Food Chemistry 193 (2016) 39–46

Contents lists available at ScienceDirect

Food Chemistry

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

Analytical Methods

Review of food composition data for edible insects ☆

Verena Nowak, Diedelinde Persijn, Doris Rittenschober, U. Ruth Charrondiere *

Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla 1, 00153 Rome, Italy

A R T I C L E I N F O

Article history:
Received 25 February 2014
Received in revised form 19 October 2014
Accepted 20 October 2014
Available online 15 November 2014

Keywords:
Edible insects
Food composition data
Tenebrio molitor
Nutrient variation
Biodiversity
Underutilised
INFOODS
FAO

A B S T R A C T

Edible insects are considered rich in protein and a variety of micronutrients, and are therefore seen as potential contributors to food security. However, the estimation of the insects' contribution to the nutrient intake is limited since data are absent in food composition tables and databases. Therefore, FAO/INFOODS collected and published analytical data from primary sources with sufficient quality in the Food Composition Database for Biodiversity (BioFoodComp). Data were compiled for 456 food entries on insects in different developmental stages. A total of 5734 data points were entered, most on minerals and trace elements (34.8%), proximates (24.5%), amino acids (15.3%) and (pro)vitamins (9.1%). Data analysis of *Tenebrio molitor* confirms its nutritive quality that can help to combat malnutrition. The collection of data will assist compilers to incorporate more insects into tables and databases, and to further improve nutrient intake estimations.

1. Introduction

The UN projected the world population to reach 9.6 billion people in 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2013) which will require increased food and feed outputs. Edible insects are traditionally consumed in many parts of the world (DeFoliart, 1997) and are considered as having potential to contribute to the world's food security (van Huis, 2013). It is estimated that at least 2 billion people eat insects on a regular basis (van Huis et al., 2013), not only because of their nutritive value but also because of their taste (Nonaka, 2009). However, especially in urban and Western societies, insects are rarely eaten or consumption is even perceived as culturally inappropriate (FAO Regional Office for Asia, 2010; van Huis, 2013) and disgusting (Nonaka, 2009). But consumer perceptions can be changed as it was recognised in Thailand: entomophagy was mainly common in Northern and Northeastern regions but in recent years, it occurs more frequently nationwide and is no longer seen as a habit of poor and rural people (FAO Regional Office for Asia, 2013).

Insects are considered food with satisfactorily energy and protein content, good amino acid and fatty acid profiles and high contents of a variety of micronutrients such as the minerals copper, iron, magnesium, manganese, phosphorous, selenium, and zinc and the vitamins riboflavin, pantothenic acid, biotin, and in some cases folic acid (Rumpold & Schlüter, 2013). Beside those characteristics that can improve the nutrition status directly, insects also have positive effects on the environment. They play an important role in waste biodegradation and as pollinators in plant reproduction. Furthermore, they have a high feed conversion efficiency and their production is less land-dependent than conventional livestock, which makes them resource-saving food and feed, and it is probable that they produce less greenhouse gases and use significantly less water than conventional livestock (FAO Regional Office for Asia & the Pacific, 2010; Nakagaki & DeFoliart, 1991). Finally, increasing the production and consumption of edible insects is suspected to have an impact on livelihood and social conditions. Gathering and farming of insects can be done with a minimal input of technical or capital resources which gives also the poorest members of society a possibility to acquire income (FAO Regional Office for Asia & the Pacific, 2010).

Up to now, about 2000 edible insect species are known (Jongema, 2013). Compared to this huge variety, only little is known about the nutrient composition and contribution. In a recent review, chemical composition of 236 edible insects have been published (Rumpold & Schlüter, 2013). However, those data are presented on a dry matter basis only, which cannot directly be used for the assessment of human nutrition and for food composition databases (FCDBs), as foods are consumed on a fresh weight basis and, therefore, data are presented on a fresh weight basis in FCDBs.

☆ The views expressed in this publication are those of the author(s) and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations.

* Corresponding author. Tel.: +39 06 570 56 134; fax: +39 06 570 53 879.
E-mail address: ruth.charrondiere@fao.org (U.R. Charrondiere).

http://dx.doi.org/10.1016/j.foodchem.2014.10.114
0308-8146/

INFOODS (International Network of Food Data Systems), since its establishment in 1984, aims to stimulate and coordinate efforts to improve the quality and availability of compositional data globally. INFOODS in collaboration with the Food and Agriculture Organization of the United Nations (FAO) published in 2010 the first version of the FAO/INFOODS Food Composition Database for Biodiversity (BioFoodComp) (Charrondiere & Burlingame, 2011; FAO/INFOODS., 2013b) according to INFOODS guidelines and standards (FAO/INFOODS, 2012a, 2012b, 2012c, 2012d). This database is a growing repository of solely analytical data. Since version 2.0, published in 2012, data on edible insects are part of the compiled food entries (Charrondière et al., 2013). FAO actively promotes the conservation and sustainable use of biodiversity for nutrition and agriculture and was explicitly requested in 2013 by the Commission on Genetic Resources for Food and Agriculture (CGRF) to regularly update the BioFoodComp (FAO, 2013).

To the best of our knowledge, no comprehensive compilation on the nutritional values on a fresh weight basis of insects was published so far. Information on food composition is fundamental and useful for nutrition-based programmes, projects and policies, as well as for optimising feed. Therefore, the objective of this review is to give a general overview of the available nutrient values on edible insects found in the scientific literature and to express, evaluate, and compare the species similarities and differences based on their nutrient composition. The mealworm (*Tenebrio molitor*) will serve as an example for detailed information on nutrient data and discussion of results.

