State of forest and tree genetic resources in dry zone Southern Africa development community countries*. Rome, Italy: Forest Resources Development Service, Forest Resources Division, Forestry Department.
- FAO (2012). Composition database for Biodiversity Version 2, BioFoodComp2. (Latest update: 06 August 2014). Accessed May 2016) <http://www.fao.org/docrep/017/ap814e/ap814e.pdf>
- Farina, L., Demey, F., & Hardouin, J. (1991). Production de termites pour l'aviculture villageoise au Togo. *Tropicalicultura*, 9(4), 181–187.
- Fasoranti, J. O., & Ajiboye, D. O. (1993). Some edible insects of Kwara State, Nigeria. *American Entomologist*, 39(2), 113–116.
- Faugier, J., Lancaster, J., Pickles, D., & Dobson, K. (2001). Barriers to healthy eating in the nursing profession: Part 2. *Nursing Standard*, 15(37), 33–35.
- FAVV (2014). Omzendbrief betreffende het kweken en in de handel brengen van insecten en levensmiddelen op basis van insecten voor humane consumptie [Circular concerning the production and trade of insects and food stuffs based on insects for human consumption]. (dated May 21, 2014) Brussels: Federaal Agentschap voor de Veiligheid van de Voedselketen (FAVV) http://www.afsca.be/levensmiddelen/omzendbrieven/_documents/2014-05-21_Omzendbriefinsecten_versie11.pdf
- FDA (2011). Defect levels handbook. <http://www.fda.gov/food/guidanceregulation/ucm056174.htm> (Accessed May 2016)
- Fecheyr-Lippens, D. C., Igic, B., D'Alba, L., Hanley, D., Verdes, A., Holford, M., ... Shawkey, M. D. (2015). The cuticle modulates ultraviolet reflectance of avian eggshells. *Biology Open*. <http://dx.doi.org/10.1242/bio.012211>
- Feng, Y., Zhao, M., He, Z., Chen, Z., & Sun, L. (2009). Research and utilisation of medicinal insects in China. *Entomological Research*, 39, 313–316.
- Feunekes, G. I. J., de Graaf, C., Meyboom, S., & van Staveren, W. A. (1998). Food choice and fat intake of adolescents and adults: Associations of intakes within social networks. *Preventive Medicine*, 27, 645–656.
- Finke, M. D. (2002). Complete nutrient composition of commercially raised invertebrates used as food for insectivores. *Zoo Biology*, 21(3), 269–285.
- Finke, M. D. (2007). Estimate of chitin in raw whole insects. *Zoo Biology*, 26, 105–115.
- Finke, M. D. (2008). Nutrient content of insects. *Encyclopedia of entomology* (pp. 2623–2646). Netherlands: Springer.
- Finke, M. D., & Onioncin, D. (2014). Insects as food for insectivores. In M. G. R. Juan Morales-Ramos, & D. Shapiro-Ilan (Eds.), *Mass production of beneficial organisms, chapter 17* (pp. 583–616). San Diego: Academic Press.
- Finke, M. D., DeFoliart, G., & Benevenga, N. J. (1989). Use of a four-parameter logistic model to evaluate the quality of the protein from three insect species when fed to rats. *The Journal of Nutrition*, 119, 864–871.
- Frias, J., Song, Y. S., Martínez-Villaluenga, C., Gonzalez de Mejia, E., & Vidal-Valverde, C. (2008). Fermented soyabean products as hypoallergenic food. *Proceedings of the Nutrition Society*, 67(OCE), E39.
- García-Orozco, K. D., Aispuro-Hernandez, E., Yepiz-Plascencia, G., Calderon-de-la-Barca, A. M., & Sotelo-Mundo, R. R. (2007). Molecular characterization of arginine kinase, an allergen from the shrimp *Litopenaeus Vannamei*. *International Archives of Allergy and Immunology*, 144(1), 23–28.
- Gardiner, A. J., & Gardiner, E. M. (2003). Edible insects, part 1. Preparation of species from Mushumbi pools. *Zimbabwe. Afr. Entomol.*, 11, 125–127.
- Ghazoul, J. (2006). *Mopani woodlands and the mopane worm: enhancing rural livelihoods and resource sustainability. Final technical report*. London: DFID.
- Ghosh, S., Haldar, P., & Mandal, D. K. (2016). Evaluation of nutrient quality of a short horned grasshopper, *Oxya hyla* Serville (Orthoptera: Acrididae) in search of new protein source. *J. Entomol. Zool. Studies*, 4(1), 193–197.
- Ginzl, M. D., Moreira, J. A., Ray, A. M., Millar, J. G., & Hanks, L. M. (2006). (Z)-9-Nonacosene—major component of the contact sex pheromone of the beetle *Megacyllene caryae*. *Journal of Chemical Ecology*, 32(2), 435–451.
- Glew, R. H., Jackson, D., Sena, L., Vanderjagt, D. J., Pastuszyn, A., & Millson, M. (1999, winter). *Gonimbrasia belina* (Lepidoptera: Saturniidae), a nutritional food source rich in protein, fatty acids and minerals. *American Entomologist*, 45(4), 250–253.
- Göhl, B. (1982). *Les aliments du bétail sous les tropiques*. Roma, Italy: FAO, Division de Production et Santé Animale.
- Gomes, A., Alam, M. A., Bhattacharya, S., Dasgupta, S. C., Mukherjee, S., Bhattacharya, S., & Gomes, A. (2011). Ethno biological usage of zoo products in rheumatoid arthritis. *Indian Journal of Experimental Biology*, 49(8), 565–573.
- Gowda Ramana, N. K. S., Prasad, J. V., & Khub Singh, C. S. (2004). Micronutrient content of certain tropical conventional and unconventional feed resources of Southern India. *Tropical Animal Health and Production*, 36(1), 77–94.
- Graczyk, T. K., & Knight, R. L. (2005). Mechanical transmission of human protozoan parasites by insects. *Clinical Microbiology Reviews*, 18(1), 128–132.
- Graham, L. A., Liou, Y. -C., Walker, V. K., & Davies, P. L. (1997). Hyperactive antifreeze protein from beetles. *Nature*, 388(6644), 727–728.
- Guo, Q., Zhang, J., Guimei, H. E., & Liu, N. (2011). Study on extraction and antioxidant activity analysis of barley pest protein. *Acta Agric Boreali-Occident Sinica*, 20, 188–192.
- Hackstein, J. H., & Stumm, C. K. (1994). Methane production in terrestrial arthropods. *Proceedings of the National Academy of Sciences of the United States of America*, 91(12), 5441–5445.
- Halpern, G. M., & Miller, A. (2002). *Medicinal mushrooms: Ancient remedies for modern ailments* (pp. 64–65). New York: M. Evans and Company, Inc.
- Han, D.X., Zhou, J., Xu, H.B., Dong, X.Z., & Chen, M.Y. (2004). Liver protective health food made of *Ligustrum lucidum* Ait. and silkworm pupae and its preparation method (pp. 1–8). China patent, 03128111.7.
- Han, Y., Kim, J., & Ahn, K. (2012). Food allergy. *Korean Journal of Pediatrics*, 55(5), 573–583.
- Hanboonsong, Y., Jamjanya, T., & Durst, P. B. (2013). *Six-legged livestock: Edible insect farming, collecting and marketing in Thailand*. Rap Publication.
- Handley, M. A., Hall, C., Sanford, E., Diaz, E., Gonzalez-Mendez, E., Drace, K., ... Croughan, M. (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(5), 900–906.
- Hardouin, J., & Mahoux, G. (2003). *Zootecnie d'insectes – Elevage et utilisation au bénéfice de l'homme et de certains animaux. Bureau pour l'Echange et la Distribution de l'Information sur le Mini-élevage (BEDIM)*, 164.
- Hartmann, C., Shi, J., Giusto, A., & Siegrist, M. (2015). The psychology of eating insects: A cross-cultural comparison between Germany and China. *Food Quality and Preference*, 44, 148–156.
- He, J. Z., Tong, Q., Huang, X. H., & Zhou, Z. H. (1999). Nutritive composition analysis of moths of *Dendrolimus houi* Lajongquiere. *Entomol. Knowledge*, 36, 83–86.
- Headings, M. E., & Rahnama, S. (2002, November 20). *The nutritional value of mopane worms, Gonimbrasia belina (Lepidoptera: Saturniidae) for human consumption*. Presentation at the Ten-Minute Papers: Section B. Physiology, Biochemistry, Toxicology and Molecular Biology Series, Ohio, USA: Ohio State University.
