OPEN

European Journal of Clinical Nutrition (2016) 70, 285–291

www.nature.com/ejcn

PERSPECTIVE

Are edible insects more or less 'healthy' than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over- and undernutrition

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BACKGROUND/OBJECTIVES: Insects have been the subject of recent attention as a potentially environmentally sustainable and nutritious alternative to traditional protein sources. The purpose of this paper is to test the hypothesis that insects are nutritionally preferable to meat, using two evaluative tools that are designed to combat over- and under-nutrition.
SUBJECTS/METHODS: We selected 183 datalines of publicly available data on the nutrient composition of raw cuts and offal of three commonly consumed meats (beef, pork and chicken), and six commercially available insect species, for energy and 12 relevant nutrients. We applied two nutrient profiling tools to this data: The Ofcom model, which is used in the United Kingdom, and the Nutrient Value Score (NVS), which has been used in East Africa. We compared the median nutrient profile scores of different insect species and meat types using non-parametric tests and applied Bonferroni adjustments to assess for statistical significance in differences.
RESULTS: Insect nutritional composition showed high diversity between species. According to the Ofcom model, no insects were significantly 'healthier' than meat products. The NVS assigned crickets, palm weevil larvae and mealworm a significantly healthier score than beef ($P < 0.001$) and chicken ($P < 0.001$). No insects were statistically less healthy than meat.
CONCLUSIONS: Insect nutritional composition is highly diverse in comparison with commonly consumed meats. The food category 'insects' contains some foods that could potentially exacerbate diet-related public health problems related to over-nutrition, but may be effective in combating under-nutrition.

European Journal of Clinical Nutrition (2016) **70,** 285–291; doi:10.1038/ejcn.2015.149; published online 16 September 2015

INTRODUCTION

As the world population rises, the global food system faces an impending crisis,[1] and a major component of this crisis is the forecast that the livestock sector is growing at a rate that is deemed unsustainable.[2] Therefore, we must look to alternative sources of protein that can be produced on a viable and sustainable commercial scale, and in recent years edible insects have been proposed as one potential 'new' protein source. The main reason for this is that many insects can be farmed at relatively low economic and environmental costs; farming insects use up to 50–90% less land per kg protein, 40–80% less feed per kg edible weight and produces 1000–2700 g less GHGEs (Greenhouse gas emissions) per kg mass gain than conventional livestock.[3] However, particularly in Europe, insects are a new food and information about the safety and nutritional value of edible insects is scarce, particularly since they are such a diverse category.[4] Yet insects are already available to purchase in certain shops across Europe. Due to restrictive legislation that allows only whole, visible insects to be sold, current marketing practices may alienate consumers who would otherwise purchase insect food.[5] However, in order to combat this problem, an international consortium known as IPIFF (International Platform for Insects as Food and Feed) is currently working to change EU laws in favour of greater freedom in marketing insects as food. This indicates that insect foods *are* reaching EU (European Union) markets, but also highlights the importance of systematic research into the nutritional content and safety of commercially available insects for human consumption.

Insects are not a new food, although they have not been farmed on a commercial scale for use as human food until fairly recently. Instead, the majority of edible insects are harvested from the wild, particularly in remote rural regions and in tropical countries with high biodiversity, where insects have been an important wild source of protein and micronutrients for millennia.[6] However, insects are also a farmed or semi-farmed resource across the world. European honeybees are thought to have been domesticated for 7000 years,[7] and the domestic silkworm, *Bombyx mori*, has been farmed for at least 5000 years.[8] Silkworm pupae, a by-product of the silk-making process, are used as human food in many areas of Asia.[9] A relative of the silkworm, the mopane caterpillar (*Imbrasia belina*), is sold widely in markets and supermarkets across southern Africa, and the mopane trade is estimated to be worth millions of US dollars.[10] In recent years, there have been systematic attempts to farm mopane worms in intentionally planted mopane forests, to meet increasing demand and to give rural women control over this important source of income, and these have met with varying success.[11] This is part of a larger pattern: in many other areas of the world, NGOs (Non-government organisations), government-funded research teams, private companies and individual entrepreneurs are