2. Materials and methods

2.1. Data sources

An extensive literature search was performed from January to March 2012 through Scopus and Science Direct. The following key words were used: edible insects/grasshopper/beetle/cricket/bug/ant/silkworm/fly/moth, nutritional value, proximate, protein/fat/carbohydrate/fibre/mineral. The compositional data were collected from scientific papers, research articles, short communications, reports and scholars research. The papers were screened for food composition data. The bibliography of the identified articles led to further relevant articles. Additionally, relevant unpublished data were directly provided by scientists, e.g. through the INFOODS discussion list (http://www.fao.org/infoods/infoods/discussion-list/en/). Furthermore, an internal database on edible insects of FAO and the Wageningen University and Research centre including 1911 references was screened for food composition data. Out of those, only 7 articles provided compositional data that fit our purpose. When information was not clear or missing in the publication, the authors were contacted for clarification.

The compositional data on edible insects in the ASEAN Food Composition Table (Puwastien, Mahidon, & System, 2000) and the West-Africa Food Composition Table (Stadlmayr et al., 2012) were used for comparison and plausibility checks.

2.2. Inclusion and exclusion of data and data quality

Foods included in BioFoodComp are foods described at cultivar/variety/breed level as well as wild and underutilised foods. Detailed criteria for biodiverse foods have been described elsewhere (INFOODS., 2013). Insects are considered underutilised foods according to the INFOODS List of underutilised species contributing to the Nutritional Indicators for Biodiversity Version 1.2 (INFOODS, 2013) and are, therefore, eligible to be included, even if they are described at species level or above. Only primary analytical data with sufficient documentation on raw, dried and processed single foods were included, which either were expressed as per edible portion on fresh weight basis (EP) or which could be transformed into this data expression.

Exclusion criteria were defined prior to data compilation (Table 1). Reasons for exclusion included, i.e. imprecise food and value description and inconsistent or implausible data. Furthermore, selected checks from the FAO/INFOODS Guidelines for Checking Food Composition Data prior to the Publication of a User Table/Database – Version 1.0 (FAO/INFOODS, 2012a) were applied. Those checks concerned mainly the consistency and plausibility of the data, for example: the sum of proximates (water, carbohydrate, fat, protein, ash, and alcohol) was within the acceptable range; the sum of amino acids corresponded to the protein value; the sum of fatty acids corresponded to the total fat content; the energy content and vitamin equivalents were calculated correctly; and outliers were identified. In case a problem was identified, values were either marked by putting them into brackets or excluded, depending on the amount of deviation from mean values and availability of data for comparison. No universe exclusion criteria was applied for all species as often no data for comparison were available because of the wide diversity within the animal class of insects. As data on insects are rarely reported and the natural variation might be high, it was decided to keep as much data as possible and put them preferably into brackets as indication of low quality instead of excluding them from the database. Reasons for such decisions were documented in the database.

In this article, data in brackets were considered for the description of the database, e.g. the number of data points, but they were excluded from the calculation of nutrient content values.

2.3. Standardisation and compilation

Standardisation of data is necessary as data expressions and definitions vary substantially throughout different publications. The standard used for the present work was based on the FAO/INFOODS compilation tool, which is a simple food composition database management system based on Microsoft Excel (Charrondiere & Burlingame, 2011; FAO/INFOODS, 2013b). Data were expressed as per 100 g EP. For an unequivocal identification of food components, the system of the INFOODS food component identifiers (tagnames) was used (FAO/INFOODS, 2012d; Klensin, Feskanich, Lin, Truswell, & Southgate, 1989). Conversions of units and denominators were done according to the FAO/INFOODS Guidelines for Converting Units, Denominators and Expressions – version 1.0 (FAO/INFOODS, 2012b). One of the most important conversions was from data presented as per dry matter to per fresh weight of edible portion (EP). The conversion was possible when either the percentage of dry matter or the water content was given in the publication or was provided by authors via personal communication using the following equation:

$$\frac{\text{Nutrient value}\,(\text{g}/100\,\text{g dry matter})}{100} \times (100 - \text{water content}\,(\text{g}/100\,\text{g EP})) = \text{nutrient value}\,(\text{g}/100\,\text{g EP})$$

All data that fulfilled the quality criteria and could be expressed as per 100 g EP were compiled in the FAO/INFOODS Food Composition Database for Biodiversity (version 2.1) (FAO/INFOODS, 2013a) which is freely available from http://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/.

2.4. Nutrient reference values to determine if the food is 'source' of a nutrient or has 'high' content according to Codex Alimentarius

According to the definitions for food labelling by Codex Alimentarius (WHO, 2007), a solid food product is a source of protein, when the protein content is at least 10% of the Nutrient Reference

Table 1
Exclusion criteria for the selection of scientific articles.

Data were excluded in the following cases
Insufficient food description
• It was not clear whether data referred to the edible portion
• Mixed dishes: only single foods were included, except for the addition of the ingredients fat and salt during cooking
Insufficient data description
• Missing or ambiguous units and denominators (e.g. not clear whether dry or fresh weight basis)
• Data displayed only graphically in figures and graphs without providing the related values
Conversion to 'per 100 g edible portion on a fresh weight basis' (EP) was not possible because of missing
• Total protein or total lipid contents as g/100 g EP, when values on fatty (or amino) acids were expressed as g/100 g or fatty acids or as g/100 g total lipid (protein)
• Water (or dry matter) content per 100 g EP, when data were expressed as percentage or g per dry matter content
Inconsistency
• The sum of the proximate composition below 95 or above 105 g, if all proximates were given and no comprehensible reason for a value out of this range could be found
• The sum of the amino acids was too low/high in comparison to the protein content
• The sum of the fatty acids was too low/high in comparison to the total lipid content

Value (NRV), and a source of vitamins and minerals, when the content is 15% of the Nutrient Reference Value. A food product may be labelled as 'high' in a nutrient, when the nutrient value is twice the value required for a 'source'. The respective thresholds were calculated for each nutrient using the NRV for labelling purposes (WHO & FAO, 2007) and compared with nutrient content values (mean, minimum and maximum) of *T. molitor* (Table 4).

