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Review article

Nutritional and sensory quality of edible insects

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ABSTRACT

Insects are for many nations and ethnic groups an indispensable part of the diet. From a nutritional point of view, insects have significant protein content. It varies from 20 to 76% of dry matter depending on the type and development stage of the insect. Fat content variability is large (2–50% of dry matter) and depends on many factors. Total polyunsaturated fatty acids' content may be up to 70% of total fatty acids. Carbohydrates are represented mainly by chitin, whose content ranges between 2.7 mg and 49.8 mg per kg of fresh matter. Some species of edible insects contain a reasonable amount of minerals (K, Na, Ca, Cu, Fe, Zn, Mn and P) as well as vitamins such as B group vitamins, vitamins A, D, E, K, and C. However their content is seasonal and dependent on the feed. From the hygienic point of view it should be pointed out that some insects may produce or contain toxic bioactive compounds. They may also contain residues of pesticides and heavy metals from the ecosystem. Adverse human allergic reactions to edible insects could be also a possible hazard.

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Contents

1. Introduction

The term “entomophagy” (from the Greek words ἔντομον *éntomon*, “insect” and φᾰγεῖν *phagein*, “to eat”) refers to the use of insects as food: human insectivory [1]. The eggs, larvae, pupae and adults of insects were used in prehistoric times as food ingredients in humans, and this trend has continued into modern times. Man was omnivorous in early development and ate insects quite extensively. Before people had tools for hunting or farming, insect constituted an important component of the human diet. Moreover, people lived mainly in warm regions, where different kinds of insects were available throughout the year. Insects were often a welcome source of protein in the absence of meat from vertebrates [2].

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Evidence of eating insects in human history has been found from analysis of fossils from caves in the USA and Mexico. For example, coprolites from caves in Mexico included ants, beetle larvae, lice, ticks and mites [3]. The evidence of entomophagy was confirmed using analytical techniques. Analysis of stable carbon isotopes showed that *Australopithecus* bones and enamel were significantly enriched in the isotope ^{13}C. This suggests that the diet of these people was mostly animals feeding on grasses, including insects [2]. Another evidence is from paintings in the Artamila caves in northern Spain (9000–3000 BC.) [3]. According to Lesnik [4] termites were included into the Plio-Pleistocene hominin diet.

Nowadays human insect-eating is traditionally practised in 113 countries around the world. Over 2000 insect species are known to be edible. Globally, the most frequently consumed species are beetles, caterpillars, bees, wasps and ants. They are followed by grasshoppers, locusts and crickets, cicadas, leafhoppers and bugs, termites, dragonflies, flies and other species [5]. The largest consumption of insects is in Africa, Asia and Latin America [5]. In most European countries, the human consumption of insects is very low and often culturally inappropriate or even taboo. The nutritional value of insects is comparable to commonly eaten meats. Considering the growing population in the world and the increasing demand for production of traditional beef, pork and chicken meat, edible insects should be seriously considered as a source of animal protein [6].

In terms of farming conditions the following insect species could be bred and consumed in Europe: house cricket (*Acheta domestica*), Jamaican field cricket (*Gryllus assimilis*), African migratory locust (*Locusta migratoria*), desert locust (*Schistocerca gregaria*), yellow mealworm beetle (*Tenebrio molitor*), superworm (*Zophobas morio*), lesser mealworm (*Alphitobius diaperinus*) western honey bee (*Apis mellifera*) and wax moth (*Galleria mellonella*) [7].

2. Why eat insects?

Increasing population growth in the world increases demand for protein sources but the amount of available farmland is limited. In 2050 the world population is estimated at more than 9 billion people, resulting in an additional need for food of half the current needs. Conventional protein sources may be insufficient and we will have to focus on alternative sources [8], which may be edible insects [9]. In Africa, Southeast Asia and the northern part of Latin America, this large group of animals is a popular delicacy and an interesting assortment of food enrichment. For example in Mexico, chapulines (grasshoppers of the genus *Sphenarium*) are a frequent national dish together with beef and beans [10].