- Henrikson, L. S., Yohe, R. M., II, Newman, M. E., & Druss, M. (1998). Freshwater crustaceans as an Aboriginal food resource in the Northern Great Basin. *Journal of California and Great Basin Anthropology*, 20, 72–87.
- Herrero, M., Wirsenius, S., Henderson, B., Riglot, C., Thornton, P., Havlík, P., ... Gerber, P. J. (2015). Livestock and the environment: What have we learned in the past decade? *Annual Review of Environment and Resources*, 40, 177–202.
- Hildebrandt, S., Kratzin, H. D., Schaller, R., Fritsché, R., Steinhart, H., & Paschke, A. (2008). In vitro determination of the allergenic potential of technologically altered hen's egg. *Journal of Agricultural and Food Chemistry*, 56, 1727–1733.
- Hoek, A. C., Luning, P. A., Weijzen, P., Engels, W., Kok, F. J., & de Graaf, C. (2011). Replacement of meat by meat substitutes. A survey on person- and product-related factors in consumer acceptance. *Appetite*, 56, 662–673.
- Hoell, H.V., Doyen, J.T., & Purcell, A.H. (1998). Introduction to insect biology and diversity (2nd ed., pp. 392–394). New York, US: Oxford University Press. ISBN 0-19-510033-6.
- Hossain, M. A., Islam, M. N., & Alim, M. A. (1993). Evaluation of silkworm pupae meal as dietary protein source for catfish (*Heteropneustes fossilis* Bloch). *Fish nutrition in practice: 4th international symposium on fish nutrition and feeding*. Biarritz, France, June 24–27, 1991 (pp. 785–779).
- Hossain, M. A., Nahar, N., & Kamal, M. (1997). Nutrient digestibility coefficients of some plant and animal proteins for rohu (*Labeo rohita*). *Aquaculture*, 151, 37–45.
- Hu, H., Wang, C., Guo, X., Li, W., Wang, Y., & He, Q. (2013). Broad activity against porcine bacterial pathogens displayed by two insect antimicrobial peptides moricin and cecropin B. *Molecular Cell*, 35, 106–114.

- Huang, H. -W., Hsu, C. -P., Yang, B. B., & Wang, C. -Y. (2014). Potential utility of high-pressure processing to address the risk of food allergen concerns. *Comprehensive Reviews in Food Science and Food Safety*, 13, 78–90.
- IFT (Institute of Food technologists) (2011). URL: <http://www.ift.org/community/students/competitions/developing-solutions-for-developing-countries.aspx> (Accessed April 2016).
- Igic, B., Fecheyr-Lippens, D., Xiao, M., Chan, A., Hanley, D., Brennan, P. R. L., ... Shawkey, M. D. (2014). A nanostructural basis for gloss of avian eggshells. *Journal of the Royal Society, Interface*. <http://dx.doi.org/10.1098/rsif.2014.1210>.
- Ioselevich, M., Steingaß, H., Rajamurodov, Z., & Drochner, W. (2004). *Nutritive value of silkworm pupae for ruminants. VDLUFA Kongress, Qualitätssicherung in landwirtschaftlichen Produktionssystemen, Rostock, 2004/09/13-17*, 116 (108 pp.).
- Iwan, M., Vissers, Y. M., Fiedorowicz, E., Kostyra, H., Kostyra, E., Savelkoul, H. F., & Wichers, H. J. (2011). Impact of Maillard reaction on immunoreactivity and allergenicity of the hazelnut allergen Cor a 11. *Journal of Agricultural and Food Chemistry*, 59, 7163–7171.
- Jintastaporn, O. (2012). Production performance of broiler chickens fed with silkworm pupa (*Bombyx mori*). *Journal of Agricultural Science and Technology A*, 2, 505–510.
- Jones, L. D., Cooper, R. W., & Harding, R. S. (1972). Composition of mealworm *Tenebrio molitor* larvae. *Journal of Zoo Animal Medicine*, 3(4), 34–41.
- Jongema, Y. (2015). List of edible insect species of the world. <http://www.ent.wur.nl/UK/Edible+insects/Worldwide+species+list/> (Accessed 2 August 2016)
- Julietta, R. E., Neto, E. M. C., Pino, J. M., Correa, M. D. S. C., Javier, G. F., & Zetina, D. H. (2007). Knowledge about useful entomofauna in the county of La Purísima Palmar de Bravo, Puebla State, Mexico. *Biotemas*, 20(2), 121–134.
- Katayama, N., Ishikawa, Y., Takaoki, M., Yamashita, M., Nakayama, S., Kiguchi, K., ... Mitsuhashi, J. (2008). Entomophagy: A key to space agriculture. *Advances in Space Research*, 41(5), 701–705.
- Kearney, M., Gibney, M. J., Martinez, J. A., de Almeida, M. D. V., Friebe, D., Zunft, H. J. F., ... Kearney, J. M. (1997). Perceived need to alter eating habits among representative samples of adults from all member states of the European Union. *European Journal of Clinical Nutrition*, 51, S30–S35.
- Kearney, M., Kearney, J. M., Dunne, A., & Gibney, M. J. (2000). Sociodemographic determinants of perceived influences on food choice in a nationally representative sample of Irish adults. *Public Health Nutrition*, 3(2), 219–226.
- Kellert, S. R. (1993). Values and perceptions of invertebrates. *Conservation Biology*, 7(4), 845–855.
- Kinyuru, J. N., Kenji, G. M., & Njoroge, M. S. (2009). Process development, nutrition and sensory qualities of wheat buns enriched with edible termites (*Macrotermes subhyalinus*) from Lake Victoria region, Kenya. *African Journal of Food Agriculture Nutrition and Development*, 9(8), 1739–1750.
- Kinyuru, J. N., Kenji, G. M., Njoroge, S. M., & Ayieko, M. (2010). Effect of processing methods on the in vitro protein digestibility and vitamin content of edible winged termite (*Macrotermes subhyalinus*) and grasshopper (*Ruspolia differens*). *Food and Bioprocess Technology*, 3(5), 778–782.
- Klasing, K. C., Thacker, P., Lopez, M. A., & Calvert, C. C. (2000). Increasing the calcium content of mealworms (*Tenebrio molitor*) to improve their nutritional value for bone mineralization of growing chicks. *Journal of Zoo and Wildlife Medicine*, 31, 512–517.
- Klunder, H. C., Wolkers-Rooijackers, J., Korpela, J. M., & Nout, M. J. R. (2012). Microbiological aspects of processing and storage of edible insects. *Food Control*, 26(2), 628–631.
- Koç, K., Incekara, Ü., & Türkez, H. (2014). In vitro biomonitoring of the potential of genotoxic and oxidative effects of commercial edible dung beetles (*Onitis* sp.), flying grasshopper (*Caelifera* sp.) and mole crickets (*Gryllotalpa* sp.). *Toxicology and Industrial Health*, 30(8), 683–689.
- Kvassay, G. (2014). Heating and storage. *The complete cricket breeding manual* (pp. 75–76) (3rd ed.). New South Wales, Australia: Zega Enterprises (Chapter 6).
- Ladron de Guevara, O., Padilla, P., Garcia, L., Pino, J. M., & Ramos-Elorduy, J. (1995). Amino acid determination in some edible Mexican insects. *Amino Acids*, 9, 161–173.
- Lamberty, M., Zachary, D. R., Bordenau, C., Robert, A., Hoffmann, J., & Bulet, P. (2001). Insect immunity: constitutive expression of a cysteine-rich antifungal and a linear anti-bacterial peptide in a termite insect. *The Journal of Biological Chemistry*, 276(6), 4085–4092.
- Laos (2010). *Agenda item 13: Comments of Lao PDR: Proposal for the new work and development of regional standard for edible crickets and their products (CRD 8) 17th session of the FAO/WHO coordinating Committee for Asia (CCASIA)*. Indonesia: Bali.
- Larson, N., & Story, M. (2009). A review of environmental influences on food choices. *Annals of Behavioral Medicine*, 38, S56–S73.
- Lee, J. W., Seo, J. H., Kim, J. H., Lee, S. Y., & Byun, M. W. (2007). Comparison of the changes of the antigenicities of a hen's egg albumin by a gamma and an electron beam irradiation. *Radiation Physics and Chemistry*, 76, 879–885.