3. Results and discussion

3.1. Description of the database

Food composition data were compiled into the BioFoodComp 2.1 together with additional information describing the food entry (metadata): the data source; the country and/or region where the samples were obtained; the food name in local language and in English; species/subspecies names; season of sampling; and other relevant information e.g. if the insects were fed on a specific diet; description of inedible parts etc. Data were documented as detailed as possible in order to include all factors that possibly affect the component values as far as they were mentioned in the data source. This includes information on how insects were obtained, i.e. whether they were farmed or collected in the wild and when farmed, on which substrate. The database holds information from 65 publications on insects. Data for 456 food entries were compiled comprising 5734 values. For each food entry, values of at least two and up to 68 components were compiled.

Data on 235 insect species were covered. For 8 food entries, no scientific name could be assigned as the food description in the paper was not detailed enough. The most common species were *T. molitor* (38 food entries) and *Acheta domesticus* (18 food entries) and for 149 species only one food entry was included. Regarding the biological taxonomy, species belonged to 18 orders of which for Lepidoptera (butterflies, moths) the most food entries were compiled (22.3% of total food entries, excluding 8 food entries without scientific name) followed by Coleoptera (beetles, grubs; 21.7%) (Fig. 1). Most of the identified edible insect species belong to Coleoptera (31%), Lepidoptera (18%), and Hymenoptera (14%) (van Huis et al., 2013). This fits well with the finding that Coleoptera and Lepidoptera are the orders of which the most nutrient data are available.

Regarding the processing state, 376 food entries were on raw insects, 41 on dried, and 39 on processed insects. Processed included the following: flour; toasted; toasted and dried; fried; deep fried; boiled; blanched; and roasted. For insects collected in the wild, 254 entries were available and for reared insects 202 food entries.

The majority of insects were sampled in Northern America (54%) followed by Africa (11%) and Asia (10%) (Fig. 2). For 10% of all food entries, the sample origin was not reported. The regional distribution of samples does not reflect human consumption of insects, as eating insects is still a rare practise in Western countries, but more the fact that the composition of insects has often been studied with the scope to assess insects as animal feed, e.g. Finke (2002) and Punzo (2003).

All insects undergo a metamorphosis with different development stages and they can be consumed in all those different stages. The majority of data was compiled for adult insects (67.5%) and larval stages (25.7%). Other reported development stages reported were eggs; immature; larva and adult; nymph; prepupae; pupa; nymph and adult. Nutrient contents can differ substantially between development stages as, e.g. shown by Hocking and Matsumura (1960) in the honey bee (*Apis mellifera*), where the moisture content was 83% in the young larva, 77% in the mature larva and 70% in the pupa.

The worksheet in BioFoodComp2.1 on edible insects contains values on 160 INFOODS tagnames. A total of 5734 values were compiled of. Most data were on minerals and trace elements (34.8%), followed by proximates (24.5%), and amino acids including aggregations of amino acids (15.3%) (Table 2). The high amount of data on amino acids reflects the high interest especially in this component group as a potential alternative protein source (Ghaly & Alkoaik, 2010; van Huis et al., 2013). Compared to other food groups such as fish and shellfish (Rittenschober, Nowak, & Charrondiere, 2013) and fruits (Stadlmayr, Charrondière, Eisenwagen, Jamnadass, & Kehlenbeck, 2013), where only 2% and 5% of available data were found for vitamins, the 9.1% of data on vitamins and provitamins for edible insects is a high number.

Like most animals, edible insects are rich in protein and fat but are poor in carbohydrates. However, insects are a special animal group regarding dietary fibres. Most of the 174 data on dietary fibres were analysed using acid detergent analysis (FIBAD, $n = 45$) or neutral detergent analysis (FIBND, $n = 69$), and 39 values were found on crude fibre and few values were found for the AOAC Prosky method (enzymatic–gravimetrical method; FIBTG, $n = 4$). In 21 cases, the method was not described sufficiently and no method-specific fibre tagname could be assigned, but 'unknown or mixed method' (FIB-). FIBTG represents the best dietary fibre expression for human consumption. However, the composition of insects has mainly been studied and published in the view of feed for animals, which explains that only a small proportion of data is analysed with the Prosky method.

According to Finke (2007), it is not yet totally clear, of which chemical compounds FIBND and FIBAD consist in insects. Differences between FIBAD and FIBND are generally explained by hemicellulose, however, it might be that other components are part of them as well, e.g. chitin in the case of edible insects. In