Compared with livestock, breeding insects seems to be more environmentally friendly because of lower greenhouse gas emissions, water pollution and land use [11]. Insects show higher feed conversion efficiency (i.e. a measure of the animal's efficiency in converting feed mass into body mass) in comparison with mammalian livestock. Van Huis et al. [11] even stated the feed conversion of house cricket (*A. domestica*) to be twice that of chickens, 4 times higher than in pigs and more than 12 times higher than in cattle.

An interesting positive aspect of entomophagy is its help in reducing pesticide use. Collection of edible insects considered as pests can contribute to reduced use of insecticides. Furthermore, the economic benefits of collecting insects as compared with the cultivation of plants should also be taken into account. In Mexico, collecting insects for human consumption resulted in a reduction in the quantity of pesticides in agricultural crop production and a decreased financial burden on farmers [10,12].

3. Nutritional value of edible insect

The nutritional value of edible insects is very diverse mainly because of the large number and variability of species. Nutritional values can vary considerably even within a group of insects depending on the stage of metamorphosis, origin of the insect and its diet [13]. Similarly the nutritional value changes according to the preparation and processing before consumption (drying, cooking, frying etc.) [11]. According to Payne et al. [14] insect nutritional composition showed high diversity between species. The Nutrient Value Score of crickets, palm weevil larvae and mealworm was significantly healthier than in the case of beef and chicken and none of six tested insects were statistically less healthy than meat. Most edible insects provide sufficient energy and proteins intake in the human diet, as well as meeting the amino acid requirements. Insects also have a high content of mono- and polyunsaturated fatty acids; they are rich in trace elements such as copper, iron, magnesium, manganese, phosphorus, selenium and zinc, as well as vitamins like riboflavin, pantothenic acid, biotin, and folic acid in some cases [15].

3.1. Energy value

The energy value of edible insects depends on their composition, mainly on the fat content. Larvae or pupae are usually richer in energy compared to adults. Conversely high protein insect species have lower energy content [16]. Ramos-Elorduy et al. [17] analysed 78 kinds of insects and calculated their calorific value in the range from 293 to 762 kcal per 100 g of dry matter. Table 1 shows the energy value of selected species of edible insects, expressed in kcal per 100 g fresh weight [11].

3.2. Proteins

Bednářová [16] examined the total protein content of seven species of insects. Total protein content was relatively the same in all measured types of insects except for the wax moth (*G. mellonella*) where the protein content (based on dry matter) was only 38.4%. The percentage of other species ranged from 50.7% for yellow mealworm (*T. molitor*) to 62.2% for the African migratory locust (*L. migratoria*). Xiaoming et al. [18] assessed protein content in 100 insect species. Protein content was in the range of 13 to 77% by dry matter (Table 2), reflecting the large variability of tested species. Eighty-seven species of edible insects were investigated in Mexico, and the average protein content was from 15% to 81%. Insect protein digestibility, which is 76 to 96% [17] was also examined in this study. These values are on average only a little smaller than values for egg protein (95%) or beef (98%) and even higher than in the case of many plant proteins [19]. Measured amounts of nitrogenous substances of insects may be higher than their actual protein content since some nitrogen is also bound in the exoskeleton [20].

Considering the amino acid composition of edible insects, they contain a number of nutritionally valuable amino acids including high levels of phenylalanine and tyrosine. Some insects contain large amounts of lysine, tryptophan and threonine, which is deficient in certain cereal proteins. For example, in Angola the intake of these nutrients may be supplemented by eating termites of the genus *Macrotermes subhyalinus* [21]. The native people of Papua New Guinea normally eat tubers, where the content of lysine and leucine is low. The resulting nutritional gap could therefore be compensated by the consumption of larvae of the *Rhynchophorus* family beetle that have high amounts of lysine. On the contrary tubers contain a high proportion of tryptophan, and aromatic amino acids which are present in limited quantities in these larvae. Nutritional intake of such a diet is therefore balanced [11,22]. Analysis of almost a hundred edible insect species showed that the content of essential amino acids represents 46–96% of the total amount of amino acids [18].

3.3. Lipids

Edible insects contain on average 10 to 60% of fat in dry matter (Table 3). This is higher in the larval stages than in adults [18]. Caterpillars belong among insects with the highest fat content. Tzompa-Sosa

Table 1
Energy value of edible insect.
Source: van Huis et al. [11].