- Lensvelt, E. J., & Steenbekkers, L. P. (2014). Exploring consumer acceptance of entomophagy: A survey and experiment in Australia and the Netherlands. *Ecology of Food and Nutrition*, 53(5), 543–561.
- Leung, P. S., Chow, W. K., Duffey, S., Kwan, H. S., Gershwin, M. E., & Chu, K. H. (1996). IgE reactivity against a cross-reactive allergen in crustacea and mollusca: Evidence for tropomyosin as the common allergen. *The Journal of Allergy and Clinical Immunology*, 98(5 Pt 1), 954–961.
- Leung, P. S., Chen, Y. C., Gershwin, M. E., Wong, S. H., Kwan, H. S., & Chu, K. H. (1998). Identification and molecular characterization of *Charybdis feriatris* tropomyosin, the major crab allergen. *The Journal of Allergy and Clinical Immunology*, 102(5), 847–852.
- Li, L., & Li, X. F. (2010). Analysis of nutritional components of *Aspongopus chinensis* in Guizhou. *Kunchong Zhishi*, 47, 748–751.
- Li, B., Predel, R., Neupert, S., Hauser, F., Tanaka, Y., Cazzamali, G., ... Park, Y. (2008). Genomics, transcriptomics, and peptidomics of neuropeptides and protein hormones in the red flour beetle *Tribolium castaneum*. *Genome Research*, 18, 113–122.
- Li, Z., Lin, H., Cao, L. M., & Jameel, K. (2006). Effect of high intensity ultrasound on the allergenicity of shrimp. *Journal of Zhejiang University. Science. B*, 7(4), 251–256.
- Li, H. C., Ji, Z. X., Gao, S. H., & Liu, S. -J. (2007a). The nutrition and health functional of *Tenebrio molitor*. *Hebei Normal University of Science and Technology*, 21(3), 17–21.
- Li, Z., Lin, H., Cao, L., & Jamil, K. (2007b). The influence of gamma irradiation on the allergenicity of shrimp (*Penaeus vannamei*). *Journal of Food Engineering*, 79(3), 945–949.
- Li, H., Zhu, K., Zhou, H., & Peng, W. (2012). Effects of high hydrostatic pressure treatment on allergenicity and structural properties of soybean protein isolate for infant formula. *Food Chemistry*, 132, 808–814.
- Limpeanchob, N., Trisat, K., Duangjai, A., Tiyafoonchai, W., Pongcharoen, S., & Suthewattananonda, M. (2010). Sericin reduces serum cholesterol in rats and cholesterol uptake into caco-2 cells. *Journal of Agricultural and Food Chemistry*, 58(23), 12519–12522.
- Lin, Q., & Li, X. (2008). Effect of scorpion venom analgesic active peptide extracted from *Buthus martensii* Karsch on evoked potential in the thalamic posterior nucleus group in rats. *Neural Regeneration Research*, 3(4), 453–455.
- Lin, W., Somwaru, A., Tuan, F., Huang, J., & Bai, J. (2007). Consumers' willingness to pay for biotech foods in China: A contingent valuation approach. *AgBioforum*, 9(3), 166–179.
- Liu, L. P., & Yu, J. P. (2008). Analysis and evaluation of nutritional of *Aspongopus chinensis* Dallas. *Shipin Xue*, 29, 406–410.
- Liu, X. D., Tian, J. J., & Chen, D. M. (2001). An allergic shock case resulted from consuming the silkworm pupae. *Chinese Recuperative Medicine*, 10(2), 80.
- Longvah, T., Mangthya, K., & Ramulu, P. (2011). Nutrient composition and protein quality evaluation of eri silkworm (*Samia ricinii*) prepupae and pupae. *Food Chemistry*, 128, 400–403.
- Looy, H., Dunkel, F. V., & Wood, J. R. (2014). How then shall we eat? Insect-eating attitudes and sustainable foodways. *Agriculture and Human Values*, 31(1), 131–141.
- López, E., Cuadrado, C., Burbano, C., Jimenez, M. A., Rodriguez, J., & Crespo, J. F. (2012). Effects of autoclaving and high pressure on allergenicity of hazelnut proteins. *Journal of Clinical Bioinformatics*, 2, 12. <http://dx.doi.org/10.1186/2043-9113-2-12>.
- Lowe, C. F., Horne, P. J., Tapper, K., Bowdery, M., & Egerton, C. (2004). Effects of a peer modelling and rewards-based intervention to increase fruit and vegetable consumption in children. *European Journal of Clinical Nutrition*, 58(3), 510–522.
- Makkar, H. P. S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 197, 1–33.
- Mangialardo, S., Piccirilli, F., Perucchi, A., Dore, P., & Postorino, P. (2012). Raman analysis of insulin denaturation by high-pressure and thermal treatments. *Journal of Raman Spectroscopy*, 43(6), 692–700.
- Manzocco, L., & Nicoli, M. C. (2012). Macromolecular crowding affects protein photosensitivity: The case of egg white immunoreactivity. *Food Chemistry*, 132, 982–988.
- Marion, A. A. (2013). Insect oil and protein: Biochemistry, food and other uses: Review. *Agricultural Sciences*, 4, 76–80.
- Marion, A. A., & Fadul, H. (2015). Extraction and characterization of gelatin from two edible Sudanese insects and its applications in ice cream making. *Food Science and Technology International*, 21(5), 380–391.
- Martin, R. D., Rivers, J. P. W., & Cowgill, U. M. (1976). Culturing mealworms as food for animals in captivity. *International Zoo Yearbook*, 16(1), 63–70.
- Martins, Y., & Pliner, P. (2005). Human food choices: An examination of the factors underlying acceptance/rejection of novel and familiar animal and nonanimal foods. *Appetite*, 45(3), 214–224.
- Meyer-Rochow, V. B. (1975). Can insects help to ease the problem of world foodshortage? *Search*, 6, 261–262.
- Meyer-Rochow, V. B. (2009). Food taboos: Their origins and purposes. *Journal of Ethnobiology and Ethnomedicine*, 5, 18.
- Meyer-Rochow, V. B. (2013). Ethno-entomological observations from North Korea (officially known as the "Democratic People's Republic of Korea"). *Journal of Ethnobiology and Ethnomedicine*, 9, 7.
- Meyer-Rochow, V. B., & Changkija, S. (1997). Uses of insects as human food in Papua New Guinea, Australia, and North-East India: Cross-cultural considerations and cautious conclusions. *Ecology of Food and Nutrition*, 36(2–4), 159–185.
- Meyer-Rochow, V. B., Okui, K., Henshall, K., & Brook, D. L. (2000). The mental concept of "worm/bug" in Japanese and English idioms. *J. Finn. Anthropol. Soc.*, 25, 29–40.
- Mitsuhashi, J. (1997). Insects as traditional foods in Japan. *Ecology of Food and Nutrition*, 36(2–4), 187–199.
- Mitsuhashi, J. (2008). *The complete world of entomophagy*. Tokyo: Yasaka Shobo Inc.
- Mitsuhashi, J. (2010). The future use of insects as human food. In P. B. Durst, D. V. Johnson, R. N. Leslie, & K. Shono (Eds.), *Forest insects as food: Humans bite back* (pp. 115–122). *Proceedings of a workshop on Asia-Pacific resources and their potential for development*. (pp. 19–21). Chiang Mai, Thailand: Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific (February 2008).
- Molavi, G. H., Massoud, J., & Gutierrez, Y. (2006). Human Gongylonema infection in Iran. *Journal of Helminthology*, 80(4), 425–428.
- Musundire, R., Osuma, I. M., Cheseto, X., Irungu, J., & Torto, B. (2016). Aflatoxin contamination detected in nutrient and anti-oxidant rich edible stink bug stored in recycled grain containers. *PLoS One*, 11(1), e0145914. <http://dx.doi.org/10.1371/journal.pone.0145914>.
- Muzzarelli, R. A. A., Terbojevich, M., Muzzarelli, C., Miliani, M., & Francescangeli, O. (2001). Partial depolymerization of chitosan with the aid of papain. In R. A. A. Muzzarelli (Ed.), *Chitin enzymology* (pp. 405–414). Grottole, Italy: Atec. Edizioni.
- Narang, M. P., & Lal, R. (1985). Evaluation of some agro-industrial wastes in the feed of jersey calves. *Agricultural Wastes*, 13, 15–21.
