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Structured abstract:

Background

Edible insects have been proposed as a more environmentally sustainable and nutritious alternative to conventional livestock. In response to the promotion of insects as food and feed by the Food and Agriculture Organization of the United Nations, insect agriculture is now a growing industry across the world. Yet information regarding the nutritional composition of commercially available insect species is disparate in terms of **data quality**, the location of published sources, and the form in which data is presented.

Scope and Approach

We conducted a **systematic review** of all published **nutrient composition** data for twelve selected species of commercially available edible insect. Our objective was to create a nutrient composition table in line with INFOODS/EuroFIR guidelines, and to present the results in a standardised form that is easily comprehensible for nutritionists and policy-makers.

Key Findings and Conclusions

Our results expose the low quality of data describing edible insect nutritional composition, when compared to INFOODS/EuroFIR recommendations. This calls attention to the need for greater adherence to international guidelines in this field. The data that were included in our final table show clear within-species variation in the proportion of both macro- and **micronutrients.** This highlights the importance of external factors such as feed and ecology in determining nutrient composition.

Keywords: Systematic review**,** Nutrient composition, Edible insects, Data quality,

Micronutrients

INTRODUCTION

In response to growing concerns about the future of world food security, insects have been highlighted as a food source that may address environmental, economic and health concerns as the global population continues to rise (Godfray, et al., 2010; Premalatha, Abbasi, Abbasi, & Abbasi, 2011). The biomass of several wild-harvested insect species is already sufficient for commercial supply (Hanboonsong, Jamjanya, & Durst, 2013), while others are intensively farmed both at household level (Hope, Frost, Gardiner, & Ghazoul, 2009) and on an industrial scale (Vantomme, 2014). Insect foods have recently become available in the US and Europe, and efforts are underway to increase the production of edible insects in developing countries (Vantomme, 2014).

Unlike traditional livestock, standardised information about the nutritional composition of commercially available edible insects is limited and inconclusive (Belluco, et al., 2013; Rumpold & Schluter, 2013; Vantomme, 2014), yet these limited data are increasingly used to justify generalised claims about the health benefits of a particular genus, order or even insects as a single homogenous food category (Dossey, 2013; Holbrook, 2013; Vantomme, 2014). Non-systematic reviews have collated data on as many species consumed by humans for which nutritional information could be found, and conclude that while many edible insects are high in nutrients considered essential or desirable for human nutrition (Belluco, et al., 2013; Bukkens, 1997; Rumpold & Schluter, 2013), insects are varied in composition and should not be considered nutritionally equivalent to traditional livestock or sea foods (Raubenheimer, Rothman, Pontzer, & Simpson, 2014). The summary report of the first conference on insects as food and feed stated that insects have ‘good nutritional quality' (Vantomme, 2014). In peer-reviewed published literature, insects have been advocated as a serious alternative to conventional meat production, both as animal feed and as human food (Paoletti, 2005; Ramos-Elorduy, 1997; Van Huis, 2013). Investments by NGOs, governmental bodies and private companies have facilitated the promotions of small scale farming of edible insects in several African and Southeast Asian countries, where it is hoped that this will result in improved livelihoods and elevated nutritional status (Durst, Johnson, Leslie, & Shono, 2010; Hanboonsong, et al., 2013; Hope, et al. 2009). Nevertheless, a great deal about the relationship between insect consumption and health status remains unknown. High quality data on nutritional composition is a crucial first step towards understanding this relationship, and is also important to professionals concerned with domestic animal and zoological nutrition.

Research objectives

For this review, our primary research objective was to collect nutrient composition data systematically for twelve insect species that were selected because they are currently commercially available in several countries throughout Europe, Africa, Southeast Asia, Oceania and North and South America. We applied the INFOODS/EuroFIR guidelines for quality when extracting data from original published sources. These guidelines have been developed to assess the quality of individual values for food components. They are applied to original data on nutrient composition, before this data is aggregated to inform nutrient composition tables. They are designed to ensure that certain standards are observed with regard to the quality of included data, based on seven criteria covering the transparency of the descriptions and identifications of foods, as well as the sampling plan, handling and quality of analysis. Assessing sources of data according to these guidelines is a crucial part of the EuroFIR generic flowchart of the process for compiling a food composition table (Westenbrink et al 2009). The guidelines have been developed based on several national systems for data quality assessment (Oseredczuk & Westenbrink 2013). In collating data on the nutrient composition of these species, and reporting on the quality of published data, we hope to facilitate species-specific consideration of the potential of insects as a food source and to inform the methodology that is employed in further studies of nutritional composition. In presenting the data as values that are standardised to “per 100g edible portion on fresh weight basis (EP)”, we intend to make our results easily comprehensible for policy-makers and nutritionists alike.