English name	Latin name	Stage	Locality	En. value (kcal/100 g)
Australian plague locust	*Chortoicetes terminifera*	Adult	Australia	499
Weaver ant	*Oecophylla smaragdina*	Adult	Australia	1272
Yellow mealworm beetle	*Tenebrio molitor*	Larva	USA	206
Yellow mealworm beetle	*Tenebrio molitor*	Adult	USA	138
Mexican leafcutting ant	*Atta mexicana*	Adult	Mexico	404
Two-spotted cricket	*Gryllus bimaculatus*	Adult	Thailand	120
Japanese grasshopper	*Oxya japonica*	Adult	Thailand	149
Brown-spotted locust	*Cyrtacanthacris tatarica*	Adult	Thailand	89
Silkworm	*Bombyx mori*	Pupa	Thailand	94
African migratory locust	*Locusta migratoria*	Adult	Netherlands	179

et al. [23] determined the total fat content in caterpillars (*Lepidoptera*) from 8.6 to 15.2 g per 100 g of insects. In contrast, the fat content ranges from 3.8 g to 5.3 g per 100 g of insects in grasshoppers and related *Orthoptera* species.

Fat is present in several forms in the insect. Triacylglycerols constitute about 80% of fat. They serve as an energy reserve for periods of high energy intensity, such as longer flights. Phospholipids are the second most important group. Their role in the structure of cell membranes has been studied [23]. The content of phospholipids in fat is usually less than 20%, but it varies according to the life stage and insect species [23,24].

There is a relatively high content of C18 fatty acids including oleic, linoleic and linolenic acids in the fat of insects [23]. Palmitic acid content is also relatively high. Fatty acid profile is affected by food, which the insects feed upon [22].

Cholesterol is the most abundant sterol in insects. Ekpo et al. [24] studied the content of cholesterol in the fat of the termite *Macrotermes bellicosus* and the caterpillar *Imbrasia belina*, which are commonly consumed in Nigeria. They found that the average cholesterol content in the lipid fraction was 3.6%. Apart from cholesterol, campesterol, stigmasterol, β-sitosterol and other sterols may be also present in edible insects [25].

3.4. Fibre

Edible insects contain a significant amount of fibre. Insoluble chitin is the most common form of fibre in the body of insects contained mainly in their exoskeleton [11]. Chitin in commercially farmed insects ranged from 2.7 to 49.8 mg per kg of fresh weight (from 11.6 to 137.2 mg per kg of dry matter) [26]. Chitin is considered as an indigestible fibre, even though the enzyme chitinase is found in human gastric juices [27]. However, it was found that this enzyme may be inactive. Active chitinase response in the body prevails among people from tropical countries where the consumption of insects has a long-term tradition [28]. Removal of chitin improves the digestibility of insect protein [26].

Chitin is also associated with the defence of the organisms against some parasitic infections and allergic states [26]. Lee et al. [29] reported that chitin was antivirally active against tumorigenesis. Chitin and its derivative chitosan have properties that could improve the immune response of specific groups of people. They helped some individuals to be more resistant against pathogenic bacteria and viruses. There are also indications that chitin could reduce allergic reactions to certain individuals [30,31]. Chitin of insect exoskeletons acts in the human body like cellulose and because of this effect it is often called “animal fibre” [32]. Bednářová et al. [33] analysed the amount of fibre in 7 different species of edible insects. The African migratory locust had the highest content, while the Jamaican field cricket contained the least fibre (Table 4).

3.5. Minerals

Edible insects can be interesting in terms of nutritional content of minerals such as iron, zinc, potassium, sodium, calcium, phosphorus, magnesium, manganese and copper [11]. For example, the large caterpillar of the moth *Gonimbrasia belina* called *mopani* or *mopane* has a high iron content (31–77 mg per 100 g of dry matter) and so does the grasshopper *L. migratoria* (8–20 mg per 100 g of dry matter) [34]. Caterpillars of *mopane* could be a good source of zinc (14 mg per 100 g of dry matter) together with palm weevil larvae *Rhynchophorus phoenicis* (26.5 mg per 100 g of dry matter) [22]. On the other hand, the heavy metal content of an edible grasshopper *Oxya chinensis formosana* determined by Hyun et al. [35] was low and safe for human consumption.