- Neves, A. T. S. G. (2015). *Determinants of consumers' acceptance of insects as food and feed: A cross-cultural study*. Faculty of Sciences: University of Porto.
- New, T. R. (2009). *Insect species conservation by ecology, biodiversity and conservation series*. Cambridge: Cambridge University Press.
- Newton, G. L., Booram, C. V., Barker, R. W., & Hale, O. M. (1977). Dried *Hermetia illucens* larvae meal as a supplement for swine. *Journal of Animal Science*, 44, 395–400.
- Newton, L., Sheppard, C., Watson, D. W., Burtie, G., & Dove, R. (2005). Using the black soldier fly, *Hermetia illucens*, as a value-added tool for the management of swine manure.

- Report for Mike Williams, Director of the Animal and Poultry Waste Management Center. North Carolina State University.
- Nishimune, T., Watanabe, Y., Okazaki, H., & Akai, H. (2000). Thiamin is decomposed due to *Anaphe* spp. entomophagy in seasonal ataxia patients in Nigeria. *The Journal of Nutrition*, 130(6), 1625–1628.
- Nkouka, E. (1987). Les insectes comestibles dans les sociétés d'Afrique Centrale. *Revue Scientifique et Culturelle du CICIBAASC LEIDEN*, 6(1), 171–178.
- Noh, J. H., Yun, E. Y., Kim, J. Y., Lee, B. -S., Hwang, J. S., Jeong, E. J., & Moon, K. -S. (2015). Toxicological evaluation of genotoxicity and 28-day oral toxicity study on freeze-dried powder of *Allomyrina dichotoma* larvae. *Journal of Asia-Pacific Entomology*, 18(4), 807–813.
- Nonaka, K. (2009). Feasting on insects. *Entomological Research*, 39(5), 304–312.
- Nordlee, J. A., Taylor, S. C., Townsend, J. A., Thomas, L. A., & Bush, R. K. (1996). Identification of a Brazil-nut allergen in transgenic soybeans. *The New England Journal of Medicine*, 334, 688–692.
- Nowak-Węgrzyn, A., & Fioocchi, A. (2009). Rare, medium, or well done? The effect of heating and food matrix on food protein allergenicity. *Current Opinion in Allergy and Clinical Immunology*, 9(3), 234–237.
- Ohishi, A., Watanabe, K., Urushibata, M., Utsuno, K., Ikuta, K., Sugimoto, K., & Harada, H. (1994). Detection of soybean antigenicity and reduction by twin-screw extrusion. *Journal of the American Oil Chemists' Society*, 71, 1391–1396.
- Ojewola, G. S., Okoye, F. C., & Ukoha, O. A. (2005). Comparative utilization of three animal protein sources by broiler chickens. *International Journal of Poultry Science*, 4, 462–467.
- Oliver, G., & Wardle, J. (1999). Perceived effects of stress on food choice. *Physiology & Behavior*, 66, 511–515.
- Olivier, C. E. (2013). Food allergy. *Allergy Journals*, S3–004. <http://dx.doi.org/10.4172/2155-6121>.
- Oonincx, D. G. A. B., & de Boer, I. J. M. (2012). Environmental impact of the production of mealworms as a protein source for humans: A life cycle assessment. *PLoS One*, 7(12), e51145.
- Oonincx, D. G. A. B., van Isterbeeck, J., Heetkamp, M. J. W., van den Brand, H., van Loon, J. J. A., & van Huis, A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PLoS ONE*, 5(12), e14445.
- Opara, M. N., Sanyigha, F. T., Ogbuewu, I. P., & Okoli, I. C. (2012). Studies on the production trend and quality characteristics of palm grubs in the tropical rainforest zone of Nigeria. *International Journal of Agricultural Science and Technology*, 8, 851–860.
- Paisley, L., Lloyd, H. M., Sparks, P., & Mela, D. J. (1995). Consumer perceptions of dietary changes for reducing fat intake. *Nutrition Research*, 15, 1755–1766.
- Parajulee, M. N., DeFoliart, G. R., & Hogg, D. B. (1993). Model for use in mass-production of *Acheta domesticus* (Orthoptera: Gryllidae) as food. *Journal of Economic Entomology*, 86, 1424–1428.
- Parent, G., & Thoen, D. (1977). Food value of edible mushrooms from upper Shaba region. *Economic Botany*, 31, 436–445.
- Patterson, R. E., Kristal, A. R., Glanz, K., McLerran, D. F., Hebert, J. R., Heimendinger, J., ... Chamberlain, R. M. (1997). Components of the working well trial intervention associated with adoption of healthful diets. *American Journal of Preventive Medicine*, 13, 271–276.
- Pemberton, R. W. (1999). Insects and other arthropods used as drugs in Korean traditional medicine. *Journal of Ethnopharmacology*, 65(3), 207–216.
- Pereira, K. S., Schmidt, F. L., Barbosa, R. L., Guaraldo, A. M. A., Franco, R. M. B., Dias, V. L., & Passos, L. A. C. (2010). Chapter 3 - Transmission of Chagas disease (American trypanosomiasis) by food. *Advances in Food and Nutrition Research*, 59(10), 63–85.
- Pérez-Pérez, J., Fernández-Caldas, E., Marañón, F., Sastre, J., Bernal, M. L., Rodríguez, J., & Bedate, C. A. (2000). Molecular cloning of paramyosin, a new allergen of anisakis simplex. *International Archives of Allergy and Immunology*, 123, 120–129.
- Perrea, T., Grunert, K. G., & Krystallis, A. (2015). Consumer value perceptions of food products from emerging processing technologies: A cross-cultural exploration. *Food Quality and Preference*, 39, 95–108.
- Philpott, M., Mackay, L., Ferguson, L. R., Forbes, D., & Skinner, M. (2007). Cell culture models in developing nutrigenomics foods for inflammatory bowel disease. *Mutation Research*, 622, 94–102.
- Pimentel, D. (1991). Ethanol fuels: Energy security, economics and the environment. *Journal of Agricultural and Environmental Ethics*, 4(1), 1–13.
- Pliner, P., & Hobden, K. (1992). Development of a scale to measure the trait of food neophobia in humans. *Appetite*, 19, 105–120.
- Pliner, P., & Pelchat, M. L. (1991). Neophobia in humans and the special status of foods of animal origin. *Appetite*, 16, 205–218.
- Pliner, P., Pelchat, M., & Grabski, M. (1993). Reduction of food neophobia in humans by exposure to novel foods. *Appetite*, 20, 111–123.
- Rahnamaeian, M., Cytryńska, M., Zdybicka-Barabas, A., Dobszlaff, K., Wiesner, J., Twyman, R. M., ... Vilcinskas, A. (2015). Insect antimicrobial peptides show potentiating functional interactions against gram-negative bacteria. *Proc. Biol. Sci. B*, 282(1806), 20150293. <http://dx.doi.org/10.1098/rspb.2015.0293>.
- Ramos-Elorduy, J., & Pino, M. J. M. (1990). Caloric content of some edible insects in Mexico. *Revista de la Sociedad Química de México*, 34(2), 56–68.
- Ramos-Buen, R. P., González-Fernández, M. J., Sánchez-Muros Lozano, M. J., García-Barroso, F., & Guil Guerrero, J. L. (2016). Fatty acid profiles and cholesterol content of seven insect species assessed by several extraction systems. *European Food Research and Technology*. <http://dx.doi.org/10.1007/s00217-016-2647-7>.
- Ramos-Bueno, R. P., González-Fernández, M. J., Sánchez-Muros-Lozano, M. J., García-Barroso, F., & Luis Guil-Guerrero, J. (2016). Fatty acid profiles and cholesterol content of seven insect species assessed by several extraction systems. *European Food Research and Technology*, 1–7. <http://dx.doi.org/10.1007/s00217-016-2647-7>.
- Ramos-Elorduy, J. (2005). Insects: A hopeful food source. In M. G. Paoletti (Ed.), *Ecological implications of minilivestock: Potential of insects, rodents, frogs and snails* (pp. 263–291). Enfield, USA: Science Publisher.
- Ramos-Elorduy, J. (2006). Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. *Journal of Ethnobiology and Ethnomedicine*, 2(51), 1–10.
- Ramos-Elorduy, J. (2009). Anthro-entomophagy: Cultures, evolution and sustainability. *Entomological Research*, 39(5), 271–288 (Special issue: trends on the edible insects in Korea and abroad).