Selection of species

The species selected for inclusion were a subset of edible insects currently commercially available worldwide, ranging from those that are harvested from the wild in rural areas, to those species that are commercially produced on an industrial scale. The sample also included insects from each of the 'Big Five'(McGrew, 2001) consumed by humans and other primates - Coleoptera, Hymenoptera, Isoptera, Lepidoptera and Orthoptera - as well as one representative of Diptera, as several species from this order are now bred for human and animal consumption (Van Huis, 2013). In the case of insects that are harvested from the wild, identification is limited to the genus level. Two species were selected within each of the following six categories:

1. Species that are gathered from the wild and sold commercially as human food: *Vespula* spp. (Southeast Asia)(Durst, et al., 2010), *Macrotermes* spp. (Sub-Saharan Africa (Van Huis, 2003) ;
2. Agricultural pest species that are traditionally harvested for human consumption: *Encosternum* spp. *(*Southeast Asia (野中, 2008), Sub-Saharan Africa (Dzerefos, Witkowski, & Toms, 2013))*, Oxya* spp. *(*Southeast Asia(Mitsuhashi & Paoletti, 2005)*);*
3. Traditionally wild-gathered species that are sold commercially as food, for which farming methods are currently being developed: *Rynchophorus phoenicus*. (Australasia, Southeast Asia, Sub-Saharan Africa, South America, (Bukkens, 1997; Hanboonsong, et al., 2013)), *Oecyphylla smaragdina*

(Southeast Asia, (Van Itterbeeck, Sivongxay, Praxaysombath, & Van Huis, 2014))

4. Species that are successfully reared on a large scale and sold commercially both for export and domestic consumption: *Acheta domesticus* (Southeast Asia, Europe, North America, Sub-Saharan Africa, (Collavo, et al., 2005; Hanboonsong, et al., 2013; Vantomme, 2014))*; Gonimbrasia bellina* (Sub-Saharan Africa, (Hope, et al., 2009));
5. Species with a long history of domestication by humans for their by-products, and also sold commercially as food: *Apis mellifera, Bombyx mori* (Chen, et al., 1998);
6. Species not traditionally consumed by humans that are currently farmed on a large scale and intended for use as food and feed: *Tenebrio molitor, Hermetia illucens* (Rumpold & Schlüter, 2014)

Where genera, rather than specific species, are selected, this is because these genera represent a suite of generalist species that are wild-harvested across a wide geographical area. Where species within these genera were specified in peer-reviewed publications, these were confirmed as human-consumed species using the Wageningen list of edible insects of the world (Jongema, 2014).

Search strategy

We aimed to compile high quality nutrient composition data from three sources: Published research articles, official online nutrient composition databases and commercial suppliers.

To identify published research articles, we searched five databases (Web of Science, Medline, Global Health, CAB Abstracts and EMBase) using the following search entry for each of the twelve species:

> (*Genus and/or species name*) AND ((edible OR edible insect OR entomophagy OR food OR feed) AND (nutrition* OR protein* or fat* OR mineral* OR vitamin*))

To identify data available in official nutrient composition tables, we searched the food composition tables available on the FAO INFOODS website (FAO INFOODS, 2014) for inclusion of the twelve selected edible insect species.

To identify commercial suppliers we conducted two Google searches: The first used the search term 'edible insects' and the second 'livefoods insects', as some of the species selected are also sold as reptile feed. We contacted every supplier listed in the first ten hits for each search, requesting nutrient composition data for one or more of the selected species.

Inclusion/exclusion criteria

To achieve a standardised comparison of unprocessed insect foods, we excluded datalines that did not comply with the following criteria for food description:

- Cooking method = uncooked
- Preparation method = Fresh; live; live-frozen
- Part of animal = Whole insect
- Edible/inedible portion = Edible

- Fortification/enrichment = No post-harvest fortification/enrichment

We also excluded datalines that did not represent the most commonly consumed life stage of each insect, deemed as follows:

- *Apis mellifera, Vespula spp* - brood
- *Acheta domesticus, Encosternum delegorguei, Oecophylla smaragdina, Oxya* spp – adult
- *Bombyx mori* – pupae
- *Macrotermes* spp – alate
- *Gonimbrasia belina, Hermetia illucens, Rhynchophorus phoenicis, Tenebrio molitor* - larvae

Data on nutrient composition that was identified within published literature, FAO/INFOODS databases, or provided by commercial suppliers, were included if they fulfilled the following criteria:

- They reported the results of original analyses for macro- and/or micro-nutrients for the species in question and/or other species on the above list, at their most commonly consumed life stage;
- If a peer-reviewed publication, the methods were sufficiently clear about the extent to which the insects underwent processing (e.g. smoking, roasting, grilling etc) prior to sampling;
- the insects were either analysed 'as sold' without mention of any added ingredients (e.g. fats, salt), or freshly captured;
- if a peer-reviewed publications, a full text article was available and this was written in English;

- the data were original and not a replicate of previously published data.

