Should we provide edible insects in children's diets?

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REVIEW

CURRENT OPINION

Should we provide edible insects in children's diets?

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Purpose of review

Diets low in animal-source foods or solely consisting of plant-based foods, hardly meet nutrition needs of children, exposing them to inadequate intake of essential nutrients. Thus, including edible insects in children's diets is relevant for meeting nutritional requirements, other potential health benefits, and building more sustainable food systems. Nutrition and health research on insects is novel and still limited. This review covers recently published research between April 2022 and November 2023 focusing on the relevance of including insects in children's diets.

Recent findings

Insects provide protein, fat and micronutrients, and are generally nutritionally equivalent to animal-source foods. The protein and fat quality of edible insects varies depending on several factors. Insects also contain chitin which could potentially be beneficial for gut health. For insects to be considered suitable for inclusion in children's diet, they must be accepted. However, children who are unfamiliar with insects respond to them with curiosity and disgust.

Summary

Insect farming can enhance their availability and consumption, potentially addressing nutrition gaps. Furthermore, transitioning from occasional to regular insect consumption requires actual exposure and integration into diets of insects. To affirm the nutrition and health potential of edible insects for children, well designed human studies are essential.

Keywords

children, edible insects, health, insects, nutrition

INTRODUCTION

While insects have been part of traditional diets throughout human history, they have only been considered in modern food systems for human consumption in recent decades. Globally, more than 2000 insect species are recognized as edible. Less than 10 of these species are explored for farmed production. Farming of crickets (*Acheta domesticus* and related species) was developed in Thailand to boost the marketing of insects that were already consumed. Farming of the mealworm species (larvae of the beetles *Tenebrio molitor* and *Alphitobius diaperinus*) was developed in Europe and USA. Grasshoppers (*Ruspolia differens* and other species) and palm weevil larvae (*Rhynchophorous* species) are harvested from the wild in Africa and are now being developed for farming. Insects can be produced using less water and space, and emit less greenhouse gases than traditional livestock, while providing similar nutritional advantages [1]. Thus, insects are relevant in modern food systems as a more sustainable animal-source food, alternative to livestock.

Insects are nutrient-dense providing protein, fat and micronutrients. Including edible insects in children's diets is relevant for meeting nutritional requirements for growth as well as for additional potential health benefits. The nutritional needs of infants and young children can hardly be met from plant-source foods alone, particularly in food insecure settings. Conversely, in high-income settings,

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KEY POINTS

- Edible insects provide good quality protein, fat and a range of micronutrients fairly similar to other animal-sourced foods.
- Including edible insects in children's diets is relevant for meeting nutritional requirements for growth as well as for additional potential health benefits.
- Four insect species relevant for farming (*Acheta domesticus, Tenebrio molitor, Alphitobius diaperinus, Locusta migratoria*) are considered well tolerated for consumption and have been approved by EFSA; nevertheless, toxin, microbial contamination and allergenicity should be considered.
- Edible insects have varied acceptability in children depending on previous exposure and cultures; however, they are well tolerated to include in children's diets.
- Well designed clinical trials are needed to determine the potential of specific insect species including the bioavailability of nutrients, safety and allergenicity, effects of production and processing on insect products, effects of insect properties on the gut, and the potential in the prevention and treatment of malnutrition.

diets excluding animal-source foods may compromise the intake of some essential nutrients for infants and young children.

Evidence on nutritional and health impacts of foods requires well designed clinical trials and population studies. Nutrition and health research on insects is novel and still limited, in both numbers and relevance of studies. This review covers recently published research between April 2022 and November 2023 focusing on the relevance of including insects in children's diets. Due to the limited number of relevant publications and the complexity of covering multiple insect species, we applied a convenient search strategy to capture the relevant literature. A total of 21 studies related to nutrition and health, seven studies covering acceptability, and four reviews were identified for the period reviewed (Table 1).

ARE INSECTS WELL TOLERATED TO CONSUME?