3.6. Vitamins

Insects contain a variety of water soluble or lipophilic vitamins [18,19,36,37]. Bukkens [22] listed a variety of insects containing thiamine. Its content ranges from 0.1 to 4 mg per 100 g of dry matter. Riboflavin is represented in edible insects in amounts from 0.11 to 8.9 mg to 100 g. Vitamin B12 is found in abundance in larvae of the yellow mealworm beetle *T. molitor* (0.47 μg per 100 g) and the house cricket *Acheta domesticus* (5.4 μg per 100 g in adults, 8.7 μg per 100 g in nymphs). However, many other species that have been analysed contain only negligible amounts of this vitamin [22,36].

Retinol and β-carotene were detected in some butterfly caterpillars, such as the species *Imbrasia oyemensis*, *Nudaurelia oyemensis*, *Ichthyodes truncata* and *Imbrasia epimethea* containing 32–48 μg of

Table 2
Protein content in 100 insect species.
Source: Xiaoming et al. [18].

Order or suborder	Latin name	Stage	Protein content (% in dry matter)
Beetles	Coleoptera	Adults and larvae	23–66
Butterflies	Lepidoptera	Pupae and larvae	14–68
Hemipterans	Hemiptera	Adults and larvae	42–74
Homopterans	Homoptera	Adults, larvae and eggs	45–57
Hymenopterans	Hymenoptera	Adult, pupae, larvae and eggs	13–77
Dragonflies	Odonata	Adults and naiads	46–65
Orthopterans	Orthoptera	Adults and nymphs	23–65

Table 3
Fat content in dry matter of edible insects.
Source: Bednářová [16].

English name	Latin name	Stage	Fat content (% in dry matter)
Silkworm	*Bombyx mori*	Pupa	29
Western honey bee	*Apis melifera*	Brood	31
African migratory locust	*Locusta migratoria*	Nymph	13
Wax moth	*Galleria mellonella*	Caterpillar	57
Jamaican field cricket	*Gryllus assimilis*	Nymph	34
Yellow mealworm	*Tenebrio molitor*	Larva	36
Giant mealworm	*Zophobas atratus*	Larva	40

Table 4
Neutral-detergent fibre content (cellulose, hemicellulose and lignin) in the dry matter of edible insects.
Source: Bednářová [16].

English name	Latin name	Stage	Fibre content (% in dry matter)
Silkworm	*Bombyx mori*	Pupa	14
Western honey bee	*Apis melifera*	Brood	11
African migratory locust	*Locusta migratoria*	Nymph	27
Wax moth	*Galleria mellonella*	Caterpillar	21
Jamaican field cricket	*Gryllus assimilis*	Nymph	8
Yellow mealworm	*Tenebrio molitor*	Larva	18
Giant mealworm	*Zophobas atratus*	Larva	17

Table 5
Taste and flavour of selected edible insect species.
Source: Ramos-Elorduy [41].

Edible insect	Taste and flavour
Ants, termites	Sweet, almost nutty
Larvae of darkling beetles	Wholemeal bread
Larvae of wood-destroying beetles	Fatty brisket with skin
Dragonfly larvae and other aquatic insects	Fish
Cockroaches	Mushrooms
Striped shield bugs	Apples
Wasps	Pine seeds
Caterpillars of smoky wainscots	Raw corn
Mealybugs	Fried potatoes
Eggs of water boatman	Caviar
Caterpillars of erebid moths	Herring

retinol and 6.8–8.2 μg of β-carotene per 100 g of dry matter. The level of retinol per 100 g of dry matter was less than 20 μg and the level of β-carotene was less than 100 μg in the case of yellow mealworms *T. molitor*, superworms *Z. morio* and house crickets *A. domesticus* [22,36,38]. According to Finke [36] several species of lepidopteran larvae and the soldiers of one species of termites (*Nasutitermes corniger*) contain significant quantities of preformed vitamin A (retinol), but in general, insects do not appear to contain much preformed vitamin A.