We refer to the data gathered according to the above criteria in terms of 'data lines'. A 'data line' refers to the published results of the nutrient analyses of an insect sample that contains multiple data points, each of which represents the quantity of a particular nutrient. Where publications indicated that a data line was the mean result of >1 replicate, the data line was not weighted accordingly but used as a single entry. Data lines were excluded if they could not be expressed on a fresh weight basis (e.g., if only dry weight figures were given and dry matter/moisture content of fresh weight samples was not recorded)

In order to evaluate the quality of the data, we conducted a further analysis of the published articles that contributed to our dataset, using the EuroFIR Quality Index. We used EuroFIR guidelines (Salvini et al 2009) to attribute scores of 1 to 5 (1 = low quality; 5 = high quality) for the seven categories: Food description, Component identification, Sampling plan, Number of analytical samples, Sample handling, Analytical method and Analytical quality control. Each category contains criteria for assessment, and for each criterion the answer YES, NO or NOT APPLICABLE is given. The combination of answers is used to determine the score for that category. For example, the scoring category 'Sample handling' contains two criteria. The first is whether the samples have been subject to appropriate stabilization treatment, and the EuroFIR guidelines list possible treatments to protect against damage or contamination. The second is whether the samples were homogenized prior to analysis. If the data source does not describe either criterion, the answer given is 'NO' and the score for this category is 1 (low quality). In this case, the only other possible score is 5 (high quality), which is given when both answers are either 'YES' or 'N/A'. Each of the seven categoryies has its own set of criteria and scoring system, with detailed guidelines to ensure an appropriate score is given.

The combination of scores for each category is used to calculate the Quality Index, which has a maximum possible value of 35.

Finally, we chose to present the extracted nutrient composition data alongside dietary reference values to facilitate understanding for non-nutrition professionals. We used US food labelling guidelines (FDA 2013) to source daily reference values for major macronutrients and essential micronutrients, and WHO recommended daily amino acid composition guidelines (WHO 2007) to source reference values for essential amino acid content. We are unaware of any literature that proposes a standard serving size for insect foods, and therefore we standardised all nutrient data to values expressed per 100g edible portion (fresh weight), as recommended by EuroFIR for the compilation of nutrient composition tables.

RESULTS

Overview of the data

Table 1 summarises the origin and number of data lines included in the systematic review, and shows much variability in the amount of data for different insects. *Tenebrio molitor* (mealworm, N=21), *Macrotermes* spp. (termite, N=13) and *Rhynchophorus phoenicis* (palm weevil, N=15) are by far the best represented, while we could identify no usable data for *Encosternum* spp. (stinkbug), *Oxya* spp. (rice grasshopper) and *Vespula* spp. (social wasp). The nutrient composition of human food must be reported on a fresh weight or 'as is' basis to be included in standardised nutrient composition tables (Greenfield & Southgate, 2003), yet many publications on edible insect composition use dry weight values and do not provide sufficient information to calculate fresh weight data; for the mopane caterpillar, for example, which is sold widely throughout Southern Africa, 11 usable data lines were identified from peer-reviewed publications, yet of these only 3 could be included in the final analyses. Of the commercial suppliers who were contacted, only a single supplier provided nutritional data, and since this was for cricket flour on a dry weight basis with no information about the fresh weight of the samples, this was not used in the current study. The bias towards dry weight data in several of the farmed insects may be because the analyses in question are considering the potential of the products as animal feed, which is usually prepared and packaged in a dried form.

Table 2 presents the results of attributing Quality Index scores to each paper that was selected for inclusion in this analysis. Scores for the articles included here ranged from 14 to 27. The main scoring categories that contributed to low Quality

Index scores were Sampling plan, Number of analytical samples and Analytical quality control. Very few articles described the development of a sampling plan to achieve a representative sample of the species in question. The number of analytical samples used was N=1 in all but one paper. Several studies described sample stabilization methods that are not considered acceptable according to EuroFIR guidelines (Salvini et al 2009). Most used one or more of the approved methods of nutritional analysis. However, replicates were not always tested, there was no mention of laboratory accreditation in any study, and reference materials were rarely used.