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Received 27 May 2015; revised 7 July 2015; accepted 10 July 2015; published online 16 September 2015

attempting to semi-farm insects that were traditionally wild harvested. For example, insect-farming initiatives in Thailand now produce palm weevils and crickets on a commercial scale,[12] and similar farming methods are currently being developed for the African palm weevil[13] and Mexican grasshopper, both of which are highly valued foods in the regions in which they are harvested from the wild.[14] This shows an increasing interest in a fairly recent phenomenon: insect farming for human food on a commercial scale originated in Southeast Asia in the late 1990s.[6]

There are many advantages to farming insects. Crickets[15] and weaver ants[16] have a high feed conversion efficiency compared with traditional livestock. The greenhouse gas and ammonia emissions of five edible insects are lower or comparable to emissions from pig farming and far lower than published figures for cattle farming,[17] and a complete life cycle analysis of mealworm production has shown that mealworms require less land, comparable energy input and emit fewer greenhouse gases, than milk, chicken, pork or beef.[18] According to current research, therefore, insects are a cheaper and more environmentally sustainable to conventional livestock.

The health consequences of insect consumption are less clear. The nutritional composition of many edible insects has been tested, and many have favourable nutrient profiles, particularly in the context of a locally-sourced traditional diet. For example, we know that that the palm weevil larvae consumed in some parts of Africa are high in lysine and leucine, both of which are found in insufficient quantities in tubers, the traditional staple food in the same regions.[19] However, there is little experimental evidence to suggest that insects are nutritionally preferable to other plant- or animal-based protein sources. Insects have been considered as a potential source of nutrients for human complementary feeding,[20] but the results of human trials on health indicators are yet to be published.

To address this lack of data linking health impacts with increased insect consumption, in the present study we chose to use evaluative tools developed 'to classify foods based on their nutritional composition'.[21] These are known as nutrient profiling models, and can be used to derive a 'healthiness' score for foods based solely on their nutritional composition. A wide range of approaches have been used towards the development of such models, and opinion is divided over which approach is most scientifically robust.[22] The scores produced by nutrient profile models have been validated against food-based dietary guidelines,[23,24] the opinions of nutrition experts,[25] theoretically constructed healthy diets,[26] healthy diets achieved in populations[26] and (most importantly) prospective health outcomes.[25]

In this study, we wish to understand the relative nutritional value of commercially available insects and commonly consumed meats in two scenarios tackling two different causes of diet-related ill health, under-nutrition and over-nutrition. For our model developed to target over-nutrition, we chose the Ofcom model, which is currently in use in the United Kingdom to regulate broadcast advertising of foods to children,[27] and is the basis of regulation in Australia and New Zealand to both regulate health and nutrition claims and support the 'healthy stars' voluntary front-of-pack labelling scheme.[28,29] We used the 'Nutrient Value Score' (NVS) as a model that targets under-nutrition. The NVS is a tool developed by the United Nations World Food Programme to inform the composition of food baskets and commodity vouchers, classifies individual foods on a continuous scale based on their nutrient composition, with an emphasis on micronutrient content.[30]

Table 1. Median and inter-quartile range for nutrients associated with over-nutrition, including those used in the Ofcom model, in 100 g of commonly consumed meats, meat by-products (offal) and insects

Daily value[a]	*N*	*Energy (Kcal)* 2000	*Nutrient content per 100 g edible portion*			
			Protein (g) 50	*Fat (g)* 65	*Saturated fat (g)* 20	*Sodium (mg)* 2400
Beef	42	169 139–218	20.6 19.2–21.6	9.3 5.1–15	3.8 2.48–6.1	60 52.5–66.5
Chicken	25	152 127–198	19.9 18–22	7.2 4–13.9	1.81 0.8–4	80 69–89.5
Pork	10	186 123–218	20.1 18.6–21.5	12.4 4–16.2	3.5 1.4–5.45	62 55.5–67.5
Offal (beef)	8	108 92–126	16.9 15.6–18.6	3.45 2.18–5.38	1	71 28–114
Offal (chicken)	10	133 110–250	16.8 10.5–18.1	6.8 3.75–19	12.1 6.4–12.9	66 50.5–79.5
Offal (pork)	13	108 97.3–125	16.9 15.3–18.2	4.15 3.13–8.3	1.2 1.05–2.39	132 119–140
Cricket (adult)	8	153 147–159	20.1 13.2–20.3	5.06 3.51–6.05	2.28	152 143–178
Honeybee (brood)	5	499	15.2 12.3–18.1	3.64 3.27–4.52	2.75	19.4
Silkworm (pupae)	3	128 126–131	14.8 13.5–20.8	8.26 7.63–11.9	3.45 2.94–3.95	14
Mopane caterpillar (final instar)	3	409	35.2 35.2–44.6	15.2 14.5–15.2	5.74	
Palm weevil (larvae)	15	479 452–582	9.96 8.38–20.7	25.3 24.7–38	9.84 8.31–32.3	11 1.2–109
Mealworm (larvae)	26	247 215–268	19.4 18.1–22.1	12.3 11.2–15.4	2.93 2.59–4.17	53.7 46.9–54.2