When edible insects gained global attention as alternative protein sources, they were not covered by food regulations worldwide. In 2015, the EU established a regulation, defining edible insects and insect-based products as 'novel foods', to be evaluated for safety (EU Regulation 2015/22839) by the European Food Safety Authority (EFSA). To date, seven insect products covering four insect species [house cricket, lesser mealworm, yellow mealworm and locust (*Locusta migratoria*] are considered to be well tolerated for consumption by EFSA [2–4].

Table 1. Publications covered in the review period

Topic covered	Human studies	Animal/ Experimental studies	Review
Are insects well tolerated to consume		(Eischeid *et al.*, 2023)	(De Marchi *et al.*,2021)
Nutritional qualities of insects (protein, fat, micronutrients)	Ref 9 (Lanng *et al.*, 2023) Ref 7 (Hammer *et al.*, 2023) Ref 18 (Hilaj *et al.*, 2022) Ref 17 (Mwangi *et al.*, 2022)	Ref 10 (Akande *et al.* 2023) Ref 12 (Brogan *et al.*, 2023) Ref 13 (Cavalheiro *et al.*, 2023) Ref 20 (Coppoolse *et al.*, 2022) Ref 21 (Fedosov *et al.*, 2023) Ref 19 (Kosečková *et al.*, 2022) Ref 8 (Malla *et al.* 2022) Ref 14 (Ochieng *et al.*, 2023) Ref 16 (Sikora *et al.*, 2023) Ref 15 (Zielinska & Pankiewicz, 2023)	Ref 11 (van Huis *et al.*, 2021) (van Huis *et al.*, 2022)
Potential health effects of insects		Ref 24 (Dai *et al.*, 2022) Ref 25 (Kang *et al.*, 2023) Ref 22 (Refael *et al.*, 2022) Ref 27 (Sarkar *et al.*, 2023) Ref 23 (Tran *et al.*, 2023)	
Are insects accepted in children's diets	Ref 29 (Erhard *et al.*, 2023) Ref 34 (Gumussoy & Rogers, 2023) Ref 28 (Hémar-Nicolas *et al.*, 2022) Ref 32 (Kulma *et al.*, 2023) Ref 30 (Maya *et al.*, 2023) Ref 31 (Maya *et al.*, 2023) Ref 33 (Stone *et al.*, 2023)		Ref 26 (van Huis & Rumpold, 2023)

Overall, the food safety concerns of insects do not exceed those of other animal-based foods and can be included in children's diets on the same conditions. However, insects must be evaluated by species as risks of accumulated toxins or microbial contamination differs [3]. The risk of allergenicity is relevant when considering insects in children's diets. A cross-reaction between crustacean and insect allergenicity (crustaceans and insects are evolutionary related to arthropods) has been documented in several studies, including a recent study [5▪]. Consumption of significant quantities of insects may trigger allergic reactions, whereas the presence of minimal traces of insects is unlikely to pose allergic risks. A review of allergens from edible insects published in 2021 confirmed the cross-reactivity with other arthropods and suggested that a major research gap exists in identifying the route of sensitization from major and minor allergens, as well as in understanding the effects of processing on insect-based food products [6▪].

NUTRITIONAL QUALITY OF INSECTS

Protein

Similar to other animal-source foods, the macronutrient value of insects is primarily represented by protein and fat. To meet the requirement for growth, protein requirements are higher per kg body weight in children than in older individuals. The protein content of the various edible parts of insect species range from 35 to 61% of dry matter [1]. The order 'Orthoptera' (crickets, grasshoppers, and locusts) are consumed as adults (they lack a larvae-stage) resulting in higher protein and lower fat content, compared to mealworm species that are consumed as larvae.

To measure the crude protein content of insects, the standard nitrogen (N) method leads to overestimation of the protein content due to nonprotein N in chitin, an amine-containing polysaccharide in the insect exoskeleton. Crude protein is standardized to an N-to-protein conversion factor of 6.25. A lower conversion factor of 5.33 has been suggested for insects, to account for chitin-N. Due to this, reported protein contents in insects might generally be overestimated.