- Ramos-Elorduy, J., Pino, J. M., Prado, E. E., Perez, M. A., Otero, J. L., & de Guevara, O. L. (1997). Nutritional value of edible insects from the state of Oaxaca, Mexico. *Journal of Food Composition and Analysis*, 10, 142–157.
- Ramos-Elorduy, J., Pino-M, J. M., & Correa, S. C. (1998). Edible insects of the state of Mexico and determination of their nutritive values. *An. Inst. Biol. Univ. Nac. Auton. Mex. Ser. Zool.*, 69. (pp. 65–104), 65–104.
- Ramos-Elorduy, J., Gonzalez, E. A., Hernandez, A. R., & Pino, J. M. (2002). Use of *Tenebrio molitor* (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. *Journal of Economic Entomology*, 95(1), 214–220.
- Ramou, E. J., Pino, J. M., & Martinez, V. H. C. (2009). Edible aquatic Coleoptera of the world with an emphasis on Mexico. *Journal of Ethnobiology and Ethnomedicine*, 5, 11. <http://dx.doi.org/10.1186/1746-4269-5-11>.
- Rao, P. U. (1994). Chemical composition and nutritional evaluation of spent silk worm pupae. *Journal of Agricultural and Food Chemistry*, 42, 2201–2203.
- Ratcliffe, N. A., Mello, C. B., Garcia, E. S., T. Butt, M., & Azambuja, P. (2011). Insect natural products and processes: New treatments for human disease. *Insect Biochemistry and Molecular Biology*, 41, 747–769.
- Rees, J. A., Moniatte, M., & Bulet, P. (1997). Novel antibacterial peptides isolated from a European bumblebee, *Bombus pascuorum* (Hymenoptera, Apoidea). *Insect Biochemistry and Molecular Biology*, 27, 413–422.
- Rizzello, C. G., De Angelis, M., Coda, R., & Gobbetti, M. (2006). Use of selected sourdough lactic acid bacteria to hydrolyze wheat and rye proteins responsible for cereal allergy. *European Food Research and Technology*, 223, 405–411.
- Rop, O., Mlcek, J., & Jurikova, T. (2009). Beta-glucans in higher fungi and their health effects. *Nutrition Reviews*, 67(11), 624–631.
- Rozin, P., & Fallon, A. E. (1987). A perspective on disgust. *Psychological Review*, 94(1), 23–41.
- Rumpold, B. A., & Schlüter, O. K. (2013). Potential and challenges of insects as an innovative source for food and feed production. *Innovative Food Science & Emerging Technologies*, 17, 1–11.
- Rumpold, B. A., & Schlüter, O. K. (2014). Nutrient composition of insects and their potential application in food and feed in Europe. *Food Chain*, 4, 129–139.
- Rundqvist, L., Tengel, T., Zdunek, J., Bjo, E., Schleucher, J., Alcocer, M. J. C., & Larsson, G. (2012). Solution structure, copper binding and backbone dynamics of recombinant Ber e 1—the major allergen from Brazil nut. *PLoS One*, 7, 1–11.
- Sampson, H. A. (2004). Update on food allergy. *The Journal of Allergy and Clinical Immunology*, 113, 805–819.
- Santos, A. B. R., Chapman, M. D., Aalberse, R. C., Vailes, L. D., Ferriani, V. P., Oliver, C., ... Arruda, L. K. (1999). Cockroach allergens and asthma in Brazil identification of tropomyosin as a major allergen with potential crossreactivity with mite and shrimp allergens. *The Journal of Allergy and Clinical Immunology*, 104, 329–337.
- Santos Oliveira, J. F., Passos de Carvalho, J., Bruno de Sousa, R. F. X., & Madalena Simao, M. (1976). The nutritional value of four species of insects consumed in Angola. *Ecology of Food and Nutrition*, 5, 91–97.
- Sasaki, M., Yamada, H., & Kato, N. (2000). Consumption of silk protein, sericin elevates intestinal absorption of zinc, iron, magnesium and calcium in rats. *Nutrition Research*, 20(10), 1505–1511.
- Schaal, S. (2006). Messel. *Encyclopedia of Life Sciences*. <http://dx.doi.org/10.1038/npg.els.0004143>. ISBN 0-470-01617-5.
- Schabel, H. G. (2010). Forest insects as food: A global review. In P. B. Durst, D. V. Johnson, R. N. Leslie, & K. Shono (Eds.), *Forest Insects as Food: Humans Bite Back* (pp. 37–64). Bangkok, Thailand: FAO.
- Schöslér, H., de Boer, J., & Boersema, J. J. (2012). Can we cut out the meat of the dish? Constructing consumer-oriented pathways towards meat substitution. *Appetite*, 58(1), 39–47.
- Sehgal, R., Bhatti, H. P., Bhasin, D. K., Sood, A. K., Nada, R., Malla, N., & Singh, K. (2003). Intestinal myiasis due to *Muscadomestica*: A report of two cases. *Japanese Journal of Infectious Diseases*, 55(6), 191–193.
- Shan, H., Tan, G., Fischer, A. R. H., Tinchin, P., Stieger, M., Steenbekkers, L. P. A., & van Trijp, H. C. M. (2015). Insects as food: Exploring cultural exposure and individual experience as determinants of acceptance. *Food Quality and Preference*, 42, 78–89.
- Shanker, K. S., Shireesha, K., Kanjilal, S., Kumar, S. V., Srinivas, C., Rao, J. V., & Prasad, R. B. (2006). Isolation and characterization of neutral lipids of desilked eri silkworm pupae grown on castor and tapioca leaves. *Journal of Agricultural and Food Chemistry*, 54(9), 3305–3309.
- Shattuck, S. O. (1999). *Australian ants: their biology and identification* (p. 149). Collingwood, Vic: CSIRO.
- Shen, L., Li, D., Feng, F., & Ren, Y. (2006). Nutritional composition of *Polyrhachis vicina* Roger (edible Chinese black ant). *Songklanakarin Journal of Science and Technology*, 28(Suppl 1), 107–114.
- Sheppard, C., Newton, G. L., Thompson, S. A., & Savage, S. (1994). A value added manure management system using the black soldier fly. *Bioresource Technology*, 50, 275–279.
- Shi, J. M., Xie, C. X., Zhang, W. J., & Shen, J. M. (1990). Effects of silkworm on serum protein, haemoglobin, glutamate-pyruvate transaminase and glucose. *J. Mod. App. Pharm.*, 7(2), 1–3.
- Shi, X., Guo, R., White, B. L., Yancey, A., Sanders, T. H., Davis, J. P., ... Kulis, M. (2013). Allergic properties of enzymatically hydrolyzed peanut flour extracts. *International Archives of Allergy and Immunology*, 162, 123–130.

- Shrestha, B., Weimin, Z., Yongjie, Z., & Xingzhong, L. (2010). What is the Chinese caterpillar fungus *Ophiocordyceps sinensis* (Ophiocordycipitaceae)? *Mycology*, 1(4), 228–236.
- Sicherer, S. H., & Sampson, H. A. (2010). Food allergy. *The Journal of Allergy and Clinical Immunology*, 125(2), S116–S125.
- Sicherer, S. H., & Sampson, H. A. (2014). Food allergy: Epidemiology, pathogenesis, diagnosis, and treatment. *The Journal of Allergy and Clinical Immunology*, 133(2), 291–307.
- Sicherer, S. H., Munoz Furlong, A., & Sampson, H. A. (2004). Prevalence of seafood allergy in the United States determined by a random telephone survey. *The Journal of Allergy and Clinical Immunology*, 114(1), 159–165.
- Smeathman, H. (1781). Some account of the termites, which are found in Africa and other hot climates. A letter from Mr. Henry Smeathman, of Clement's Inn, to Sir Joseph Banks, Bart. P. R. S. *Philosophical Transactions of the Royal Society of London*, 71, 139–192.
- Sonkaria, S., Ahn, S. -H., & Khare, V. (2012). Nanotechnology and its impact on food and nutrition: A review. *Recent Patents on Food, Nutrition & Agriculture*, 4(1), 8–18.
- Sribandit, W., Wiwatwitaya, D., Suksard, S., & Offenber, J. (2008). The importance of weaver ant (*Oecophylla smaragdina* Fabricius) harvest to a local community in North-eastern Thailand. *Asian Myrmecology*, 2, 129–138.