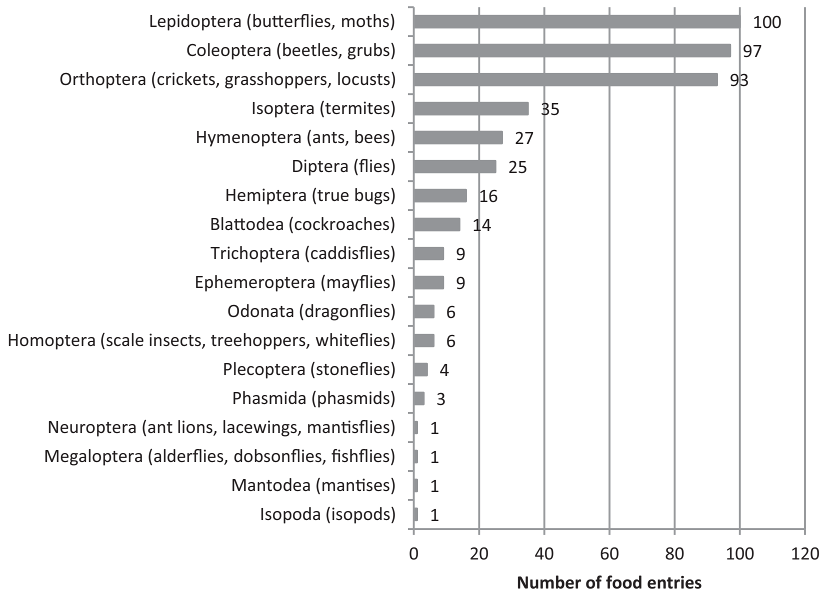

Fig. 1. Number of food entries, by order, included in BioFoodComp (total number food entries = 448).

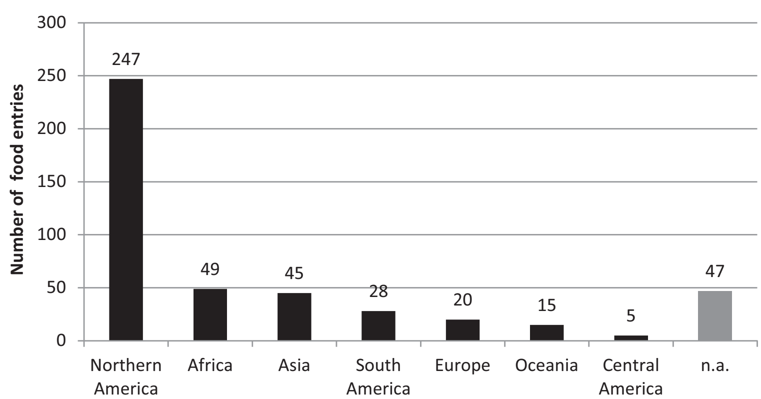

Fig. 2. Number of food entries, by continent of origin of insect sample (n = 456); n.a.: no information available.

27 cases, both FIBAD and FIBND were reported for the same insect and FIBND values in general exceeded FIBAD values; the differences ranged from 0.0 to 9.5 g/100 g EP.

The FIBAD fraction includes considerable amounts of ammonia which is thought to be to come to a great extent from ammonia released through the breakdown of chitin (Finke, 2007). Therefore, the chitin-bound nitrogen, which is estimated to about 3–9% of nitrogen (Punzo, 2003), is double counted (as fibre and as protein) if the protein content is provided as crude protein, i.e. determined by analysing total nitrogen which is multiplied by a nitrogen-to-protein conversion factor. The sum of proximates in those cases can exceed 105 if no correction factor is being applied (Finke, 2007) (D. Oonincx, personal communication, March 21, 2012), what normally is not done. Therefore, values for the sum of proximates of >105 were accepted in cases, where the double counting could be the reason for an elevated value.

Calcium was the mineral with the most data entries (320 data points) followed by iron (290), magnesium (278), potassium (254), sodium (254), phosphorus (163), zinc (132), copper (121) and manganese (106). Only few data for toxic trace elements were compiled (0.3%), however, the collection of those compounds is not a priority for BioFoodComp (Charrondière et al., 2013) and no specific search was therefore performed but data were included when also other compositional data were available in the respective data source.

3.2. Descriptive analysis of nutrient data of *T. molitor*

To illustrate the differences in nutrient content within one species, data are presented in more detail for the *T. molitor*. *T. molitor* (order Coleoptera) is known as the mealworm in its larval stage and as the meal beetle in its adult stage. The mealworm is commonly used as feed for insectivores and also for human consumption (Finke, 2002). *T. molitor* represents the species with the most food entries (i.e. lines) in BioFoodComp2.1 covering 40 food entries for mealworms (36 larvae, 1 pupa and 3 adult beetles). Data derived from 14 different publications. Only in 4 of those, data were expressed per EP, data from the remaining 10 publications needed to be converted from per dry matter basis to per EP. All food entries were on raw and farmed insects. Table 3 shows proximate values for the larvae of *T. molitor*. Values considered of lower quality and, therefore, were put into brackets, were not considered for the following analysis.

Water values were similar for all maturity states (Table 3). In other insects, a decrease of the water content with increasing maturity was reported, e.g. for the honey bee, and the fruit fly

Table 2
Number of data points per component group, by component group.

Food component	Number of data points	Percent of data points
Energy	110	1.9
Proximates		
Water	439	7.7
Carbohydrates	103	1.8
Dietary fibre	174	3.0
Ash	238	4.2
Fat	256	4.5
Protein	191	3.3
Polysaccharides	7	0.1
Fatty acids and aggregations[a]	447	7.8
Total nitrogen	209	3.6
Nitrogen-to-protein conversion factor	61	1.1
Amino acids and aggergations[a]	876	15.3
Vitamins		
Fat-soluble vitamins	315	5.5
Water-soluble vitamins	207	3.6
Minerals and trace elements	1997	34.8
Toxic trace elements	17	0.3
Sterols including cholesterol	14	0.2
Other[b]	73	1.3
Total	5734	100.0

[a] Aggregation refers to the sum of individual fatty or amino acids.
[b] Other include: glycolipids, phospholipids, ammonium and choline, lignin, chitin, nitrogen from acid detergent fibre.

(Bernard & Allen, 1997; Hocking & Matsumura, 1960). In *T. molitor*, on the other hand, adults were not shown to have a lower water content, even when considering values deriving from a single study where both, larvae and adults were analysed using the same methodology (Finke, 2002).