Vitamin E was found in the larvae of the red palm weevil *Rhynchophorus ferrugineus*, which have on average 35 mg of α-tocopherol and 9 mg of tocopherols β + γ per 100 g of dry matter [22]. The silkworm *Bombyx mori* contained 9.65 mg of tocopherols per 100 g of dry matter [39]. Escamoles and eggs of the Formicidae family could serve as a good source of vitamins A, D and E. They contained 505 μg/100 g of retinol, 3.31 μg/100 g of cholecalciferol and 2.22 mg/100 g of alpha-tocopherol [40]. According to Rumpold and Schlüter [15], insects are generally rich in riboflavin, pantothenic acid, and biotin. On the other hand, they are not an efficient source of vitamin A, vitamin C, niacin, and in most cases thiamin. Oonocx and Dierenfeld [37] also reported that the vitamin E content was low for most analysed insect species (6–16 mg/kg DM), except for *Dorsophila melanogaster* and *Microcentrum rhombifolium* (112 and 110 mg/kg DM). The retinol content, as a measure of vitamin A activity, was low in all specimens, but varied greatly among samples (0.670–886 mg/kg DM). It should be noted that the content of vitamins and minerals in wild edible insects is seasonal and in the case of farm bred species it can be controlled via feed.

4. Sensory quality of edible insect

In many countries of the world insects are consumed alive immediately after being caught. In the case of further processing, the best method for their humane killing is scalding by hot water after starvation for 1–3 days [32]. Other subsequent culinary processing may be cooking, baking, frying or drying. Larvae of the yellow mealworm, smaller larvae of mealworms and migratory locusts belong to the three most common types of insects offered in special stores where edible insects are bred and processed for human consumption [11,32,41].

Sensory properties are important criteria accompanying the consumption of edible insects. Taste and flavour of insects are very diverse (Table 5). Flavour is mainly affected by pheromones occurring at the surface of the insect organism [41]. It also depends on the environment where insects live and the feed that they eat. Selection of feed can also be adapted depending on how we wish insects to taste. If insects are scalded, they are practically tasteless, because pheromones are washed off by rinsing. During cooking insects take the flavour of added ingredients.

The exoskeleton of insects has a great influence on the texture. Insects are crunchy and sounds accompanying their eating resemble the sounds of crackers or pretzels [41]. Pupae, larvae (caterpillars) and nymphs are the most consumed stages of edible insects as they contain a minimal amount of chitin. Therefore, they are not so crispy during their consumption and are more digestible for the human body. The vast majority of insects is almost odour-free due to the exoskeleton [41]. A pleasing colour does not always indicate that an insect is delicious. During cooking, the insect's colour usually changes from the original shades of grey, blue or green to red [41]. Insects containing a considerable amount of oxidized fat, or improperly dried insects, may be black. Properly dried insects are golden or brown and can be easily crushed by the fingers [32].

5. Risks of insects eating

Eating insects could pose certain risks that must be taken into account. The risk profile related to the consumption of insects has been recently published by the EFSA [7]. A large collection of insects in the wild could pose serious interference to the landscape ecosystem. Therefore, it is recommended to consume insects reared at farms in controlled and defined conditions. The subsequent health safety of edible insects is thus ensured by the choice of appropriate and safe feed. The results of analyses carried out in the years 2003–2010 has shown possible risks of eating insects fed by bran containing a higher concentration of heavy metals [42]. It is not recommended to consume insects fed by an inappropriate diet, for example by organic wastes. On the other hand, Fontenot [43] concluded that with good management, animal wastes can be used safely as animal feed for insect protein synthesis.

Some insects can also contain naturally present toxic substances such as cyanogenic glycosides [44]. According to Vijver et al. [45] *T. molitor* larval body concentrations of Cd and Pb correlated also to the total metal pool of the soil in which the insects lived.