- Srinroch, C., Srisomsap, C., Chokchaichamnankit, D., Punyari, P., & Phiriyaikul, P. (2015). Identification of novel allergen in edible insect, *Gryllus bimaculatus* and its cross-reactivity with *Macrobrachium* spp. allergens. *Food Chemistry*, 184, 160–166.
- Srivastava, S. K., Babu, N., & Pandey, H. (2009). Traditional insect bioprospecting-as human food and medicine. *Indian Journal of Traditional Knowledge*, 8(4), 485–494.
- Stabentheiner, A., Kovac, H., & Brodschneider, R. (2010). Honey bee colony thermoregulation – Regulatory mechanisms and contribution of individuals in dependence on age, location and thermal stress. *PLoS One*, 5, e8967. <http://dx.doi.org/10.1371/journal.pone.0008967>.
- Stack, J., Dorward, A., Gondo, T., Frost, P., Taylor, F., & Kurebgaseka, N. (2003). Mopane worm utilisation and rural livelihoods in southern Africa. In *The international conference on rural livelihoods, forests and biodiversity, Bonn, Germany, 19–23 May* (pp. 2003).
- Steen, L., Glorieux, S., Goemaere, O., Brijs, K., Paelinck, H., Foubert, I., & Fraeye, I. (2016). Functional properties of pork liver protein fractions. *Food and Bioprocess Technology*, 9(6), 970–980.
- Steiner, J. E. (1977). Facial expressions of the neonate infant indicating the hedonics of food-related chemical stimuli. In J. Weiffenbach (Ed.), *Taste and development: The genesis of sweet preference*. DHEW Publication No. NIH 77–1068. (pp. 173). Washington DC: US Government Printing Office.
- St-Hilaire, S., Cranfill, K., McGuire, M. A., Mosley, E. E., Tomberlin, J. K., Newton, L., ... Irving, S. (2007). Fish offal recycling by the black soldier fly produces a foodstuff high in omega-3 fatty acids. *Journal of the World Aquaculture Society*, 38, 309–313.
- Stubbs, R. J., van Wyk, M. C., Johnstone, A. M., & Harbron, C. G. (1996). Breakfasts high in protein, fat or carbohydrate: Effect on within-day appetite and energy balance. *European Journal of Clinical Nutrition*, 50, 409–417.
- Su, G., Zhao, T., Sun-Waterhouse, D., & Zhao, M. (2016). Effect of anchovy (*Coilia mystus*) protein hydrolysate and its Maillard reaction product on combating memory-impairment in mice. *Food Research International*, 82, 112–120.
- Suh, H. J., Kim, S. R., Lee, K. S., Park, S., & Kang, S. C. (2010). Antioxidant activity of various solvent extracts from *Allomyrina dichotoma* (Arthropoda: Insecta) larvae. *Journal of Photochemistry and Photobiology, B*, 99, 67–73.
- Sun, L., Feng, Y., He, Z., Ma, T., & Zhang, X. (2007). Studies on alkaline solution extraction of polysaccharide from silkworm pupa and its immunomodulating activities. *Forest Research*, 20, 782–786.
- Sun-Waterhouse, D. (2011). The development of fruit-based functional foods targeting the health and wellness market: A review. *International Journal of Food Science and Technology*, 46(5), 899–920.
- Sun-Waterhouse, D., & Wadhwa, S. S. (2013). Industry relevant approaches for minimising the bitterness of bioactive compounds in functional foods: A review. *Food and Bioprocess Technology*, 6(3), 607–627.
- Sun-Waterhouse, D., & Waterhouse, G. I. N. (2016). Recent advances in the application of nanomaterials and nanotechnology in food research. In A. M. Grumezescu (Ed.), *Nanotechnology in Food Industry. Vol. I, Novel approaches*. US: Academic Press, Elsevier (ISBN 0128043792, 9780128043790).
- Sun-Waterhouse, D., Chen, J., Chuah, C., Wibisono, R., Melton, L. D., Laing, W., ... Skinner, M. A. (2009). Kiwifruit-based polyphenols and related antioxidants for functional foods: Kiwifruit extract-enhanced gluten-free bread. *International Journal of Food Sciences and Nutrition*, 60(57), 251–264.
- Sun-Waterhouse, D., Zhao, M., & Waterhouse, G. I. N. (2014). Protein modification during ingredient preparation and food processing: Approaches to improve food processability and nutrition. *Food and Bioprocess Technology*, 7(7), 1853–1893.
- Surendra, K. C., Olivier, R., Tomberlin, J. K., Jha, R., & Khanal, S. K. (2016). Bioconversion of organic wastes into biodiesel and animal feed via insect farming. *Renewable Energy*, 98, 197–202 (Special Issue: New Horizons in Biofuels Production and Technologies).
- Sutton, P. A., Wilde, M. J., Martin, S. J., Cvačka, J., Vrskoslav, V., & Rowland, S. J. (2013). Studies of long chain lipids in insects by high temperature gas chromatography and high temperature gas chromatography–mass spectrometry. *Journal of Chromatography, A*, 1297, 236–240.
- Taheri-Kafrani, A., Gaudin, J. C., Rabesona, H., Nioi, C., Agarwal, D., Drouet, M., ... Haertle, T. (2009). Effects of heating and glycation of β -lactoglobulin on its recognition by IgE of sera from cow milk allergy patients. *Journal of Agricultural and Food Chemistry*, 57, 4974–4982.
- Tammineedi, C. V. R. K., Choudhary, R., Perez-Alvarado, G. C., & Watson, D. G. (2013). Determining the effect of UV-C, high intensity ultrasound and nonthermal atmospheric plasma treatments on reducing the allergenicity of a-casein and whey proteins. *LWT-Food Science and Technology*, 54(1), 35–41.
- Tan, H. S. G., Fischer, A. R. H., Tinchin, P., Stieger, M., Steenbekkers, L. P. A., & van Trijp, H. C. M. (2015). Insects as food: Exploring cultural exposure and individual experience as determinants of acceptance. *Food Quality and Preference*, 42, 78–89.
- Taylor, S. L. (2008). Molluscan shellfish allergy. *Advances in Food and Nutrition Research*, 54, 139–177.
- Tchuinkam, T., Mpoame, M., Make-Mveinhy, B., Simard, F., Lélé-Defo, E., Zébazé-Togouet, S., ... Njiné, T. (2011). Optimization of breeding output for larval stage of *Anopheles gambiae* (Diptera: Culicidae): Prospects for the creation and maintenance of laboratory colony from wild isolates. *Bulletin of Entomological Research*, 101, 259–269.
- Teffo, L. S., Toms, R. B., & Eloff, J. N. (2007). Preliminary data on the nutritional composition of the edible stink-bug, *Encosternum delegorguei* Spinola, consumed in Limpopo province, South Africa. *South African Journal of Science*, 107, 434–436.
- Teffo, L. S. (2006). *Nutritional and medicinal value of the edible stinkbug, Encosternum delegorguei Spinola consumed in the Limpopo Province of South Africa and its host plant Dodonea viscosa Jacq. var. angustifolia*. Pretoria: University of Pretoria (Phd thesis).
- Toms, R., & Thagwana, M. (2003). Eat your bugs! (Science in Africa). www.scienceinfrica.co.za/2005/january/mopane.htm.
- Tong, L., Yu, X., & Lui, H. (2011). Insect food for astronauts: Gas exchange in silkworms fed on mulberry and lettuce and the nutritional value of these insects for human consumption during deep space flights. *Bulletin of Entomological Research*, 101, 613–622.
- Torrent, J., Alvarez-Martinez, M. T., Harricane, M. -C., Heitz, F., Liautaud, J. -P., Balny, C., & Lange, R. (2004). High pressure induces scrapie-like prion protein misfolding and amyloid fibril formation. *Biochemistry*, 43(22), 7162–7170.
- Tsuchida, K., & Wells, M. A. (1990). Isolation and characterization of a lipoprotein receptor from the fat body of an insect, *Manduca sexta*. *The Journal of Biological Chemistry*, 265(10), 5761–5767.
- Türker, H., Incekara, Ü., & Erman, O. (2010). Biomonitoring of the genotoxic potentials of aqueous extracts of two edible insects species in vitro. *Turkish Journal of Entomology*, 34(4), 411–417.