Protein quality is also determined by digestibility. Insect protein quality and digestibility, assessed in animal and in-vitro models, was recently reviewed [7▪,8▪]. In one study, Hammer *et al.* [7▪] investigated the in-vitro Digestible Indispensable Amino Acid Scores (DIAAS) of processed mealworms (*Tenebrio molitor*) and house cricket (*Acheta domesticus*), reporting negative impacts of chitin reduction and oven drying on digestibility. In another study, Malla *et al.* [8▪] determined DIAAS in growing pigs – the most valid model on protein quality for humans – assessing five insect species, out of which four are relevant as food (banded cricket (*Gryllus sigillatus*), house cricket, yellow mealworm, lesser mealworm/buffalo worm (*Alphitobius diaperinus*). Sulphur-containing amino acids were the first limiting amino acids in the four species, in view of children above 6 months. Crickets and lesser mealworm had DIAAS above 75 indicating good protein quality. However, if applying the insect-specific N-conversion of 5.33, the DIAAS would be proportionally higher, classifying crickets as excellent and mealworm as good sources of protein quality for children above 3 years.

A human study compared partially defatted house cricket powder with pea and whey for amino acids bioavailability and muscle synthesis in healthy adults ($n=50$) [9▪]. The amino acid response in blood showed lower levels of most amino acids after intake of the cricket test meal compared to whey, indicating inferior amino acids bioavailability. The test meal composition did not account for the non-protein N in cricket, which may explain the amino acids difference in blood response. Additionally, there was no difference in activation of the rapamycin complex 1 (mTORC1) signalling pathway in exercised muscles, indicating cricket proteins were metabolized similarly to pea and whey.

The application of insects in therapeutic products, such as Ready-to-Use Therapeutic foods (RUTFs) for treatment of severe acute malnutrition, is relevant as an alternative to dairy protein. A study in Nigeria assessed the composition of a RUTF product after substituting milk, with powdered grasshopper (*Locusta migratoria*) [10▪]. The optimal amino acid composition, including essential amino acids was 5% dairy protein and 25% grasshopper protein. However, this product was not tested for its efficacy to treat malnutrition.

Fat

Lipids are the second most abundant nutrient component in insects, ranging from 13 to 77% of dry matter. The fatty acid composition of insects, specifically the long-chain polyunsaturated fatty acids (LCPUFA) is partially determined by the constituents in the substrate [11▪]. LCPUFAs are beneficial for children's cognitive development. While specific impacts of insect fatty acid on child nutrition and health have not been reported, three recent studies reviewed their lipid content and quality. The lipid content and composition of three species – house cricket, locusts (*Locusta migratoria*) and silkworm pupae (*Bombyx mori*) – was assessed via thin layer and gas chromatography [12▪]. Total fat content ranged from 15.4, 11.4 and 33.3 g/100 g dry weight for the three species, respectively, with distinct differences in fat composition. Triacylglycerol accounted for 25% of total fat from locust, 38% from crickets and 70% from silkworm pupae, while phospholipids amounted to 25% of total fat both from cricket and locust and 6.1% from silkworm pupae. Regarding fatty acid composition, the essential fatty acids, linoleic (ω6) and alpha-linolenic (ω3) fatty acids showed very different trends in cricket and silkworm pupae powder. Cricket powder had the highest (35 g/100 g fatty acid) concentration of linoleic FA, and silkworm pupae powder had the lowest (6 g/100 g fatty acid), whereas the opposite was found for linolenic fatty acid (cricket powder 1 g/100 g fatty acid vs. 33 g/100 g fatty acid in silkworm pupae). Equally large differences in the ω-6: ω-3 ratios were found. Other major fatty acids in the insect powders were palmitic, stearic and oleic acids [12▪]. A study by Cavalheiro *et al.* [13▪] assessed fatty acid composition of cricket flour as meat replacer in frankfurters, by replacing 2.5 g/100 g, 5.0 g/100 g and 7.5 g/100 g of pork meat with cricket powder. Inclusion of the highest amount of cricket flour (7.5 g/100 g) led to higher levels of PUFA. A study by Ochieng *et al.* [14▪] also found that adding grasshoppers to cookies increased the amounts of PUFAs. For nutritional value in children' diets, insects should be evaluated species by species for accurate determination of lipids.