[a]Daily values from the US Food Labelling Guide.[43] All are daily reference values (DRVs) with the exception of sodium, which is a recommended daily intake (RDI) value.

MATERIALS AND METHODS

Meat and insect nutrient composition data

For a broad geographical spread of meat nutrient composition data, we selected one database per continent from the FAO INFOODS website, with the exception of South America where no English language databases were available:

1. Asia: The Concise ASEAN Food Composition Tables.
2. Africa: Food Composition tables for Africa.
3. Europe: UK COFIDS tables.
4. North America: USDA Food tables for standard reference (abridged list).
5. Oceania: The Pacific Islands Food Composition Tables.

For chicken, pork and beef products in each database, we included every dataline with the keywords: '[Meat name]'; 'raw'. We excluded processed meats (for example, cured, dried, smoked, minced and enhanced) and any meats that were described as 'weighed with bone'. Offal and meat by-products are traditional foods that, similarly to insects, are rejected in contemporary 'Western' diets.[31,32] Therefore, in order to evaluate these under-utilized meat products separately, any foods that fulfilled the above criteria but were not a specific cut of meat or a whole

Table 2. Median and inter-quartile range for the eight micro-nutrients used to calculate the Nutrient Value Score (NVS), in 100 g of commonly consumed meats, meat by-products (offal) and insects

Daily value[a]	*N*	*Micronutrient content per 100 g edible portion*							
		Calcium (mg) *1000*	*Iron (mg)* *18*	*Iodine (mg)* *0.095*	*Vitamin C (mg)* *60*	*Thiamin (mg)* *1.5*	*Vitamin A (mg)* *1.5*	*Riboflavin (mg)* *1.7*	*Niacin (mg)* *20*
Beef	42	5	1.95	10	0	0.08	0	0.23	4.7
		5–8.25	1.54–2.31	9–11		0.07–0.07	0–2	0.17–0.25	4.05–5.25
Chicken	25	8	0.88	6	1.1	0.075	0	0.16	6.5
		6.75–12	0.7–1	5–7.5	0–2	0.0675–0.12	0–16.5	0.125–0.22	4.87–7.65
Pork	10	7	0.8	5	0	0.77	0	0.235	5.6
		6–10	0.7–0.8		0–0.25	0.635–0.928		0.18–0.28	4.85–6.86
Offal (beef)	8	15	7.3	16	1	0.175	249	0.355	4.6
		11.3–23.5	3.8–10.5		0–5.5	0.11–0.28	128	0.185–1.13	3.48–6.65
Offal (chicken)	10	10	2.45	16	6	0.09	39.5	0.375	3.85
		7.75–13.3	1.25–6.07		1–14	0.05–0.125		0.123–0.578	2.25–6.45
Offal (pork)	13	10.5	4.8	7	6	0.27	5.5	0.47	4.18
		7.75–11.8	2.55–6.35		0–10.5	0.12–0.32	0–27.5	0.368–1.44	2.53–8.65
Cricket	8	104	5.46	0.021	3	0.04	6.53	3.41	3.84
		49.8 - 287	2.47–8.01				6.44–24.4		
Honeybee	5	30	18.5		10.25		25.7	3.24	
		22.7–37.3	15.2–21.9				19.1–27.4		
Silkworm	3	42	1.8			0.12		1.05	0.9
Mopane caterpillar	3	700							
Palm weevil larvae	15	39.6	2.58		0.00425		11.3	2.21	
		0.028–48	0.528–8.4						
Mealworm	26	42.9	1.87	0.017	1.2	0.24	9.59	0.81	4.07
		30	1.6–2.45				5.7–20.5		

[a]Daily values from the US Food Labelling Guide.[43] All are daily reference values (DRV) with the exception of vitamins and minerals, which are recommended daily intake (RDI) values.