Key nutrients

The data lines summarised in **Table 3** show the reported composition of ten species of edible insect at their most commonly consumed life stage, expressed per 100g edible portion. The table also shows the recommended intake or reference value for each nutrient (WHO 2004, 2007, 2012). The data shows considerable variation *within* insect species, particularly for key nutrients such as protein, fat and saturated fat. For example, the standard deviation of the protein content of the house cricket (15.6±8.1g) and the honey bee (15.2±8.19g) exceeds 50% of the mean, and this is also the case for the fat content of the weaver ant (10.8±12.3g) and mealworm (14.7±8.28g), and the saturated fat content of the silkworm (2300±2230mg), the palm weevil (17500±20900mg) and the mealworm (3630±1900mg). Where a single species is represented by multiple data lines and/or multiple studies, there is also high variation in reported mineral content; this is evident in **Table 4.**

Furthermore, high variation is also evident *between* insect species, even with regard to major macronutrients. In this fairly small sample of just 10 edible insects, 100g of fresh product can contribute between 102kcal (weaver ant) and 529kcal (palm weevil larvae) of energy, between 10.8g (weaver ant) and 35.2g (mopane caterpillar) of protein, and between 3.98g (honeybee) and 31.8g (palm weevil larvae) of fat. The species that are consumed in their larval form tend to have higher fat content, a finding that is to be expected due to energy requirements during development. This highlights the importance of life stage in determining the nutritional value of insects as food and consequent implications for human health. It is recommended that people limit their intake of saturated fat to minimise risk of cardiovascular disease. While values for saturated fat content are fairly low in some insect species such as crickets (2280mg) and silkworm (2300mg), this is not consistently the case: palm weevil larvae and termites contain 17500mg and 13900mg saturated fat respectively.

Table 3 also shows the reported values for vitamins and minerals that have been highlighted as nutritionally important in a diet with reduced meat and dairy intake for environmental reasons (Millward & Garnett 2010), as this is one of the key arguments for promoting insects as human food (Van Huis 2013): Iron (Fe), zinc (Zn), calcium (Ca), Iodine, vitamin B12 and riboflavin (vitamin B2). Levels of these nutrients vary greatly between species. None of the analyses included in this review have found high levels of calcium or iodine, but several species are high in other key nutrients. However, for values with a larger sample size within a species, the standard deviation of these vitamins and minerals is notably high. This may be due to soil contamination of samples in some cases, but other factors, such as variation in the diet of the insects, are also likely to play a role. This variation therefore highlights the extent to which external factors can affect the nutrient content of any particular food.

Other vitamins and minerals

Table 4 shows vitamin and mineral values for ten insects. No single vitamin or mineral is found in similar quantities across all eight insects for which data are available. For many micronutrients, there is a considerable range recorded both between and within species. It is likely that this reflects actual variation in micronutrient content due to the influence of geographic location, diet and seasonality, particularly in wild insects. Feed composition may explain variation in micronutrient composition in farmed insects.

Amino acid composition

Table 5 shows how essential amino acid content varies both within and between ten insect species. The lowest indispensable amino acid is not consistent among insects. The mopane caterpillar has the highest levels across all essential amino acids, and Valine is the lowest amino acid for this species. Valine is also low in the palm weevil, but unlike the mopane caterpillar this species is also low in Isoleucine; Isoleucine is also the lowest amino acid in the silkworm. However, for the five insects with N>1 reported values (house cricket, silkworm, termite, palm weevil and mealworm), high standard deviations suggest that there may be a great deal of within-species variation in amino acid content.

CONCLUSION

This paper is the first attempt to review systematically and to collate all available nutrient composition data on a subset of commercially relevant edible insects. Results are presented here as percentages of dietary reference values, and complete nutrient composition tables are provided as online supplemental material.

The systematic review of published literature highlighted significant gaps in data available on the nutritional content of major edible insect species. To an extent, these gaps may reflect a geographical bias due to a lack of English-language publications. Of the twelve species selected for inclusion, no usable data were available for two insects, *Oxya* spp. (rice grasshopper) and *Vespula* spp. (social wasp), which are most commonly consumed in Asia and therefore nutritional data may have been published in non-English language journals. There does not seem to be an unbalance towards wild-harvested or farmed species. Of the three most well represented species, one is wild-harvested (*Macrotermes* spp. - termite), one is semi-cultivated (*Rhynchophorus phoenicis* - palm weevil) and the third is intensively farmed (*Hermetia illucens* – black soldier fly). 15 data lines could not be used because they described dry weight values and did not include information on fresh weight or moisture content. This significantly limited the quantity of data available for some species, notably *Gonimbrasia belina* (mopane worm). Overall, usable data were surprisingly scarce.

The results presented here report nutrient values per 100g of fresh product, which is a standard measurement for food composition tables (Greenfield & Southgate, 2003), but 100g is unlikely to represent the standard serving size for these insects.

Although the majority of publications included in this review were written to evaluate insects as human food, not a single paper mentioned serving size. Future research into the potential health benefits or otherwise of insect consumption would greatly benefit from the determination of standard serving sizes for individual insect species.