Other possible risks of consuming edible insects are eating inappropriate developmental stages of insects, poor handling and culinary treatment. According to Bouvier [46] consumption of grasshoppers and locusts without removing their feet can lead to intestinal blockage, which could have fatal consequences. Eating insects can also cause allergies. Some insects have a rigid external covering for the body formed of chitin, which is difficult to digest for humans. Today, due to the lack of food containing chitin there is a deficiency of the enzyme chitinase which cleaves chitin. Some individuals have such a small amount of this enzyme that the eating of insects can cause an allergic reaction to them [7]. People most at risk are those who are allergic to seafood, such as shrimp [33].

It is also important to consider the risk of transmission of infectious diseases from some insect species. Intestinal microbiota of insects could be a suitable medium for the growth of undesirable microorganisms. Klunder et al. [20] evaluated the microbial content of fresh, processed and stored edible insects *T. molitor*, *A. domesticus* and *Brachytrupes*. The results showed that various types of Enterobacteriaceae and sporulating bacteria can be identified and subsequently isolated from raw insects entering them most likely during contact with the soil [47]. If proper fasting, heat treatment and appropriate storage conditions are not assured edible insects may become dangerous from a microbiological point of view [10,48].

6. Conclusion

Insects are a nutritionally interesting material, and may be included among the common diet of consumers in EU countries in the future. They could also be used as a nutritional supplement for special diets for example for athletes. Inclusion of potentially suitable species of insects into the normal diet requires defined and standardized conditions of their rearing as well as the detailed monitoring of their composition including biologically active substances. Though the EFSA has already assessed hygienic and toxicological risks related to edible insects, more research on their composition and nutrient profile should be carried out in order to be able to fully implement edible insects as food into the EU legislation documents.

Conflicts of interest

None.