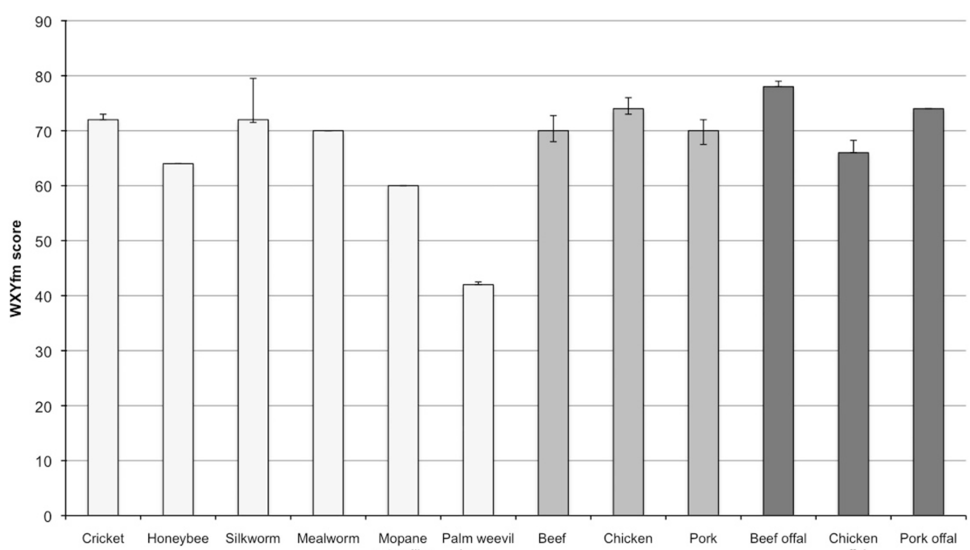

Figure 1. Bar graph showing the median values and inter-quartile range of Ofcom (adjusted) scores for insects (light grey), meat (medium grey) and offal (dark grey). Higher scores indicate healthier foods.

carcass (for example, organs, skin and blood) were grouped as 'offal'. Where a range of values was provided, only the single best estimate (mean/median) was used. Where a value was listed as 'Tr' (trace), we replaced this with '0'.

We also extracted datalines for six commercially available edible insect species that are currently produced using intensive or non-intensive farming: Cricket (*Acheta domesticus*), honeybee (*Apis mellifera*), domesticated silkworm (*Bombyx mori*), mopane caterpillar (*Imbrasia belina*), African palm weevil larvae (*Rhynchophorus phoenicis*) and yellow mealworm (*Tenebrio molitor*). These data were taken from all English language FAO INFOODS databases and from a systematic review of published literature, and the datalines describe the nutrient composition of fresh insects in their raw, unprocessed state. Full details of methods and selection criteria are currently in review.[33]

For all the foods described above, we extracted data for energy and the 12 macro- and micronutrients relevant to calculating Ofcom Scores and NVSs. The final database contained 128 datalines for meat (42 for beef, 25 for chicken, 31 for pork and 30 for offal) and 55 for insects. Many datalines had missing values for certain nutrients. In such cases, we replaced missing values with the median value for that category.

Nutrient profile models

First, we chose the Ofcom model, which scores foods on the basis of their nutritional content per 100 g of the following nutrients to limit: energy, total sugars, sodium and saturated fat; and balances this against constituent elements considered conducive to health – fruit, nuts and vegetables, fibre and protein. Full details on how the Ofcom model is applied are available here.[27]

We used Stata syntax (freely available on request) to generate Ofcom Scores for each food in the database, and adjusted the scores to fall on a scale from 1 to 100 where 1 is the least healthy and 100 is the most healthy.

Second, we chose the NVS, which was developed to inform food assistance programmes for populations who are at high risk of undernutrition and micronutrient deficiencies. The NVSs are based on quantities of energy, protein, fat and eight micronutrients measured per 100 g (or relevant, food basket-specific quantity) of food to evaluate the relative nutritional quality of foods. We calculated the scores for each food in the database using an Excel file (freely available on request).

We ran pair-wise non-parametric Mann–Whitney U comparisons for the scores (both Ofcom and NVS) of each category of food, using Stata software. We applied the Bonferroni adjustment to determine the appropriate *P*-value indicating the significance of our results. Since we ran 132 pair-wise comparisons for 12 categories of food, the original *P*-value of 0.05 was reduced to 0.000378, and only the comparisons with *P*-values lower than this were considered as significant.