All available protein values were calculated from the total nitrogen content. The applied nitrogen-to-protein conversion factor was 6.25 when reported in the publication. Protein values in larvae ranged from 13.68 to 22.32 g/100 g EP. The limit for the food label 'source of protein' is 5 g/100 g EP, for 'high in protein' 10 g/100 g EP (WHO & FAO, 2007), which means that all larva, adult, and pupa samples can be regarded as high in protein. Therefore, the general consideration of insects as good protein source (van Huis et al., 2013) can be confirmed.

Fat values for larvae showed ranges from 8.90 to 19.94 g/100 g EP for fat analysed with continuous extraction. Both the minimum and the maximum value, derived from the same publication where the minimum value refers to mealworms with a mean weight of 0.15 g and the maximum value from bigger mealworms with a mean weight of 0.75 g (Pennino, Dierenfeld, & Behler, 1991). This fact points out the necessity of a very detailed food description in food composition tables in order to ensure least possible errors in nutrient intake estimations. Data for saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA) were available for three food entries only, deriving from the same publication (Bednářová, Zorníková, Rozíková, & Borkovcová, 2011), and for further three food entries, SFA, MUFA, and PUFA were calculated from the individual fatty acids (Finke, 2002; Jones, Cooper, & Harding, 1972). *T. molitor* provides considerable amounts of PUFA (3.17–6.75 g/100 g EP) representing between 21% and 62% of total lipids. Rumpold and Schlüter (2013) in their review could not report fatty acid data on *T. molitor*, however, they reported a mean PUFA content of 27% of total lipid for the insect order Coleoptera, which lies within the range of our findings; however,

Table 3
Descriptives of proximate composition per 100 g EP of *Tenebrio molitor*, by maturity stage.

		n	Mean ± sd	Min	Max
Energy (kcal)[a]	Adult	3	178 ± 13	166	192
	Larva	14	214 ± 39	160	283
	Pupa	1	207		
Energy (kJ)[a]	Adult	3	742 ± 54	695	800
	Larva	14	892 ± 160	665	1172
	Pupa	1	863		
Water (g)	Adult	3	62.1 ± 1.4	61.2	63.7
	Larva	26	62 ± 4.6	55.6	71.0
	Pupa	1	61		
Total nitrogen (g)	Larva	3	2.92 ± 0.3	2.43	3.21
Protein (g)	Adult	2	24.13	23.7	24.59
	Larva	6	17.85 ± 3.33	13.68	22.32
	Pupa	1	12.01		
Total lipid (continuous extraction) (g)	Adult	1	7.1		
	Larva	7	13.07 ± 3.88	8.9	19.94
Total lipid (method unknown) (g)	Adult	2	6.14	5.4	6.87
	Larva	6	12.91 ± 2.6	10.11	16.8
	Pupa	1	12.91		
Saturated fatty acids (g)	Larva	3	2.2 ± 0.53	1.83	2.8
Monounsaturated fatty acids (g)	Larva	3	2.51 ± 0.72	1.91	3.3
Polyunsaturated fatty acids (g)	Larva	3	5.85 ± 1.22	4.46	6.75
Available carbohydrate calculated by difference (g)	Larva	2	1.4 ± 1.84	0.1	2.7
Total carbohydrate calculated by difference (g)	Larva	1	3.61		
Acid detergent fibre (FIBAD) (g)	Adult	3	6.8 ± 0.6	6.2	7.4
	Larva	3	2.38 ± 0.21	2.13	2.5
	Pupa	1	2.0		
Neutral detergent fibre (FIBND) (g)	Adult	2	12 ± 0.7	11.5	12.4
	Larva	8	5.2 ± 1.3	2.9	7.3
Crude fibre (FIBC) (g)	Larva	1	2.1		
Ash (g)	Adult	3	1.38 ± 0.32	1.2	1.75
	Larva	14	1.51 ± 0.79	0.9	3.81
	Pupa	1	1.33		

Values adapted from: Barker, Fitzpatrick, and Dierenfeld (1998), Bednářová, Adam, Jelen, and Borkovcová (2011), Bednářová, Zorníková, et al. (2011), Bernard and Allen (1997), Borkovcová, Hönigová, and Kráčmar (2005), Finke (2002), Ghaly and Alkoaik (2009), Hunt et al. (2001), Jones et al. (1972), Kráčmar et al. (2005), Ng, Liew, Ang, and Wong (2001), Oonincx and van der Poel (2011), Pennino et al. (1991) and Punzo (2003).
[a] Energy values were calculated for completeness according to the FAO/INFOODS Guidelines for Converting Units, Denominators and Expressions (FAO/INFOODS, 2012b).

Table 4
Mineral and vitamin content of *Tenebrio molitor* (adult, larva, and pupa) compared to the limits for the label 'source of' or 'high in' a nutrient (WHO & FAO, 2007). Data are per 100 g EP.