MICRONUTRIENTS

Edible insects are potentially good sources of vitamins and minerals. However, considerable intra- and inter species micronutrient variation has been documented due to location of origin, age at harvest, feeding substrates, and food processing [1]. Edible insects have been recognized for high concentrations of iron, magnesium, manganese, phosphorous, selenium, zinc and vitamin B12 [1]. However, the bioavailability of micronutrients from insects is crucial in determining their potential as alternative food sources. Two studies investigated the effect of formulation and food processing on the nutritional content of insect products. Ochieng *et al.* [14▪] evaluated the nutritional characteristics of cookies enriched with either blanched, boiled or toasted grasshoppers. Blanching and boiling led to higher micronutrient content including iron and zinc, in comparison to toasting the grasshoppers. Another study evaluated the nutritional value of house cricket flour, defatted flour and protein isolate intended as supplements for athletes [15▪]. Defatting flour enhanced the concentration of several minerals.

Sikora *et al.* [16▪] assessed minerals of 12 commercial insect-based foods available in the EU. The products were enriched with lesser mealworm, yellow mealworm, house cricket, locust (*Locusta migratoria)* and silkworm larvae. Potassium (K) and sodium (Na) were abundant while the products were low in calcium and magnesium. Of microelements, zinc, iron, and copper were found in relatively high concentrations. It was concluded that products with cricket were the most nutrient-dense. Another study on the nutritional properties of replacing pork with cricket in frankfurters found high concentrations of zinc, calcium and manganese, with low concentrations of Na [13▪].

Insects contain a notable amount of iron, however, the absorption of iron from edible insects has not been well established. Mwangi *et al.* [17▪] carried out an exploratory isotopic study to establish fractional iron absorption from maize flour enriched with house crickets in 20 iron-depleted females. The fractional absorbed iron was low in all meals, specifically the cricket meals, probably due to inhibitory components such as chitin or other substances in the insects. A comparable isotopic study was conducted to assess fractional iron absorption of maize porridge enriched with whole yellow mealworm powder or its dechitinized protein fraction in 21 females [18▪]. Contrary to findings of Mwangi *et al.* [17▪], iron was moderately well absorbed with no differences between whole mealworms or its dechitinized protein fraction. The discrepancy in outcomes between these studies may be attributed to differences in iron and chitin abundance between the insect species, as well as in the structural properties of chitin during metamorphic stages of the insects, or differences in the presence of other antinutrient components.

Edible insects have been reported to have high amounts of zinc [11▪,15▪,16▪]. In populations at risk of deficiency, enhanced zinc intake benefits children by reducing the risk of infections promoting growth, development and immune function. One study included in this review evaluated mineral profile of edible insects, reporting house cricket powder to be the most abundant in zinc content amounting to 25.5 mg/100 g. Unprocessed house crickets, yellow mealworm, desert locust (*Schistocerca gregaria*) and 'super worm' (*Zophobas morio*) contained zinc in the ranges of 7.9–16.9 mg/100 g dry matter [19▪]. Replacing 10% of wheat flour with cricket powder resulted in higher (two-fold) zinc content. Another study by Coppoolse *et al.* [20▪] utilized linear programming analysis to model the potential of house crickets in enhancing zinc content in children's diets in Kenya. Food-based dietary recommendations based on locally available and consumed foods including house crickets were modelled to optimize diets of 2 to 3-year-old children. The regular zinc intake was 4.46 mg/day for children, providing 52.2% of reference intake. In the linear programming best-case scenario (optimized by a selection of high-nutrient-dense foods within each food group), inclusion of house crickets improved the zinc intake from 89 to 121% of the reference intake.