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References

[1] J. Evans, M.H. Alemu, R. Flore, M.B. Frøst, A. Halloran, A.B. Jensen, G. Maciel-Vergara, V.B. Meyer-Rochow, C. Münke-Svendsen, S.B. Olsen, C. Payne, N. Roos, P. Rozin, H.S.G. Tan, A. van Huis, P. Vantomme, J. Eilenberg, 'Entomophagy': an evolving terminology in need of review, J. Insects Food Feed 1 (2015) 293–305.
[2] M. Sponheimer, D. de Ruiter, J. Lee-Thorp, A. Späth, Sr/Ca and early hominin diets revisited: new data from modern and fossil tooth enamel, J. Hum. Evol. 48 (2005) 147–156.
[3] Entomophagy: human Consumption of Insects, in: J. Mitsuhashi, J.L. Capinera (Eds.), Encyclopedia of Entomology, Springer, Heidelberg, Springer 2008, pp. 1341–1343.
[4] J.J. Lesnik, Termites in the hominin diet: a meta-analysis of termite genera, species and castes as a dietary supplement for South African robust australopithecines, J. Hum. Evol. 71 (2014) 94–104.
[5] Y. Jongema, World List of Edible Insects, Laboratory of Entomology, Wageningen University, Wageningen, 2015 (available at: http://www.wageningenur.nl/en/Expertise-Services/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm).
[6] A.L. Dreon, M.G. Paoletti, The wild food (plants and insects) in Western Friuli local knowledge (Friuli-Venezia Giulia, North Eastern Italy), Contrib. Nat. Hist. 12 (2009) 461–488.
[7] EFSA, Risk profile related to production and consumption of insects as food and feed, EFSA J. 13 (2015) 4257.
[8] H.C.J. Godfray, I.R. Crute, L. Haddad, D. Lawrence, J.F. Muir, N. Nisbett, J. Pretty, S. Robinson, C. Toulmin, R. Whiteley, The future of the global food system, Philos. Trans. R. Soc. B-Biol. Sci. 365 (2010) 2769–2777.
[9] Y. Luan, X. Cui, M. Ferrat, Historical trends of food self-sufficiency in Africa, Food Secur. 5 (2013) 393–405.
[10] R. Cerritos, Z. Cano-Santana, Harvesting grasshoppers *Sphenarium purpurascens* in Mexico for human consumption: a comparison with insecticidal control for managing pest outbreaks, Crop. Prot. 27 (2008) 473–480.
[11] A. van Huis, J. van Itterbeeck, H. Klunder, E. Mertens, A. Halloran, G. Muir, P. Vantomme, Edible Insects. Future Prospects for Food and Feed Security, FAO, Rome, 2013 (201 pp.).
[12] R. Cerritos, Insects as food: an ecological, social and economical approach, CAB Rev.: Perspect. Agric. Vet. Sci. Nutr. Nat. Res. 4 (2009) 1–10.
[13] M.D. Finke, D. D. Oonincx, Insects as food for insectivores, in: J. Morales-Ramos, G. Rojas, D.I. Shapiro-Ilan (Eds.), Mass Production of Beneficial Organisms: Invertebrates and Entomopathogens, Elsevier, New York 2014, pp. 583–616.
[14] C.L.R. Payne, P. Scarborough, M. Rayner, K. Nonaka, Are edible insects more or less 'healthy' than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over- and undernutrition, Eur. J. Clin. Nutr. 70 (2016) 285–291.
[15] B.A. Rumpold, O.K. Schlüter, Nutritional composition and safety aspects of edible insects, Mol. Nutr. Food Res. 57 (2013) 802–823.
[16] M. Bednářová, Possibilities of Using Insects as Food in the Czech Republic Dissertation thesis Mendel University, Brno, 2013 50–92.
[17] J. Ramos-Elorduy, J.M. Pino, E.E. Prado, M.A. Perez, J.L. Otero, O.L. de Guevara, Nutritional value of edible insects from the state of Oaxaca, Mexico, J. Food Compos. Anal. 10 (1997) 142–157.
[18] C. Xiaoming, F. Ying, Z. Hong, Review of the nutritive value of edible insects. Edible insects and other invertebrates in Australia: future prospects, Proceedings of a Workshop on Asia-Pacific Resources and their Potential for Development, 19–21 February 2008, Bangkok 2010, pp. 85–92.
[19] M.D. Finke, Nutrient content of insects, in: J.L. Capinera (Ed.), Encyclopedia of Entomology, Kluwer Academic, Dordrecht, London 2004, pp. 1562–1575.
[20] H.C. Klunder, J. Wolkers-Rooijackers, J.M. Korpela, M.J.R. Nout, Microbiological aspects of processing and storage of edible insects, Food Control 26 (2012) 628–631.
[21] A. Sogbesan, A. Ugwumba, Nutritional evaluation of termite (*Macrotermes subhyalinus*) meal as animal protein supplements in the diets of *Heterobranchus longifilis*, Turk. J. Fish. Aquat. Sci. 8 (2008) 149–157.
[22] S.G.F. Bukkens, 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, Science Publishers, New Hampshire 2005, pp. 545–577.