The high variation within species for nutrient values reported here requires further investigation and validation. Some of the differences observed here may be due to reporting error, while others may reflect genuine variation based on differences in geographical origin, insects' diets, etc, particularly in the case of micronutrients. The lack of representative sampling strategies behind the available data is a particular cause for concern, as is the lack of rigorous quality control.

With regard to the claimed health benefits associated with edible insects, no firm conclusions can be drawn for the reasons outlined above. However, high quantities of mineral elements such as iron and zinc in certain species do support claims that edible insects could help to combat food scarcity in countries where micronutrient deficiencies are common (Christensen, et al., 2006; Illgner & Nel, 2000; Van Huis, 2013). In particular, honey bee, termite, weaver ant and palm weevil, all of which can be harvested from the wild or semi-cultivated in tropical countries, contain high quantities of iron (18.5mg, 12.3mg, 8.15mg and 11.8mg respectively, per 100g), and could therefore be recommended as a food resource to combat iron deficiency, the micronutrient deficiency with the greatest health burden in developing countries (Meerman, 2012). Zinc, an element that has been successfully used in combination with iron supplementation to combat this deficiency (Zlotkin, et al., 2003), is notably high in the house cricket (11mg per 100g) and the mealworm (6.05mg per 100g), two species that are currently farmed on an industrial scale. Therefore these species have potential to combat malnutrition in developing countries. However, copper is thought to interfere with the absorption of iron (Turgut, et al., 2007), and therefore the high copper content in termite, palm weevil and mealworm (0.843mg, 0.968mg and 0.914mg respectively, per 100g) may limit their utility in this context.

It is also important to note that some insects have high quantities of nutrients that should be limited in diets, which suggests that some insects may be less beneficial to human health than hitherto believed. High consumption of saturated fat, particularly in diets rich in refined carbohydrates, elevates risk of cardiovascular disease (WHO 2003) and current WHO guidelines advise limiting intake of fat and particularly saturated fat (WHO 2015). Therefore species high in saturated fat are unlikely to be ideal for inclusion in the diet of countries with a high incidence of cardiovascular disease and/or a diet based on refined carbohydrates. The species that are high in these 'nutrients to limit' – termite and palm weevil, which contain 28.2g and 31.8g of fat, and 13900mg and 17500mg of saturated fat per 100g – are consumed in many parts of Southern Africa, one of many parts of the world where the double burden of malnutrition is an increasing health problem (Boutayeb, 2006).

In conclusion, without knowledge of standard serving sizes and thorough validation of the within-species variation reported here, it is too early to make firm conclusions about the potential impacts of consumption of these insects on human health. The greatest current barrier to our understanding of insect nutritional composition is a lack of adherence to global standards of nutrient composition analysis, such as those provided by INFOODS/EuroFIR. This may reflect a lack of sufficient outreach to scientific researchers by national and international organisations who compile and use nutrient composition data, and inadequate instruction on this topic at undergraduate and postgraduate level.

However, despite these inconsistencies in the data, it is not too early to highlight the health potential of certain insects in combating micronutrient deficiencies, nor to caution that due to high quantities of nutrients to limit, some insects may have detrimental effects on health. Tentative conclusions can be made on a species-specific basis, but further systematic research is necessary to understand factors affecting the nutrient composition of edible insects, and consequent implications for human health.

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All authors contributed to research design; CP conducted research and analyzed data; CP wrote the paper; all authors read and approved the final manuscript.

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Table 1. Summary of the systematic review process

Insect	Common name[1]	Peer-reviewed publications identified by: Initial search[2]	Elimination based on title and abstract[3]	Elimination based on content[4]	Data lines from peer-reviewed publications identified by: Literature search[5]	Commonly consumed caste/life stage/species[6]	Fresh weight data[7]	Further data lines identified by FAO/INFOODS database search: Initial search[8]	Elimination of duplicate data[8]	Total usable datalines[9]	Life stage
Acheta domesticus	(House) cricket	52	11	3	5	3	3	19	5	**8**	Adult
Apis mellifera	Honeybee	658	21	2	2	2	2	3	3	**5**	Brood
Bombyx mori	Silkworm	665	27	3	6	2	2	2	1	**3**	Pupae
Encosternum spp.	Stinkbug	5	4	0				1	0	**0**	Adult
Gonimbrasia belina	Mopane worm (MW)	19	11	5	13	10	2	2	0	**2**	Larvae
Hermetia illucens	Black soldier fly (BSF)	29	7	1	1	1	1	1	0	**1**	Larvae
Macrotermes spp.	Termite	63	32	12	23	9	9	9	4	**13**	Alate
Oecyphylla smaragdina	(Weaver) ant	6	5	2	3	1	0	3	3	**3**	Adult
Oxya spp.	Grasshopper	27	8	1	1	1	0	0	0	**0**	Adult
Rhynchophorus phoenicus	Palm weevil	24	24	10	18	14	14	6	1	**15**	Larvae
Tenebrio molitor	Mealworm	191	24	8	18	13	8	34	13	**21**	Larvae
Vespula spp.	(Social) wasp	37	3	0	0	0	0	0	0	**0**	Larvae
Totals		**1776**	**177**	**47**	**90**	**56**	**41**	**80**	**30**	**71**	