Cobalamin, also known as vitamin B12, is essential for blood cell formation and development of brain and nerve cells. Deficiency in vitamin B12 is prevalent in populations with diets low in animal protein. As an animal-source food, edible insects are potentially a rich source of cobalamin, but the evidence is currently limited. One study included in this review assessed the accurate determination of vitamin B12 from cricket powders. Fedosov *et al.* [21▪] suggest that majority of the current methodological approaches overestimate vitamin B12 content by including physiologically inactive analogues of cobalamin. High amounts of inactive vitamin B12 analogues (40–60 μg/100 g) were reported compared to active vitamin B12 (0.75–2.2 μg/100 g) in crickets, recommending the use of competitive binding and high-pressure light chromatography assays for the proper determination of vitamin B12 in insects [21▪]. For relevance in children's diet, studies of micronutrient contents in insect-based foods should be accompanied with realistic estimates for actual intakes.

POTENTIAL HEALTH EFFECTS OF INSECTS

Chitin found in the exoskeleton of insects has been reported to positively influence gut health, presumably as a prebiotic fostering the growth of beneficial intestinal bacteria [11▪]. Two recent studies examined the potential impact of insects on gut health. In one study, in-vitro digestion, powders of cricket and silkworm pupae increased microbiome diversity without altering short-chain fatty acid production. Isolated chitin from crickets stimulated the growth of commensal bacteria, including *Ruminococcacaea, Lachnospiracacae, Faecalibacterium* and *Roseburia* [22▪]. Furthermore, Tran *et al.* [23▪] reported rapid restoration of gut microbiota, including an abundance in *Lactobacillus,* by exposing pregnant mice to different levels of grasshopper and cricket extracts after induced disruption of the gut microbiome. The findings suggest a positive influence of edible insects on the gut. Nevertheless, there is uncertainty in the exact mechanism of chitin on the gut, necessitating further research.

Protein has higher satiating properties than other macronutrients. Circulating amino acids and appetite-regulating hormones may increase the feelings of fullness. Dai *et al.* [24▪] assessed appetite regulation in men ($n = 25$) after consuming 25 g of either cricket or beef-derived beverages. Plasma concentrations of several amino acids were higher after consuming cricket than beef, while the concentrations of appetite hormones and subsequent energy intake were similar.

For associations between insect consumption and body weight, Kang *et al.* [25▪] conducted a study in obese mice consuming a high fat diet combined with different concentrations of protein from defatted yellow mealworm, lesser mealworm or casein. Mice fed on diets with mealworms gained less body weight compared to those on the casein diet. Furthermore, the mealworm-based diets increased serum high-density lipoprotein and a decrease in low-density lipoprotein, indicating potential health benefits.

Edible insects have been investigated for prevention of noncommunicable diseases. The greater wax moth (Galleria mellonella), yellow mealworm and the silkworm pupae have been reported to have angiotensin-converting enzyme (ACE) inhibitory levels of potential biological relevance to lower risks of hypertension and cardiovascular diseases [26▪]. Sarkar *et al.* [27▪] also documented ACE inhibitory properties from extracts of other silkworm species, *Antheraea assama* and *Philosomia ricinii*.

Edible insects may have therapeutic potential suggested by Tran *et al.* [23▪], who conducted an animal study evaluating the effects of grasshoppers (*Oxya chinensis sinuosa)* and field crickets (*Gryllus bimaculatus*) on improving autistic behaviour in an animal model, based on a framework of dysfunction in the blood–brain barrier (BBB). Cricket and grasshopper extracts were reported to improve BBB function.

ARE INSECTS ACCEPTED IN CHILDREN'S DIETS?

To be considered in children's diets, insects must be acceptable. Western cultures have little history of insect consumption, with an exception of the Sardinian delicacy 'casu martzo', a cheese infected with the larvae of the *Piophilidae* cheese fly. Generally, insects are not only unfamiliar as food, but they are also perceived with disgust, the so-called 'yuck' factor. In cultures with a tradition of consuming insects, new insect species may be novel to consumers.

Over the past decade, a considerable number of studies on consumer attitudes towards insects have been published. A review published in June 2023 covered 23 primary studies published in 2022–2023 [26▪]. In total five studies were conducted in children, of which one was published within our review period [28▪]. Additionally, two studies in children were published in 2023 [29▪,30▪].