		n	Mean ± sd	Min	Max	'Source of'	'High in'
Calcium (mg)	Adult	3	24 ± 2	23	27	120	240
	Larva	20	150 ± 150	13	472		
	pupa	1	43				
Chloride (mg)	Adult	1	191				
	Larva	2	181 ± 8	175	187		
Iron (mg)	Adult	3	2.87 ± 0.64	2.18	3.46	2.1	4.2
	Larva	8	1.89 ± 0.93	1.08	4		
	pupa	1	1.68				
Iodine (μg)	Adult	1	22			22.5	45
	Larva	1	17				
Potassium (mg)	Adult	3	368 ± 36	340	408		
	Larva	4	337 ± 27	297	359		
	pupa	1	355				
Magnesium (mg)	Adult	3	69 ± 7	61	74	45	90
	Larva	7	92 ± 8	80	104		
	pupa	1	86				
Manganese (mg)	Adult	3	0.456 ± 0.1096	0.368	0.582		
	Larva	8	0.287 ± 0.158	0.004	0.52		
	pupa	1	0.546				
Molybdaenum (μg)	Adult	1	39				
Sodium (mg)	Adult	3	66 ± 7	62	74		
	Larva	4	50 ± 7	40	56		
	pupa	1	55				
Phosphorus (mg)	Adult	3	295 ± 16	277	307		
	Larva	20	368 ± 98	227	530		
	pupa	1	300				
Selenium (μg)	Adult	2	13.6 ± 3.4	11.19	16		
	Larva	3	16.3 ± 7.61	10.9	25		
	pupa	1	12.09				
Zinc (mg)	Adult	3	4.86 ± 0.65	4.36	5.59	2.25	4.5
	Larva	8	4.33 ± 0.72	3.45	5.2		
	pupa	1	3.9				
Vitamin A (IU)	Larva	2	29	28	30	120	240
α-Tocopherol (mg)	Larva	2	1.9	1.6	2.2		
Vitamin E (IU)	Larva	4	0.99 ± 0.25	0.63	1.17		
Pyridoxin (mg)	Larva	2	0.70	0.58	0.81	0.3	0.6
Thiamin (mg)	Larva	2	0.18	0.12	0.24	0.21	0.42
Riboflavin (mg)	Larva	2	1.21	0.81	1.61	0.24	0.48
Niacin (mg)	Larva	2	4.10	4.07	4.13	2.7	5.4
Panthotenic acid (mg)	Larva	2	2.04	1.45	2.62		
Folate (μg)	Larva	2	137	117	157	30	60
Biotin (μg)	Larva	2	33.5	30	37		
Vitamin B12 (μg)	Larva	2	0.30	0.13	0.47	0.15	0.3
Vitamin C (mg)	Larva	2	1.8	1.2	2.4	9	8

n: number of observations; sd: standard deviation; min: minimum; max: maximum.
Values adapted from: Barker, Fitzpatrick, and Dierenfeld (1998), Bednářová, Adam, et al. (2011), Bednářová, Zorníková, et al. (2011), Bernard and Allen (1997), Borkovcová, Hönigová, and Kráčmar (2005), Finke (2002), Ghaly and Alkoaik (2009), Hunt et al. (2001), Jones, Cooper, and Harding (1972), Kráčmar et al. (2005), Ng, Liew, Ang, and Wong (2001), Oonincx and van der Poel (2011), Pennino et al. (1991) and Punzo (2003).

the range within this group was very wide (2.78–65.29% PUFA of total lipids).

Data for dietary fibre are only available for the acid detergent fibre (FIBAD), neutral detergent fibre (FIBND), and crude fibre. No value was found for the AOAC Prosky method, which represents best dietary fibre for human consumption. Values show in general a high variability and are higher in adult beetles compared to larvae which can be explained by the cuticle of the beetle which consists of chitin and is analysed with the fibre fractions.

Mineral values showed an extreme variability within and between species. This is in agreement with Oonincx and Dierenfeld (2012) who explained reasons for the high variability in trace elements with small sample size, species-specific metabolism, varying accuracy of sampling and/or analytical techniques, and contamination. According to the thresholds for food labels 'source of' and 'high in' (WHO & FAO, 2007), *T. molitor* larvae are a source of calcium, zinc and high in magnesium; pupae are a source of magnesium; and adult mealworms are a source of iron, iodine, and magnesium, and high zinc. Insects have been shown to be low in calcium as they do not have an internal skeleton (Hunt, Ward, & Ferguson, 2001). In general, this could be confirmed with our data (12–65 mg calcium/100 g EP), with the exception of values deriving form a study with the aim to increase the calcium content by feeding high calcium diets (21–472 mg calcium/100 g EP) (Hunt et al., 2001) (Table 4), being the only values that reached the levels required for labelling as source of calcium or high in calcium. The big variation in calcium content is not only due to incorporation of calcium from feed into the insect's body but also through the so-called gut loading. The latter one refers to the practice of feeding of insects with nutrient-dense feed in order that the nutrients in the gastrointestinal tract complement the nutrients contained in the insect's body (Finke, 2003; Oonincx & van der Poel, 2011).

Only few data were available for vitamins (59 data points). Table 4 shows values for larvae only, as for adult beetles only one value was available per vitamin and for pupa none. According to the data collected, the mealworm larvae can be labelled as a source of vitamin B6, riboflavin, niacin, folate and vitamin B12 and as high in pyridoxine, riboflavin, folate and vitamin B12. For vitamin E and panthotenic acid no NRV for food labelling are available. However, data are available only for two food entries, which indicates the need for more data.

4. Conclusions

Data on edible insects are available in the scientific literature, however, often the data quality does not meet the requirements for inclusion in food composition tables and, therefore, the use of those data for nutrient intake estimations of humans is limited. To the best of our knowledge, BioFoodComp2.1 represents the largest compilation of analytical data of this food group on fresh weight basis of edible portion.

Compared to the high number of insect species consumed worldwide, only few analytical data are available. But nutrient contents of insects vary not only due to species and development stages but also due to location, season, feed and gut content. Since the variation in nutrient contents is so wide, more data are needed to make the differences more visible. The issue of fibre needs more research concerning which fibre fractions and additional components (e.g. nitrogen) the different analytical methods capture and if for human nutrition, it would not be more adequate to analyse fibre in insects using Prosky and similar methods.

Comparison of nutrient contents of *T. molitor* with the content required for the labels 'source of' and 'high in' showed that the mealworm is a good source of protein and a couple of micronutrients.