1. Common names in English that correspond to scientific names are given here in full; hereafter common names are used in data tables.
2. Results of searching Web of Science, CAB Abstracts, Embase, Medline and Global Health, using the search term '(Genus and/or species name) AND ((edible OR edible insect OR entomophagy OR food OR feed) AND (nutrition* OR protein* or fat* OR mineral* OR vitamin*))' and removing duplicates (N=747). Searches were performed on 15.07.2014 and 16.07.2014.

3. All titles and abstracts were read, and publications deemed very unlikely to have nutritional data for the insect in question were discarded.
4. Papers were discarded unless they fulfilled the following criteria: Full text available in English; nutrient composition tables available for at least one of the twelve insect species, excluding those that mentioned added ingredients such as fats or salt, or described products in which insects were mixed with other ingredients; the data presented were original; the methods used were described; the insects had not been subject to an experimental diet aimed to manipulate nutritional content.
5. Several papers described more than one insect, or the same insect at several stages of life.
6. Only the data lines describing insects at the caste or life stage at which they are most commonly consumed were retained.
7. Papers that gave dry weight values and did not report fresh weight or moisture content were discarded.
8. Only four databases available online via the FAO/INFOODS website (FAO/INFOODS 2014) referred to one or more of the twelve species of insect by name. The numbers here refer to datalines that listed insects at their most commonly consumed caste or life stage with no added ingredients. See Appendix for details of the database search.
9. The FAO/INFOODS Food Composition Database for Biodiversity (FAO/INFOODS 2014) contained information sourced from the same references identified in the literature search; these were discarded.
10. Total usable data lines from the combined literature and database search results.

Table 2. Quality Index scores for each of the 24 published articles used for data extraction.

	EuroFIR Quality Index scoring catgeory[1]							
Author and date of publication	**Food description**	**Component identification**	**Sampling plan**	**Number of analytical samples**	**Sample handling**	**Analytical method?**	**Analytical quality control**	**Total Score**
Adepoju et al 2014	5	5	2	1	5	4	3	**25**
Banjo et al 2006	5	5	2	1	1	5	1	**20**
Barker et al 1998	5	5	3	1	5	5	3	**27**
Bednarovna et al 2013	5	5	2	1	5	3	1	**22**
Edjala et al 2009	4	5	1	1	1	5	3	**20**
Ekpo et al 2007	5	5	2	1	5	5	3	**26**
Ekpo et al 2009	5	5	2	1	5	5	3	**26**
Ekpo et al 2010	5	5	1	1	1	5	3	**21**
Ekpo et al 2011	4	5	1	1	1	1	1	**14**
Elemo et al 2011	4	5	1	1	1	5	3	**20**
Finke 2013	4	5	2	1	1	5	3	**21**
Finke 2002	4	5	2	5	1	5	3	**25**
Ghaly 2009	4	5	3	1	1	5	1	**20**
Ijeomah et al 2013	3	5	2	1	1	5	1	**18**
Kenji et al 2010	5	5	2	1	5	5	3	**26**
Kinyuru et al 2010	5	5	2	1	5	5	3	**26**
Morah 1998	3	5	1	1	1	5	1	**17**
Okaraonye et al 2008	5	5	1	1	1	5	3	**21**
Omotose et al 2007	5	5	1	1	5	5	3	**25**
Siemianowska et al 2013	5	5	2	1	1	5	1	**20**
Tomotake et al 2010	4	5	2	1	5	3	1	**21**
Ukhun and Osasona 1985	4	5	2	1	1	5	1	**19**
Womeni et al 2012	4	5	1	1	1	5	3	**20**
Yi et al 2013	5	5	2	1	5	5	1	**24**

1. Each category has a maximum score of 5, and the maximum total score is 35. Details of scores within scoring categories can be found in the Online Supplemental Material.

Table 3. Mean, standard deviation and sample size of selected key nutrient values for ten insect species, expressed as per 100g edible portion. All values are given to 3 s.f.