Hémar-Nicolas *et al.* [28▪] evaluated the acceptance of insects as food in 43 children aged 8–13 years from France, assessing perception and willingness to eat insects. Using semi-structured interviews, they found that the children considered insects culturally nonedible and associated insects with traditional cultures, survival and dirt. Acceptability was determined by sensory perception, and disgust was the main reason for rejection of insects. Nevertheless, children were curious about eating insects in an experiential setting with peer interaction, in contrast to a family environment associated with protection.

Another study among school children aged 9–11 years in Denmark ($n=181$) used pre and postexposure questionnaires to evaluate impact of exposure to information related to edible insects on willingness to taste them [29▪]. Pictures of insects and insect foods did not increase the expressed willingness to taste them, and food neophobia was a strong predictor not to try insects.

Furthermore, a study among 14 to 15-year-old Danish school children evaluated insect foods prepared at home in an online classroom during COVID-19 lockdown ($n=220$), as well as in an in-person classroom ($n=65$) [30▪]. For the online setting, the researchers provided a package with ingredients for parents to pick up prior to the home session. The students had a lesson about edible insects, and then tasted either a cricket cracker, or prepared a hot 'dahl' dish with a spicy cricket powder. The majority (88%) of the children were willing to taste the insect products. For the in-person classroom session, it was found that information improved the perception of insects as a suitable and sustainable substitution of meat. More than half of the children had previous experience with tasting insects, typically at a single occasion, for example, an event.

A 6-week randomized intervention study by Maya *et al.* [31▪] investigated actual consumption of insect-based dinner meals (six different products, with servings containing insect protein equalizing typical meat meals (13 g protein for adults and 9 g for children), 3 days a week) by families in Copenhagen, Denmark, compared to a control group who were provided plant-based products ($n=80$ paired children/parents). In the insect group, 22 of the 40 families completed the intervention. Children were more likely to consume the insect-based dinners if their parents did, though the products were rated differently by children and adults. Children had preferences for familiar products, like 'minced meat'. The weekly replacement of meat with insect protein averaged 5.5% for adults and below 5% for children. Substantial replacement of meat with insects or other alternative proteins requires gradual consumer adjustment and may be challenging to consumers [31▪].

Recent consumer studies in adults are diverse in aims and methods. For example, one study in the Czech Republic found powdered insects to be preferred over whole insects, and smaller insects over larger insects [32▪]. An intervention in the United Kingdom ($n=280$) indicated an increase in acceptance and willingness to consume insects after consumers actively engaged with information on edible insects [33▪]. Another intervention in the USA ($n=120$) found that exposure to positive information on the qualities of insects (specifically crickets) positively contributed to overcoming disgust and increased intake of a cricket serving [34▪].

CONCLUSION

The recently reviewed literature affirms and introduces new knowledge on the nutritional and health qualities of edible insects. This review confirms that insects provide good quality protein, fat and a range of micronutrients relevant to children's diets. The bioavailability of micronutrients is, however, not well established. Variation in nutritional profiles between and within species highlights the need to distinguish between insect species and their origin. Moreover, insects have the potential to provide additional health benefits, such as of chitin which positively impacts gut health of children. Nevertheless, further evidence is vital to ascertain other indicative bioactivity and health benefits. To be relevant for inclusion in children's diet, insects must be acceptable. Consumer studies show that insects are received with curiosity as well as with disgust among children. Most studies focus on introducing insects to consumers either in a hypothetical context or as a single exposure. For the promotion of regular insect consumption, it is essential to prioritise actual exposure and integration of insects into dietary practices. Overall, insects are safe for children's consumption similar to other animal-source foods, although attention should be given to potential allergenicity. Edible insects as a nutritional source for children have the potential to provide a well rounded nutritional profile that is nearly equivalent to animal sourced foods. Well designed human studies are needed to further clarify the potential of insects as part of ordinary diets, as well as for prevention and treatment of malnutrition in children.

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Conflicts of interest

None.

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■■ of outstanding interest

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