It is expected that data will help national food composition table compilers to incorporate edible insects into their databases. This will further lead to more precise nutrient intake estimation and will be useful for researchers, governments and donors to promote the use of insects as feeds and foods. However, more data of good quality are needed, especially on micronutrients, covering more insect species, diets, regions, and seasons.

Acknowledgements

Acknowledgment for financial contribution: Food and Agriculture Organization of the United Nations (FAO), Nutrition Division (ESN).

References

Barker, D., Fitzpatrick, M. P., & Dierenfeld, E. S. (1998). Nutrient composition of selected whole invertebrates. *Zoo Biology, 17*(2), 123–134.

Bednářová, M., Adam, V., Jelen, F., & Borkovcová, M. (2011). Protein profile of Tenebrio molitor (In Czech). In MendelNet 2011 – Proceedings of international Ph.D. students conference. (pp. 549–554). Brno: Mendel University in Brno, Faculty of Agronomy.

Bednářová, M., Zorníková, G., Rozíková, V., & Borkovcová, M. (2011). Fat amount and composition in selected insect species (In Czech), (pp. 60–64). Presented at the XXXVII. International conference on foods and raw materials quality – "Ingr Days".

Bernard, J. B., & Allen, M. E. (1997). *Feeding captive insectivorous animals: Nutritional aspects of insects as food. Fact sheet 003*. Nutrition Advisory Group.

Borkovcová, M., Hönigová, M., & Kráčmar, S. (2005). Insects as a part of pet's and farm animal's diets (Hmyz ve vyzive zajmovych a hospodarskych zvirat). In *Kábrtovy dietetické dny* (pp. 101–104). Brno: Veterinární a farmaceutická univerzita v Brně.

Charrondiere, U. R., & Burlingame, B. (2011). Report on the FAO/INFOODS compilation tool: A simple system to manage food composition data. *Journal of Food Composition and Analysis, 24*(4–5), 711–715. http://dx.doi.org/10.1016/j.jfca.2010.09.006.

Charrondière, U. R., Stadlmayr, B., Rittenschober, D., Mouille, B., Nilsson, E., Medhammar, E., et al. (2013). FAO/INFOODS food composition database for biodiversity. *Food Chemistry, 140*(3), 408–412. http://dx.doi.org/10.1016/j.foodchem.2012.08.049.

DeFoliart, G. R. (1997). An overview of the role of edible insects in preserving biodiversity. *Ecology of Food and Nutrition, 36*(2–4), 109–132. http://dx.doi.org/10.1080/03670244.1997.9991510.

FAO. (2013). *Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture* (No. CGRFA-14/13/Report): Rome. Retrieved from <http://www.fao.org/docrep/meeting/028/mg538e.pdf>.

FAO Regional Office for Asia and the Pacific. (2010). *Forest insects as food: humans bite back: Proceedings of a workshop on Asia-Pacific resources and their potential for development, 19–21 February 2008, Chiang Mai, Thailand*. (P. B. Durst, Ed.). Bangkok, Thailand: Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific.

FAO Regional Office for Asia and the Pacific (2013). *Six-legged livestock: Edible insect farming collection and marketing in Thailand*. Bangkok, Thailand: Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific.

FAO/INFOODS. (2012a). *FAO/INFOODS Guidelines for Checking Food Composition Data prior to the Publication of a User Table/Database – Version 1.0*. Rome: FAO. Retrieved from <http://www.fao.org/fileadmin/templates/food_composition/documents/Guidelines_data_checking_02.pdf>.

FAO/INFOODS. (2012b). *FAO/INFOODS Guidelines for Converting Units, Denominators and Expressions*. Rome: FAO. Retrieved from <http://www.fao.org/infoods/infoods/standards-guidelines/en/>.

FAO/INFOODS. (2012c). *FAO/INFOODS Guidelines on Food Matching*. Rome: FAO. Retrieved from <http://www.fao.org/docrep/017/ap805e/ap805e.pdf>.

FAO/INFOODS. (2012d). Food Composition: Tagnames for Food Components. Retrieved September 28, 2012, from <http://www.fao.org/infoods/tagnames_en.stm>.

FAO/INFOODS. (2013a). *FAO/INFOODS Food Composition Database for Biodiversity Version 2.1*. Rome: FAO. Retrieved from <http://www.fao.org/docrep/019/i3560e/i3560e.pdf>.

FAO/INFOODS. (2013b). INFOODS: Software Tools. Retrieved February 15, 2014, from <http://www.fao.org/infoods/infoods/software-tools/en/>.

Finke, M. D. (2002). Complete nutrient composition of commercially raised invertebrates used as food for insectivores. *Zoo Biology, 21*(3), 269–285. http://dx.doi.org/10.1002/zoo.10031.

Finke, M. D. (2003). Gut loading to enhance the nutrient content of insects as food for reptiles: A mathematical approach. *Zoo Biology, 22*(2), 147–162. http://dx.doi.org/10.1002/zoo.10082.

Finke, M. D. (2007). Estimate of chitin in raw whole insects. *Zoo Biology, 26*(2), 105–115. http://dx.doi.org/10.1002/zoo.20123.

Ghaly, A. E., & Alkoaik, F. N. (2009). The yellow mealworm as a novel source of protein. *American Journal of Agricultural and Biological Sciences, 4*(4), 319–331. http://dx.doi.org/10.3844/ajabssp.2009.319.331.

Ghaly, A. E., & Alkoaik, F. N. (2010). Nutritional value of the maize stalk borer and American bollworm as unconventional protein sources. *American Journal of Applied Sciences, 7*(1), 1–12.

Hocking, B., & Matsumura, F. (1960). Bee brood as food. *Bee World, 41*(5).