[23] D.A. Tzompa-Sosa, L.Y. Yi, H.J.F. van Valenberg, M.A.J.S. van Boekel, C.M.M. Lakemond, Insect lipid profile: aqueous versus organic solvent-based extraction methods, Food Res. Int. 62 (2014) 1087–1094.
[24] K.E. Ekpo, A.O. Onigbinde, I.O. Asia, Pharmaceutical potentials of the oils of some popular insects consumed in southern Nigeria, Afr. J. Pharm. Pharmacol 3 (2009) 51–57.
[25] M. Sabolová, A. Adámková, L. Kouřimská, D. Chrpová, J. Pánek, Minor lipophilic compounds in edible insects, Potravinarstvo 10 (2016) (in print).
[26] M.D. Finke, Estimate of chitin in raw whole insects, Zoo Biol. 26 (2007) 105–115.
[27] M.G. Paoletti, L. Norberto, R. Damini, S. Musumeci, Human gastric juice contains chitinase that can degrade chitin, Ann. Nutr. Metab. 51 (2007) 244–251.
[28] R.A.A. Muzzarelli, M. Terbojevich, C. Muzzarelli, M. Miliani, O. Francescangeli, Partial depolymerization of chitosan with the aid of papain, in: R.A.A. Muzzarelli (Ed.), Chitin Enzymology, Atec, Grottammare 2001, pp. 405–414.
[29] K.P. Lee, S.J. Simpson, K. Wilson, Dietary protein-quality influences melanization and immune function in an insect, Funct. Ecol. 22 (2008) 1052–1061.
[30] W.G. Goodman, Chitin: a magic bullet? Food Insects Newsl. 2 (1989) 6–7.
[31] R.A.A. Muzzarelli, Chitins and chitosans as immunoadjuvants and non-allergenic drug carriers, Mar. Drugs 8 (2010) 292–312.
[32] M. Borkovcová, M. Bednářová, V. Fišer, P. Ocknecht, Kitchen Variegated by Insects 1, Lynx, Brno, 2009.
[33] M. Bednářová, M. Borkovcová, J. Mlček, O. Rop, L. Zeman, Edible insects — species suitable for entomophagy under condition of Czech Republic, Acta Univ. Agric. Silvic. Mendelianae Brun. 61 (2013) 587–593.
[34] D.G.A.B. Oonincx, J. van Itterbeeck, M.J.W. Heetkamp, H. van den Brand, J.J.A. van Loon, A. van Huis, An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption, PLoS One 5 (2010) e14445.
[35] S.H. Hyun, K.H. Kwon, K.H. Park, H.C. Jeong, O. Kwon, H. Tindwa, Y.S. Han, Evaluation of nutritional status of an edible grasshopper, *Oxya chinensis formosana*, Entomol. Res. 42 (2012) 284–290.
[36] M.D. Finke, Complete nutrient composition of commercially raised invertebrates used as food for insectivores, Zoo Biol. 21 (2002) 269–285.
[37] D.G.A.B. Oonincx, E.S. Dierenfeld, An investigation into the chemical composition of alternative invertebrate prey, Zoo Biol. 31 (2012) 40–54.
[38] D.G.A.B. Oonincx, A.F.B. van der Poel, Effects of diet on the chemical composition of migratory locusts (*Locusta migratoria*), Zoo Biol. 30 (2011) 9–16.
[39] L. Tong, X. Yu, H. Lui, 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, Bull. Entomol. Res. 101 (2011) 613–622.
[40] V. Melo-Ruiz, T. Quirino-Barreda, C. Calvo-Carrillo, K. Sánchez-Herrera, H. Sandoval-Trujillo, Assessment of nutrients of escamoles ant eggs *Liometupum apiculatum* M. by spectroscopy methods, J. Chem. Chem. Eng. 7 (2013) 1181–1187.
[41] J. Ramos-Elorduy, Creepy Crawly Cuisine: The Gourmet Guide to Edible Insects, Park Street Press, South Paris, 1998.
[42] M. Bednářová, M. Borkovcová, G. Zorníková, L. Zeman, Insect as food in Czech Republic, Proceedings MendelNet, 24 November, 2010, Mendel University, Brno 2010, pp. 674–682.
[43] J.P. Fontenot, Nutrient recycling: the North American experience — review, Asian Australas. J. Anim. Sci. 12 (1999) 642–650.
[44] M. Zagrobelny, A.L. Dreon, T. Gomiero, G.L. Marcazzan, M.A. Glaring, B.L. Moller, M.G. Paoletti, Toxic moths: source of a truly safe delicacy, J. Ethnobiol. 29 (2009) 64–76.
[45] M. Vijver, T. Jager, L. Posthuma, W. Peijnenburg, Metal uptake from soils and soil–sediment mixtures by larvae of *Tenebrio molitor* (L.) (Coleoptera), Ecotoxicol. Environ. Saf. 54 (2003) 277–289.
[46] G. Bouvier, Quelques questions d'entomologie vétérinaire et lutte contre certains arthropodes en Afrique tropicale, Acta Trop. 2 (1945) 42–59.
[47] K. Reineke, I. Doehner, K. Schlumbach, D. Baier, A. Mathys, D. Knorr, The different pathways of spore germination and inactivation in dependence of pressure and temperature, Innovative Food Sci. Emerg. Technol. 13 (2012) 31–41.
[48] V. Giaccone, Hygiene and health features of "minilivestock", in: M.G. Paoletti (Ed.), Ecological Implications of Minilivestock; Role of Rodents, Frogs, Snails, and Insects for Sustainable Development, Science Publishers, New Hampshire 2005, pp. 579–598.