RESULTS

Table 1 shows the median and interquartile range of values in each food category for the nutrients used to calculate the Ofcom model. Saturated fat and sodium are the major parameters in this model that are relevant to animal products. Of the meat products, chicken offal is notably high in saturated fat (12.1 g per 100 g) but others have a relatively low median value (range = 1–3.8 g per 100 g) considering that the recommended daily allowance is 20 g.[4] Insects, however, have a far greater range of median values, from 2.28 to 9.84 g of saturated fat per 100 g. Median values for the sodium content of insects (range = 0–152 mg per 100 g) also show a greater range than for meat (range = 60–132 mg per 100 g). Values for protein content show the same pattern, with insects containing median values of between 9.96 g and 35.2 g of protein per 100 g, compared with 16.8–20.6 g for meat.

Table 2 shows the median and interquartile range of values in each food category for the additional nutrients used to calculate the NVSs. Complete information is missing for all but two of the six insect species. The median iron content of crickets and honeybees is 180 and 850% greater (respectively) than for beef, which has the highest iron content of the three meats. However, iron content of beef offal is higher than crickets. All of the insects had higher calcium and riboflavin levels than any of the meats or meat offals.

Table 3. *P*-values (Mann–Whitney *U* rank-sum test) indicating the significance of differences in Ofcom scores and Nutrient Value Scores of insects, meat and meat by-products (offal)

Ofcom score	*N*	*Cricket*	*Honeybee*	*Silkworm*	*Mopane caterpillar*	*Nutrient Value Score*							
						Palm weevil larvae	*Mealworm*	*Beef*	*Chicken*	*Pork*	*Beef offal*	*Chicken offal*	*Pork offal*
N		8	5	3	3	15	26	42	25	10	8	10	13
Cricket	8		0.143	0.0143	0.0134	0.0092	0.005	*< 0.0001*	*< 0.0001*	0.0149	0.248	0.105	0.328
Honeybee	5	0.196		0.0253	0.0219	0.0012	0.0004	0.0004	0.0005	0.0004	0.143	0.114	0.221
Silkworm	3	0.422	0.0253		0.0369	0.0066	0.0038	0.008	0.0084	0.0419	1	0.665	0.128
Mopane caterpillar	3	0.324	0.334	0.825		0.0065	0.0038	0.008	0.0053	0.0557	1	0.664	0.126
Palm weevil larvae	15	< **0.0001**	0.0006	0.0373	0.0063		0.0197	*< 0.0001*	*< 0.0001*	0.236	0.696	0.128	0.956
Mealworm	26	0.401	0.188	0.526	0.463	*< 0.0001*		*< 0.0001*	*< 0.0001*	0.307	0.452	0.0181	0.437
Beef	42	0.859	0.126	0.359	0.252	*< 0.0001*	0.251		0.688	< **0.0001**	0.146	0.0398	0.0019
Chicken	25	0.0028	0.0155	0.105	0.0708	*< 0.0001*	0.0004	0.0059		< **0.0001**	0.166	0.0379	0.0017
Pork	10	0.902	0.123	0.299	0.21	*< 0.0001*	0.579	0.991	0.0129		0.602	0.11	0.903
Beef offal	8	*0.0001*	0.0021	0.0095	0.0093	*0.0001*	*< 0.0001*	*< 0.0001*	0.01	*0.0001*		0.817	0.79
Chicken offal		0.0283	0.913	0.823	0.652	*0.0001*	0.0058	0.031	0.0017	0.0217	0.0007		0.468
Pork offal		0.11	0.0132	0.148	0.0429	*0.0003*	0.0026	0.136	0.327	0.187	0.0003	0.0075	

Numerical values in bold text indicate that the score of the food on the top row of the table was significantly ($P < 0.000378$) greater than the score of the food on the left column; Values in italicised text indicate that the score of the food on the left column of the table was significantly ($P < 0.000378$) greater than the score of the food on the top row. Standard text indicates no significant difference ($P > 0.000378$; the *P*-value was adjusted from 0.05 using the Bonferroni correction).