Hunt, A., Ward, A., & Ferguson, G. (2001). Effects of a high calcium diet on gut loading in varying ages of crickets (*Acheta domestica*) and mealworms (*Tenebrio molitor*). In M. S. Edwads, K. J. Lisi, M. L. Schlegel, & R. E. Bray (Eds.), *Presented at the fourth conference on zoo and wildlife nutrition* (pp. 94–98). AZA Nutrition Advisory Group.

INFOODS. (2013, December). INFOODS List of underutilized species contributing to the nutrition indicators for biodiversity (version 1.2).

Jones, L. D., Cooper, R. W., & Harding, R. S. (1972). Composition of Mealworm *Tenebrio molitor* Larvae. *The Journal of Zoo Animal Medicine, 3*(4), 34–41.

Jongema, Y. (2013). List of edible insects of the world (April 4, 2012) – Wageningen UR. Retrieved January 20, 2014, from <http://www.wageningenur.nl/en/Expertise-Services/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm>.

Klensin, J. C., Feskanich, D., Lin, V., Truswell, S., & Southgate, D. A. T. (1989). *Identification of food components for INFOODS data interchange*. Tokyo: United Nations University Press [Retrieved from <ftp://ftp.fao.org/es/esn/infoods/Klensinetal1989Identificationoffoodcomponents.pdf>].

Kráčmar, S., Borkovcová, M., Hönigová, M., Hedbávný, J., Fialová, M., & Zeman, L. (2005). Risk elements in insects used as a part of pet's and farm animal's diet (Rizikové prvky u hmyzu využívaného ve výživě zájmových a hospodářských zvířat). In XIV (Ed.), *Vedecké symposium o ekológii vo vybraných aglomeráciach Jelšavy – Lubeníka a Stredného Spiša* (pp. 75–78). Košice: Ústav geotechniky SAV.

Nakagaki, B. J., & DeFoliart, G. R. (1991). Comparison of diets for mass-rearing acheta dornesticzs (Orthoptera: Gryllidae) as of food conversion efficiency with values reported for livestock. *Journal of Economic Entomology, 84*(3), 891–896.

Ng, W.-K., Liew, F.-L., Ang, L.-P., & Wong, K.-M. (2001). Potential of mealworm (*Tenebrio molitor*) as an alternative protein source in practical diets for African catfish, *Clarias gariepinus*. *Aquaculture Research, 32*(Suppl. 1), 273–280.

Nonaka, K. (2009). Feasting on insects. *Entomological Research, 39*(5), 304–312. http://dx.doi.org/10.1111/j.1748-5967.2009.00240.x.

Oonincx, D. G. A. B., & Dierenfeld, E. S. (2012). An investigation into the chemical composition of alternative invertebrate prey: Nutrient content of alternative prey species for insectivores. *Zoo Biology, 31*(1), 40–54. http://dx.doi.org/10.1002/zoo.20382.

Oonincx, D. G. A. B., & van der Poel, A. F. B. (2011). Effects of diet on the chemical composition of migratory locusts (*Locusta migratoria*). *Zoo Biology, 30*(1), 9–16. http://dx.doi.org/10.1002/zoo.20308.

Pennino, M., Dierenfeld, E. S., & Behler, J. L. (1991). Retinol, α-tocopherol and proximate nutrient composition of invertebrates used as feed. *International Zoo Yearbook, 30*(1), 143–149. http://dx.doi.org/10.1111/j.1748-1090.1991.tb03477.x.

Punzo, F. (2003). Nutrient composition of some insects and arachnids. *Biological Sciences, 66*(2), 84–98.

Puwastien, P., Mahidon, M., & System, A. N. (2000). *ASEAN food composition tables 2000*. Thailand: Institute of Nutrition, Mahidol University.

Rittenschober, D., Nowak, V., & Charrondiere, U. R. (2013). Review of availability of food composition data for fish and shellfish. *Food Chemistry, 141*(4), 4303–4310. http://dx.doi.org/10.1016/j.foodchem.2013.07.007.

Rumpold, B. A., & Schlüter, O. K. (2013). Nutritional composition and safety aspects of edible insects. *Molecular Nutrition & Food Research, 57*(5), 802–823. http://dx.doi.org/10.1002/mnfr.201200735.

Stadlmayr, B., Charrondière, U. R., Eisenwagen, S., Jamnadass, R., & Kehlenbeck, K. (2013). Nutrient composition of selected indigenous fruits from sub-Saharan Africa: Nutrient composition of selected indigenous fruits from sub-Saharan Africa. *Journal of the Science of Food and Agriculture, 93*(11), 2627–2636. http://dx.doi.org/10.1002/jsfa.6196.

Stadlmayr, B., Charrondière, U. R., Enujiugha, V. N., Bayili, R. G., Fagbohoun, E. G., Samb, B., et al. (2012). *West African food composition table/table de composition des aliments d'afrique de l'ouest*. Rome: FAO.

United Nations, Department of Economic and Social Affairs, Population Division. (2013). *World Population Prospects – The 2012 Revision - Key Findings and Advance Tables* (Working Paper No. ESA/P/WP.227.). New York. Retrieved from <http://www.unfpa.org/webdav/site/global/shared/documents/news/2013/KEY%20FINDINGS%20WPP2012_FINAL-2.pdf>.

Van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology, 58*(1), 563–583. http://dx.doi.org/10.1146/annurev-ento-120811-153704.

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., & Vantomme, P. (2013). *Edible insects: Future prospects for food and feed security*. Rome: Food and Agriculture Organization of the United Nations.

WHO & FAO (2007). *Food labelling* (5th ed.). Rome: WHO, FAO [Retrieved from <ftp://ftp.fao.org/codex/Publications/Booklets/Labelling/Labelling_2007_EN.pdf>].