English name	Dry matter (g)	Energy (kcal)	Crude protein (g)	Fat (g)	Saturated fat (mg)	Na (mg)	Fe[3] (mg)	Zn[4] (mg)	Ca (mg)	Iodine (mg)	B12 (µg)	B2 (mg)
RNI/**RV**/***UL***[2]			**46**	***65***	***2170***	***2000***	*24.5*	*4.9*	*1000*		*2.4*	*1.1*
Cricket	32.4±6.93	153±17.9	15.6±8.1	4.56±2.15	2280	163±	6.11±4.96	11±5.95	99.6±79.2	0.021	5.37	3.41
	(7)	(2)	(3)	(6)	(1)	(3)	(4)	(4)	(4)	(1)	(1)	(1)
Honeybee	40.4±29.2	499	15.2±8.19	3.98±1.29	2750	19.4	18.5±9.44		30±20.6			3.24
	(5)	(1)	(2)	(3)	(1)	(1)	(2)		(2)			(1)
Silkworm	33.7±12.6	128±7.48	17.9±7.76	10.2±4.58	2300±2230	14	1.8		42			1.05
	(3)	(2)	(3)	(3)	(3)	(1)	(1)		(1)			(1)
Mopane caterpillar	65.6±0		35.2±0	15.2±0	5740							
	(2)		(2)	(2)	(1)							
Black soldier fly		199	17.5	14	8300	88.7	6.66	5.62	934	0.026	5.58	1.62
		(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Termite	71.9±23.7		24.5±6.78	28.2±8.79	13900±5260	53.7±41.5	12.3±14.4	1.77±1.67	19.2±14.8			1.83±1.45
	(10)		(9)	(8)	(5)	(3)	(5)	(3)	(6)			(5)
Weaver ant	40.5±12.6	102±26.3	10.8±7.96	10.8±12.3		71.5±21.9	8.15±3.46	4.9	35.5±17.7			0.675±0.29
	(3)	(3)	(3)	(3)		(2)	(2)	(1)	(2)			(2)
Palm weevil larvae	59.8±24.7	529±137	15.9±10.7	31.8±15.6	17500±20900	147±280	11.8±20.9	4.63±4.93	36.1±33.3			2.21
	(12)	(3)	(12)	(11)	(5)	(8)	(9)	(5)	(9)			(1)
Mealworm	41±15.3	306±176	20.9±9.48	14.7±8.28	3630±1900	51.2±7.53	2.47±1.11	6.05±3.52	77.5±87.3	0.017	0.47	0.81
	(17)	(6)	(10)	(16)	(8)	(4)	(7)	(7)	(7)	(1)	(1)	(1)

1. Column heading abbreviations are as follows: Na: Sodium; Fe: Iron; Zn: Zinc; Ca: Calcium; B2: Riboflavin.
2. Daily Recommended Nutrient Intake (RNI) values are from the FAO publication Vitamin and Mineral Requirements in Human Nutrition (WHO 2004). Daily Reference Values (RV) are the World Health Organization Reference Values (WHO 2007). Upper Limit (UL) values are WHO recommendations (WHO 2012, 2015). In all cases values represent those recommended for a premenopausal woman aged between 19-50 years, the value for protein assumes a weight of 55kg, and the value for fat assumes an energy intake of 2000kcal per day.

3. Fe content is based on 12% bioavailability.

4. Zn content is based on moderate bioavailability.

Table 4. Mean, standard deviation and sample size for vitamin and mineral content of eight edible insect species.

	Vitamins[1]										Mineral elements[2]				
English name	Vit A (μg)	Vit E (mg)	Vit C (mg)	Vit D (μg)	Vit B1 (mg)	Vit B3 (mg)	Vit B5 (mg)	Vit B6 (mg)	Vit B7 (mg)	Vit B9 (mg)	K (mg)	Mg (mg)	P (mg)	Mn (mg)	Cu (mg)
RNI[3]	*500*	*7.5*	*45*	*5*	*1.1*	*14*	*5*	*1.3*	*0.03*	*400*		*220*			
Cricket	14.4±11.9	2.26±1.77	3	640	0.04	3.84	2.3		0.017	150	505±229	55.1±21.8	496±237	1.66±0.906	0.75±0.127
	(5)	(5)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(3)	(4)	(4)	(4)	(4)
Honeybee	12.4	0.6±0.424	0.0103								403	21.4±22.9	126		
	(1)	(2)	(1)								(1)	(2)	(1)		
Silkworm					0.12	0.9					139		167		
					(1)	(1)					(1)		(1)		
Black soldier fly		0.62	1		0.77	7.1	3.85	0.601	0.035	270	435	174	356	6.18	0.403
Termite	5.61±4.99	0.0036	0.00321±0.000283	2.22	0.435±0.615	1.58±1.22		0.453±0.568		125±91.7	143±106	9.46±10	91.7±60.4	0.711±0.559	0.843±0.95
	(3)	(1)	(2)	(1)	(2)	(3)		(3)		(2)	(4)	(6)	(5)	(3)	(3)
Weaver ant	0		2		0.225±0.0212	3.4					222	34	206		
	(1)		(1)		(2)	(1)					(1)	(1)	(1)		
Palm weevil larvae	11.3		0.00425								152±244	42.5±59.4	129±208	4.27±7.81	0.968±1.25
Mealworm	16.9±12.2	1.31±0.744	1.2	640	0.24	4.07	2.62		0.03	0.157	351±7.76	142±86	617±507	0.429±0.229	0.914±0.506
	(4)	(6)	(1)	(1)	(1)	(1)	(1)		(1)	(1)	(4)	(6)	(7)	(7)	(7)