Figure 1 shows the median and inter-quartile range of Ofcom scores for each food, and Table 3 shows the *P*-values for pair-wise comparisons of these scores using the Mann–Whitney *U* test and the Bonferroni correction. There is no indication that any insect used in this analysis is a significantly 'healthier' alternative to meat using this model; instead, beef offal is classified as 'healthier' than three insects: crickets, palm weevil larvae and mealworms ($P = 0.0001$; $P = 0.0001$; $P < 0.0001$); and all meat and offal products are 'healthier' than palm weevil larvae. However, there is also significant variation between insect species: both crickets ($P < 0.0001$) and mealworms ($P < 0.0001$) are 'healthier' than palm weevil larvae.

Figure 2 shows the median and inter-quartile range of NVSs for each food, and Table 3 also shows the *P*-values for pair-wise comparisons between these scores. Using this model, there is no significant variation between insect species. Crickets ($P < 0.0001$), palm weevil larvae ($P < 0.0001$) and mealworm ($P < 0.0001$) have a significantly higher score than beef and chicken, but the only other pair-wise comparisons with any significant difference are those showing that pork products are more nutritious than beef ($P < 0.0001$) and chicken ($P < 0.0001$). However, of the insect species, only crickets and mealworm had nutritional information for every nutrient used to calculate this model; all the others had missing values.

DISCUSSION

The results presented here are the first systematic comparison of the nutritional composition of insects and meat, and their relative healthiness according to contemporary nutrient profiling models.

Our first key finding from these analyses is that insects vary widely between species in terms of nutrient content and consequently their potential for combating crucial public health problems. Due to this variation, we suggest that the term 'insects' is not a useful food category in discussions of health and nutrition. Second, we find that many insect foods have a higher content of energy, sodium and saturated fat than conventional livestock. On the one hand, this suggests that these species are not suitable for promotion as alternatives to meat if the main priority is to combat diseases linked to over-nutrition, particularly since reducing dietary intake of sodium and replacing saturated fat with unsaturated fat is thought to reduce risk of heart disease.[34,35] Although the associations between saturated fat consumption and diet-related disease are controversial there remains strong evidence supporting the relationship between substituting saturated fats with unsaturated fats and reduced blood cholesterol.[34] Similarly there is evidence for associations between blood cholesterol levels and coronary heart disease,[34] and directly between fatty acid consumption on coronary heart disease.[36] Third, we find that insects tend to have very high micronutrient content, particularly in the case of micronutrients that are known to be deficient in many areas where food insecurity is high. Therefore, these species may be good candidate foods to promote in areas of food insecurity and malnutrition.

Overall, the data presented here shows no evidence that any commercially available insect evaluated in the current study is significantly preferable to meat for the purpose of combating diet-related disease caused by over-nutrition. Offal and meat by-products, on the other hand, are potentially healthier alternatives to commonly consumed cuts of meat, yet offal and meat by-products are not popular foods in Europe. In the United Kingdom, for example, offal has declined in popularity in recent decades[37] and in Italy it is still seen as the 'food of the poor'.[38] Therefore, although the promotion of insects does seem to be justifiable on environmental grounds, when considering health in situations of over-nutrition some meat by-products may be a more appropriate alternative to commonly consumed livestock products. Furthermore, the current study also shows that only a single insect – palm weevil larvae – is significantly inferior to meat using a model designed to combat over-nutrition.

However, analyses of nutrient composition using the NVSs tell a different story. According to the parameters set by this model, at least three insects do have a significantly higher nutritional value than the commonly consumed meats beef and chicken, and not a single comparison shows insects to be nutritionally inferior to meat. Insects as a commodity have many non-health-related positive benefits compared with livestock in terms of both financial and environmental cost, particularly in developing countries where under-nutrition is a key problem. The finding that insects and meat do not show significant divergence in nutritional composition suggests that there is no health-related trade-off in promoting insect foods over meat.

Elsewhere, data on the dry weight nutrient composition of a broad range of insect species are available,[4] and other research has compared the nutritional composition of meat and other protein sources. Quorn products, which are made using