- Tzompa-Sosa, D. A., Yi, L., van Valenberg, H. J. F., van Boekel, M. A. J. S., & Lakemond, C. M. (2014). Insect lipid profile: Aqueous versus organic solvent-based extraction methods. *Food Research International*, 62, 1087–1094.
- UN (2012). *World urbanization prospects, the 2011 revision*. New York, USA.
- USFDA (2009). Color additives: FDA's regulatory process and historical perspectives. <http://www.fda.gov/ForIndustry/ColorAdditives/RegulatoryProcessHistoricalPerspectives/default.htm> Accessed April 2016
- Usub, T., Lertsatitthanakorn, C., Poomsaad, N., Wiset, L., Yang, L., & Siriamornpun, S. (2008). The experimental performance of a solar tunnel dryer for drying silkworm pupae. *Biosystems Engineering*, 101, 209–216.
- Vadivel, V., Kunyanga, C. N., & Biesalski, H. K. (2012). Health benefits of nut consumption with special reference to body weight control. *Nutrition*, 28, 1089–1097.
- van Bilsen, J. H. M., Knipfels, L. M. J., Penninks, A. H., Nieuwenhuizen, W. F., De Jongh, H. H. J., & Koppelman, S. J. (2013). The protein structure determines the sensitizing capacity of Brazil nut 2S albumin (Ber e1) in a rat foodallergy model. *Clinical and Translational Allergy*, 3(1), 36. <http://dx.doi.org/10.1186/2045-7022-3-36>.
- van Bortel, E. L., van den Broek, L. A., Koppelman, S. J., & Gruppen, H. (2008a). Legumin allergens from peanuts and soybeans: Effects of denaturation and aggregation on allergenicity. *Molecular Nutrition & Food Research*, 52, 674–682.
- van Bortel, E. L., Koppelman, S. K., Van den Broek, L. A. M., & Gruppen, H. (2008b). Heat denaturation of Brazil nut allergen Ber e 1 in relation to foodprocessing. *Food Chemistry*, 110, 904–908.
- van Broekhoven, S., Bastiaan-Net, S., de Jong, N. W., & Wichers, H. J. (2016). Influence of processing and in vitro digestion on the allergic cross-reactivity of three mealworm species. *Food Chemistry*, 196, 1075–1083.
- van Der Poel, L., Chen, J., & Penagos, M. (2009). Food allergy epidemic - is it only a western phenomenon? *Current Opinion in Allergy and Clinical Immunology*, 22, 121–126.
- van dijk, M., & Meijerink, G. W. (2014). A review of global food security scenario and assessment studies: Results, gaps and research priorities. *Global Food Security*, 3, 227–238.
- van Huis, A. (1996). *The traditional use of arthropods in Sub-Saharan Africa*. *Proc. Sect. Exp. Appl. Entomol. Neth. Entomol. Soc. (N.E.V.)*, 7, (pp. 3–20), 3–20.
- van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology*, 58(1), 563–583.
- van Huis, A., & Motte-Florac, É. (2003). Medical and stimulating properties ascribed to arthropods and their products in sub-Saharan Africa. In J. M. C. Thomas (Ed.), *Insects in oral literature and traditions. Ethnoscience: 11. Société d'études linguistiques et anthropologiques de France (series): 407*. (pp. 367–382). Paris, France: Peeters.
- van Huis, A., van Gurp, H., & Dicke, M. (2012). *Het insectenkookboek*. Amsterdam: The Netherlands, Atlas.
- van Huis, A., Van Itterbeek, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). *Edible insects - Future prospects for food and feed security*. *FAO Forestry Paper* 171.
- Vandermeer, C., Chan, A., & Waterhouse, G. (2014). *What makes these nipples GOLD ?! A structural investigation*. New Zealand: University of Auckland.
- Veldkamp, T., van Duinkerken, G., van Huis, A., Lakemond, C. M. M., Ottevanger, E., Bosch, G., & van Boekel, M. A. J. S. (2012). Insects as a sustainable feed ingredient in pig and poultry diets - A feasibility study. *Rapport 638 - Wageningen livestock research*. ISSN 1570-8616. Lelystad, Netherlands: Wageningen UR Livestock Research.
- Verbeke, W. (2015). Profiling consumers who are ready to adopt insects as a meat substitute in a western society. *Food Quality and Preference*, 39, 147–155.
- Vercruysse, L., Smaghe, G., Herregods, G., & Van Camp, J. (2005). ACE inhibitory activity in enzymatic hydrolysates of insect protein. *Journal of Agricultural and Food Chemistry*, 53, 5207–5211.
- Vercruysse, L., Smaghe, G., Matsui, T., & Van Camp, J. (2008). Purification and identification of an angiotensin I converting enzyme (ACE) inhibitory peptide from the

- gastrointestinal hydrolysate of the cotton leafworm, *Spodoptera littoralis*. *Process Biochemistry*, 43(8), 900–904.
- Verkerk, M. C., Tramper, J., van Trijp, J. C. M., & Martens, D. E. (2007). Insect cells for human food. *Biotechnology Advances*, 25(2), 198–202.
- Vickery, V. R., & Kevan, D. K. (1985). *The grasshoppers, crickets, and related insects of Canada and Adjacent Regions. The Insects and Arachnids of Canada (Part 4, Publication 1777)*. Ottawa, Canada: Agriculture Canada.
- Vonkavaara, M., Pavel, S. T. L., Hölzl, K., Nordfelth, R., Sjöstedt, A., & Stöven, S. (2012). Francisella is sensitive to insect antimicrobial peptides. *Journal of Innate Immunity*, 5, 50–59.
- Wang, X.-L., & Yao, Y.-J. (2011). Host insect species of *Ophiocordyceps sinensis*: A review. *Zookeys*, 127, 12743–12759.
- Wang, Y., Liu, J., Ruan, H. X., Wu, K.-F., Gao, M., Yu, H., & Huang, J.-Y. (2001). The immunological regulation effect of water extract from polyrhachisvicina roger on normal and immune deficient mice. *Journal of Guiyang Medical College*, 26(1), 9–14.
- Wang, B. G., Sun, X. X., Zhao, L. Y., Zhang, G. Y., Mei, S. J., An, Y., & Wang, C. (2002). Study on nutritional value of silkworm pupa powder. *China Public Health*, 18(5), 575–576.
- Wardle, J., Steptoe, A., Oliver, G., & Lipsey, Z. (2000). Stress, dietary restraint and food intake. *Journal of Psychosomatic Research*, 48, 195–202.
- Watanabe, M., Watanabe, J., Sonoyama, K., & Tanabe, S. (2000). Novel method for producing hypoallergenic wheat flour by enzymatic fragmentation of the constituent allergens and its application to food processing. *Bioscience, Biotechnology, and Biochemistry*, 64, 2663–2667.
- Wei, M. C., & Liu, G. Q. (2001). The research and exploitation of insect product. *Journal of Central South University of Forestry & Technology*, 21(2), 86–90.
- Wei, K. M., & Xu, Q. Y. (1999). Status quo and advantages of synthetical medicinal exploitation of sericultural resource in Zhejiang Province. *Zhejiang Journal of Traditional Chinese Medicine*, 34(11), 501–503.
- Wei, Z. J., Liao, A. M., Zhang, H. X., Liu, J., & Jiang, S.-T. (2009). Optimization of supercritical carbon dioxide extraction of silkworm pupal oil applying the response surface methodology. *Bioresource Technology*, 100(18), 4214–4219.
- Weissman, D. B., Gray, D. A., Pham, H. T., & Tijssen, P. (2012). Billions and billions sold: Pet-feeder crickets (Orthoptera: Gryllidae), commercial cricket farms, an epizootic densovirus, and government regulations make for a potential disaster. *Zootaxa*, 3504, 67–88.
- Will, R., Ironside, J. W., Zeidler, M., Estibeiro, K., Cousens, S. N., Smith, P. G., ... Hofman, A. (1996). A new variant of Creutzfeldt-Jakob disease in the UK. *Lancet*, 347(9006), 921–925.
- Wilson, M. E., Lorente, C. A., Allen, J. E., & Eberhard, M. L. (2001). Gongylonema infection of the mouth in a resident of Cambridge, Massachusetts. *Clinical Infectious Diseases*, 32(9), 1378–1380.
- Woods, R. K., Abramson, M., Raven, J. M., Bailey, M., Weiner, J. M., & Walters, E. H. (2001). International prevalences of reported food allergies and intolerances. Comparisons arising from the European community respiratory health survey (ECRHS) 1991–1994. *European Journal of Clinical Nutrition*, 55(4), 298–304.