1. Abbreviations are as follows: E: d-alpha-tocopherol, when calculating equivalents we assumed that 0.667mg of d-alpha-tocopherol is equivalent to 1IU of Vitamin E; B1: Thiamin; B3: Niacin; B5: Pantothenic acid; B6: Pyridoxine; B7: Biotin; B9: Folate or folic acid.
2. Abbreviations are as follows: K: Potassium; Mg: Magnesium; P: Phosphorus; Mn: Manganese; Cu: Copper.
3. Daily Recommended Nutrient Intake (RNI) values are from the FAO publication Vitamin and Mineral Requirements in Human Nutrition (WHO 2004). In all cases values represent those recommended for a premenopausal woman aged between 19-50 years.

Table 5. Mean, standard deviation and sample size for amino acid composition data for eight edible insect species.

	Amino acid[1]														
English name	**His**	**Ile**	**Leu**	**Lys**	**Met+Cys**	**Phe+Tyr**	**Thr**	**Trp**	**Val**	**Arg**	**Ser**	**Pro**	**Ala**	**Gly**	**GluA**
WHO RV[2]	***690***	***1380***	***1794***	***2070***	***1012***	***1748***	***1058***	***276***	***1794***						
Cricket	89.9±59.3	160±9.3	310±148	221±157	102±77.7	371±292	147±103	34.8±30.8	226±168	267±200	170±96.6	227±158	344±232	212±153	453±336
	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Honeybee	308	383	617	548	317	1040	412	65.9	551	610	432	702	515	494	1250
	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Silkworm	406	598	1230±606	1370±371	1050±335	1880±1200	709±472	273±182	969±408	1180±105	800±299	1230±913	1200±224	992±41.6	2200±483
	(1)	(1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Mopane caterpillar			2490	1460	1590	2750	2560	1060	1120	2410	1210	876	1300	1100	5100
			(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Black soldier fly			1210	1190	439		682	300	1290	1230	702	1020	1220	914	1970
Termite			1620±744	1300±518	1300±518	1970±822	728±276	340±180	1240±875	1380±680	631±264	841±493	1490±1060	900±375	2240±511
			(4)	(4)	(4)	(4)	(4)	(2)	(4)	(4)	(4)	(3)	(4)	(4)	(4)
Palm weevil larvae			877±696	660±607	648±578	1060±1070	441±416	210±0	486	1020±1160	559±535	493±636	525±653	635±673	2640±2050
			(6)	(6)	(5)	(6)	(6)	(2)	(6)	(6)	(6)	(5)	(5)	(6)	(5)
Mealworm	665±172	950±151	1470±718	895±405	828±695	1270±543	579±256	123±81.4	788±501	909±511	694±280	789±553	1110±494	604±372	1870±815
	(3)	(3)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(4)	(5)	(5)	(5)

1. Column heading abbreviations are as follows: His: Histidine; Ile: Isoleucine; Leu: Leucine; Lys: Lysine; Met: Methionine; Cys: Cystine; Met+Cys: Methionine and Cystine combined; Phe+Tyr: Phenylalanine and Tyrosine combined; Thr: Threonine; Trp: Tryptophan; Val: Valine.

2. WHO RV: World Health Organization Reference Values (WHO 2007) for the daily amino acid requirements of a 55kg woman consuming 46g of protein per day.

Highlights

- We select twelve currently commercially available edible insects including farmed and wild-caught species
- We conduct a systematic review of peer-reviewed published literature and publicly available databases describing nutrient composition of all twelve species
- We present the results of our review as nutrient composition tables for ten of the selected species using mean values from a total of 75 data lines, expressed as a percentage of daily reference values
- Currently available nutrient composition data for edible insects shows high variation between and within species
- All insect species reviewed here contain high quantities of certain vitamins and minerals considered to be beneficial to human health
- Certain insects contain high quantities of nutrients that may be harmful to health if consumed in large quantities