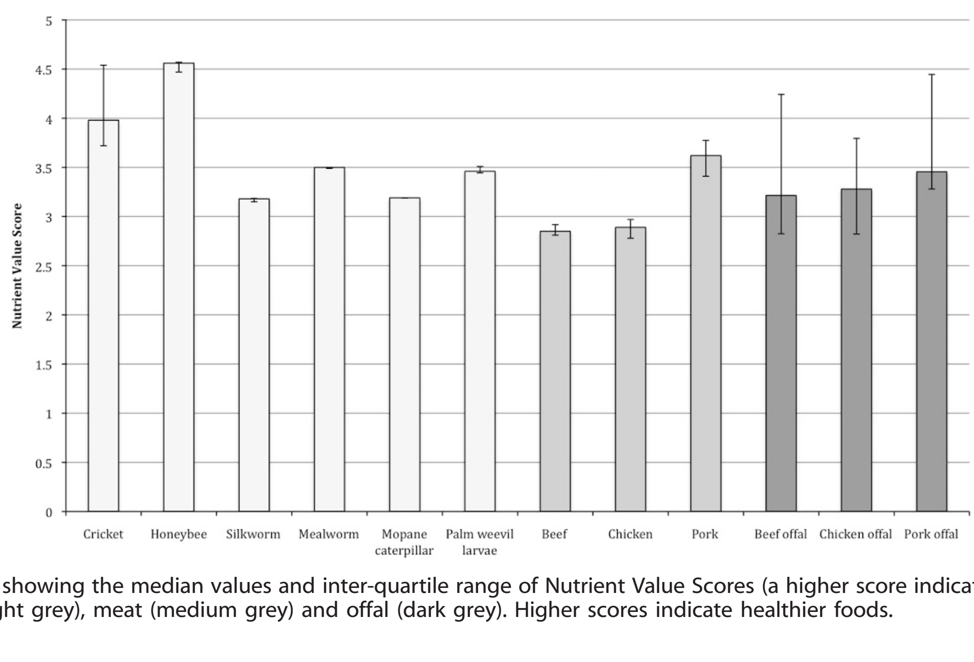

Figure 2. Bar graph showing the median values and inter-quartile range of Nutrient Value Scores (a higher score indicates a more nutritious food) for insects (light grey), meat (medium grey) and offal (dark grey). Higher scores indicate healthier foods.

myco-protein and marketed as alternatives to meat, have macronutrient composition profiles that are comparable to the meat products upon which they are based.[39] Non-traditional, wild meat species have lower levels of nutrients to limit such as cholesterol, sodium, saturated fat and polyunsaturated fatty acids compared with farmed livestock, and also have a higher iron content.[40] Insects offer yet another alternative to traditional meats, and as shown in this study, some do have favourable nutrient profiles compared with meat.

However, nutrient composition is only a proxy for effects on human health, and this is a significant limitation of the present study. There have been few trials with human subjects showing the effects of insect consumption, and to date, the results of such trials are inconclusive. Two insect-based products fed to infants, containing caterpillars[41] and termites,[42] had a positive effect on blood haemoglobin levels and bodily iron stores compared with control groups. However, in both cases there was no observable effect on growth rates or prevalence of stunting. Therefore, the link between nutritionally favourable insect foods and health outcomes requires further research. The results of the present study can be used to inform the choice of candidate species for future human trials.

A further limitation of our study is the lack of fresh weight data on the micronutrient content of several commercially available insects. As a result, we have substituted missing data with category medians, inflating the units of analyses for our statistical tests, and biasing our results away from the null hypothesis. Therefore, comparisons between meat and insects with missing values using the NVS nutrient profile model, which places emphasis on micronutrient content, are not conclusive at this stage, and should therefore be treated with caution.

Overall, in this paper we present systematically collected nutritional information on a range of commercially available and commonly consumed insects, meats and meat by-products. We use relevant nutrient profiling models to combine this information into a single measure of 'healthiness', enabling a direct comparison of insect and meat products. Our key findings are that the nutritional profiles of insects show great variation; meat products may be nutritionally preferable to certain insects in the context of overnutrition; and several insects are potentially superior to meat in situations of undernutrition.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

All authors contributed to research design; CP conducted the analyses and wrote the initial draft of the manuscript; all authors commented on, edited and approved the final manuscript. We would like to thank the Daiwa Anglo-Japanese Foundation and the Great Britain Sasakawa Foundation for directly funding this research project. As individual researchers we would like to thank the Japanese Ministry for Education, Culture, Sports, Science and Technology (MECT), the British Heart Foundation, the University of Oxford, UK, Rikkyo University, Tokyo, and the Japanese Society for the Promotion of Science (JSPS) (Japanese Grants-in-Aid for Scientific Research, Projects No. 22251002 and 26310314), for ongoing financial support. We would also like to acknowledge the contribution of the following individuals and organisations for their inspiration, encouragement and support in the course of this research project: Professor WC McGrew, Kushihara Agroforestry, the Oxford Food Forum and the Japan Vespula Society.

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