- Womni, H. M., Linder, M., Tiencheu, B., Mbiapo, F. T., Villeneuve, P., Fanni, J., & Parmentier, M. (2009). Oils of insects and larvae consumed in Africa: potential sources of polyunsaturated fatty acids. *OCL – Oléagineux, Corps Gras, Lipides*, 16(4), 230–235.
- Wu, Q., Jia, J., Yan, H., Du, J., & Gui, Z. (2015). A novel angiotensin-I converting enzyme (ACE) inhibitory peptide from gastrointestinal protease hydrolysate of silkworm pupa (*Bombyx mori*) protein: Biochemical characterization and molecular docking study. *Peptides*, 68, 17–24.
- Xia, Z., Chen, J., & Wu, S. (2013). Hypolipidemic activity of the chitoooligosaccharides from *Clanis bilineata* (Lepidoptera), an edible insect. *International Journal of Biological Macromolecules*, 59, 96–98.
- Yabutani, T., Waterhouse, G. I. N., Sun-Waterhouse, D., Metson, J. B., Iinuma, A., Thuy, L. T. X., ... Motonaka, J. (2014). Facile synthesis of platinum nanoparticle-containing porous carbons, and their application to amperometric glucose biosensing. *Microchimica Acta*, 181(15–16), 1871–1878.
- Yang, G. H. (1998). *Utility of Chinese resource insects and its industrialization*, 1st Ed., pp. 5–54 Beijing, China: China Agriculture Science Press.
- Yang, H. X., Zhu, X. R., & Lu, H. S. (2002). Research progress on application of silkworm pupa in medical science. *Bulletin of Science and Technology*, 18(4), 318–322.
- Yang, W. W., Chung, S.-Y., Ajayi, O., Krishnamurthy, K., Konan, K., & Goodrich-Schneider, R. (2010). Use of pulsed ultraviolet light to reduce the allergenic potency of soybean extracts. *International Journal of Food Engineering*, 6, 1556–3758.
- Yang, R., Zhao, X., Kuang, Z., Ye, M., Luo, G., Xiao, G., ... Xiong, Z. (2013). Optimization of antioxidant peptide production in the hydrolysis of silkworm (*Bombyx mori* L.) pupa protein using response surface methodology. *Journal of Food, Agriculture and Environment*, 11(1), 952–956.
- Yao, M., Xu, Q., Luo, Y., Shi, J., & Li, Z. (2015). Study on reducing antigenic response and IgE-binding inhibitions of four milk proteins of lactobacillus casei 1134. *Journal of the Science of Food and Agriculture*, 95(6), 1303–1312.
- Yen, A. L. (2005). Insects and other invertebrate foods of the Australian aborigines. In M. G. Paoletti (Ed.), *Ecological implications of minilivestock: Potential of insects, rodents, frogs and snails* (pp. 367–388). New Hampshire, USA: Science Publishers.
- Yen, A. L. (2010). Edible insects and other invertebrates in Australia: Future prospects. In P. B. Durst, D. V. Johnson, R. L. Leslie, & K. Shono (Eds.), *Forest insects as food: Humans bite back* (pp. 65–84) Proceedings of a workshop on Asia-Pacific resources and their potential for development. Bangkok, Thailand: FAO Regional Office for Asia and the Pacific.
- Yen, A. L. (2015). Insects as food and feed in the Asia Pacific region: Current perspectives and future directions. *Journal of Insects as Food and Feed*, 1, 33–55.
- Yen, A. L., Hanboonsong, Y., & van Huis, A. (2013). The role of edible insects in human recreation and tourism. In R. H. Lemelin (Ed.), *The management of insects in recreation and tourism* (pp. 169–185). Cambridge, UK: Cambridge University Press.
- Yhoun Aree, J., Puwastien, P., & Attig, G. A. (1997). Edible insects in Thailand: An unconventional protein source? *Ecology of Food and Nutrition*, 36(2–4), 133–149.
- Yhoun-Aree, J., & Viwatpanich, K. (2005). Edible insects in the Laos PDR, Myanmar, Thailand, and Vietnam. In M. G. Paoletti (Ed.), *Ecological implications of minilivestock* (pp. 415–440). New Hampshire, USA: Science Publishers.
- Yi, L., Lakemond, C. M., Sagis, L. M., Eisner-Schadler, V., van Huis, A., & van Boekel, M. A. (2013). Extraction and characterisation of protein fractions from five insect species. *Food Chemistry*, 141, 3341–3348.
- Yi, H.-Y., Chowdhury, M., Huang, Y.-D., & Yu, X.-Q. (2014). Insect antimicrobial peptides and their applications. *Applied Microbiology and Biotechnology*, 98, 5807–5822.
- Yin, W. Y., & Peng, L. (1998). Effects of amino acids of silkworm pupae on immune function in mice. *Journal of Toxicology and Health*, 12(1), 63.
- Youn, K., Yun, E. Y., Lee, J., Kim, J. Y., Hwang, J. S., Jeong, W. S., & Jun, M. (2014). Oleic acid and linoleic acid from *Tenebrio molitor* larvae inhibit BACE1 activity in vitro: Molecular docking studies. *Journal of Medicinal Food*, 17(2), 284–289.
- Yu, D., & Li, B. (2005). Bioactive peptide from bee venom for adjuvant-induced arthritis in rats. *Chinese Journal of Clinical Rehabilitation*, 9(15), 242–243.
- Yu, C. J., Lin, Y. F., Chiang, B. L., & Chow, L. P. (2003). Proteomics and immunological analysis of a novel shrimp allergen, Pen m 2. *Journal of Immunology*, 170(1), 445–453.
- Yu, J., Ahmedna, M., Goktepe, I., Cheng, H., & Maleki, S. (2011). Enzymatic treatment of peanut kernels to reduce allergen levels. *Food Chemistry*, 127, 1014–1022.
- Zagobelny, M., Dreon, A. L., Gomiero, T., Marazzan, G. L., Glaring, M. A., Möller, B. L., & Paoletti, M. G. (2009). Toxic moths: Source of a truly safe delicacy. *Journal of Ethnobiology*, 29(1), 64–76.
- Zang, Q. Z., Wan, S. Y., He, G. X., & Xu, J. H. (1992). Separation and analysis of polysaccharide from silkworm pupae. *Traditional Chinese Patent Medicine*, 14(3), 35–36.
- Zhang, T., Pan, W., Takebe, M., Schofield, B., Sampson, H., & Li, X.-M. (2008). Therapeutic effects of a fermented soy product on peanut hypersensitivity is associated with modulation of T-helper type 1 and T-helper type 2 responses. *Clinical and Experimental Allergy*, 38(11), 1808–1818.
- Zhao, X., Vázquez-Gutiérrez, J. L., Johansson, D. P., Landberg, R., & Langton, M. (2016). Yellow mealworm protein for food purposes - extraction and functional properties. *PLoS One*, 11(2), e0147791. <http://dx.doi.org/10.1371/journal.pone.0147791>.
- Zheng, L., Zhao, Y., Xiao, C., Sun-Waterhouse, D., Zhao, M., & Su, G. (2014). Mechanism of the discrepancy in the enzymatic hydrolysis efficiency between defatted peanut flour and peanut protein isolate by Flavorzyme. *Food Chemistry*, 168, 100–106.
- Zhou, S. W. (1982). *The history of entomology in China* (pp. 180–186). Beijing, China: Science press.
- Zhou, J. X. (2004). Health food derived from silkworm pupae approved. *Food Info. Tech.*, 4, 64.
- Zhou, J., & Han, D. X. (2006). Safety evaluation of protein of silkworm (*Antheraea pernyi*) pupae. *Food and Chemical Toxicology*, 44, 1123–1130.
- Zhou, H., Wang, C., Ye, J., Tao, R., Chen, H., & Cao, F. (2016). Effects of enzymatic hydrolysis assisted by high hydrostatic pressure processing on the hydrolysis and allergenicity of proteins from ginkgo seeds. *Food and Bioprocess Technology*, 9(5), 839–848.
- Zielińska, E., Baraniak, B., Karaś, M., Rybczyńska, K., & Jakubczyk, A. (2015). Selected species of edible insects as a source of nutrient composition. *Food Research International*, 77, 460–466.