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Edible Insects: Sustainable nutrient-rich foods to tackle food insecurity and malnutrition

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Abstract

The COVID-19 pandemic, global climate change, and a fast-growing human population have been reported to be leading millions into food insecurity. According to an FAO report, in 2020 over 811 million people were undernourished with 418 million in Asia, 282 million in Africa and 60 million in Latin America and the Caribbean. The world is off-track in ending hunger and improving nutrition, targets set by the United Nations (UN), to be achieved by 2030. The promotion of sustainable food sources such as entomophagy can help to deliver sustainable nutrition to many populations to reach the aforementioned UN targets. This narrative review explores the existing evidence around the use of edible insects to address food insecurity and malnutrition, including health, social and environmental benefits. For example, the house cricket (*Acheta domesticus*) provides on the order of three times as much energy, protein, and iron as an equal amount of beef or chicken and, unlike them, is an excellent source of calcium. An effective decontamination technique (to address safety issues such as allergens and pathogens) is required to produce edible insect powder. Insect powder can be used to effectively fortify conventional food products with iron, zinc, calcium and dietary fibre, which are often difficult to obtain in adequate amounts in many common dietary regimes, especially in low-income circumstances. In communities where the consumption of insects is already culturally accepted, promotion of their consumption could also help address chronic diseases related to poor diets such as type 2 diabetes. In addition to their high nutrient content, many edible insects provide anti-inflammatory factors. Supporting the harvesting and even rearing of edible insects could generate increased income from selling them in local markets.

Keywords: Edible insects, food insecurity, nutrition, food enrichment, sustainable food systems

Introduction

It is estimated that by 2050 the world will have a global population of approximately nine billion inhabitants, (1) requiring a doubling of food production. This might not be sustainable and will unavoidably put pressure on arable land and other natural resources required for crop production and animal farming (2), particularly given the negative impact of climate change and water shortages on arable land for food production (3). Concomitantly, hunger continues to grow globally with more than 2 billion people suffering from food insecurity in the world (4). In 2020, it was estimated that 811 million people went to bed hungry, an increase from 690 million in 2019, due to the COVID-19 pandemic (4). For example, in Africa 21% of the population are undernourished (4, 5). Despite having a global target set to halt hunger by 2030, rates are rising (4, 5). There is an urgent need for efficient ways of producing food and avoiding waste.

Food insecurity does not always mean having an empty stomach (acute hunger), but can also refer to being without reliable access to sufficient, affordable and nutritious food. Food security encompasses three main domains: adequacy of food supplies; stability of supplies and access to available supplies (6). Therefore, food insecurity should be viewed beyond the food agenda. Improving food and nutritional security by identifying more environmentally sustainable foods and providing comprehensive and clear recommendations on sustainable foods to consumers and policymakers (2) could help achieve a number of the seventeen sustainable development goals (SDG) by 2030 (7).

Edible insects have been part of many human diets for centuries and might be a promising component of a set of holistic actions to address global food insecurity, especially in communities where insects are already part of the local diet (8). There have been a number of claims that edible insects are sustainable and environmentally friendly sources of nutrient-rich foods and have been referred to as the ‘food of the future’ (9, 10). This narrative review aims to summarise and appraise the potential advantages of edible insects when employed to address food insecurity in the most affected countries, especially where insects are culturally acceptable as part of the diet.

Panorama of Malnutrition

The term malnutrition is used to characterise deficiencies, excesses or imbalances in the intake of energy and/or macro (e.g., protein) and micronutrients (e.g., vitamins and minerals) of an individual (11). Malnutrition encompasses two groups of conditions. The first group is undernutrition which includes acute and chronic hunger as well as hidden hunger or micronutrient deficiency. These conditions can be exacerbated by concurrent infections and diseases. The second type of malnutrition is overweight or obesity. Simplistically, these conditions result from an imbalance between energy consumed (excess) and energy expended (insufficient). However, overweight or obesity can occur concurrently with micronutrient deficiencies (6, 11).

The Global Report on Food Crises (GRFC), which is a joint consensus-based evaluation of acute food insecurity worldwide by 16 different organisations, shows that in 2019 the number of acutely food-insecure people reached the highest level (135 million), reflecting the worsening of this condition. Although conflicts were the main driver of acute food crises in 2019, extreme weather and economic shocks had become gradually significant (12).

It is estimated that 2 billion people suffer from moderate or severe food insecurity globally and women are more affected than men (4). Although the highest levels of total food insecurity (moderate or severe) have been observed in Africa and Asia, Latin America, and the Caribbean have experienced the fastest growth in food insecurity: rising from 22.9% in 2014 to 31.7% in 2019.

These pre-COVID-19 pandemic statistics show that the world is far from halting the rise in all forms of malnutrition by 2025 or achieving the Zero Hunger goal and ending food insecurity by 2030. The COVID-19 pandemic has caused a spike in food insecurity and hunger globally making it even more challenging to achieve the Zero Hunger goal (4). Based on current data, FAO estimates that Sustainable Development Goal 2 (Zero Hunger by 2030) will be missed by a margin of nearly 660 million people. Of these 660 million, 30 million may be linked to the pandemic's lasting effects (4).

Hunger and malnutrition are largely caused by violations of human rights, inequalities, injustice and discrimination that permeates our modern society. Violations of human rights are intertwined with the unjust, unhealthy and unsustainable global food system (13). For instance, the increased consumption of cereal-based products is linked with “pesticide-laden monocrops” (e.g., corn and wheat), which has a significant negative environmental impact. Increasing food production using mass-produced ultra-processed foods through for-profit industrial systems, far from addressing global hunger and malnutrition, contributes to it by increasing obesity (14). These approaches may be worsening these problems. The re-link with other food systems might provide an alternative solution to the production of sufficient, nutritious, affordable, and culturally appropriate foods (13).

Entomophagy: Opportunities and challenges

Entomophagy refers to the consumption of insects by humans (1). Edible insects have been part of the human diet in many parts of the world, particularly in tropical and subtropical countries (8). There are over 1,900 edible insects worldwide and 2 billion people eat insects as part of their traditional diets (1). Edible insects in these regions are considered a delicacy; their consumption is driven by their taste and not food scarcity (15). In some countries, the market price for edible insects is higher than for conventional meat products (15). This is partly because some of these insects are seasonal and they are available in the market only for a few months each year.

The consumption of insects, in a few instances, has also been promoted by local governments as a strategy for pest control (16). On the other hand, overexploitation and ecosystem degradation have threatened some species (e.g., wild caterpillars) (15).

In Western countries, entomophagy is ignored as a visible alternative, as insects are not featured as a culturally acceptable option and are often seen with disgust (1). Entomophagy is thus strongly influenced by cultural factors (8). A Canadian study has shown that people often refer to insects as a sustainable protein source, but consider their consumption undesirable (17).

Benefits of Edible Insects

There are several environmental, social, nutritional and health benefits of the consumption of edible insects as a source of food (1, 10, 15, 18).

Environmental benefits of edible insect farming

Insects are cold-blooded and therefore they have a more efficient feed-to-body mass conversion ratio. Feed conversion ratios (FCR, kg feed/kg weight gain) vary depending on the animal species and feeding composition and regimes (15). Crickets, for example, require only 2 kg of feed for every 1 kg of body weight while cattle require approximately 8 kg of feed to produce 1 kg of weight gain (1). The proportion of edible mass also differs between traditional livestock and insects. The average proportion of edible weight for beef cattle is 50% (19), while for cricket only 3% of its body mass is not digestible due to its chitinous exoskeleton (15). The proportion of edible weight can vary from 80% to 97% depending on how the cricket is consumed, as some people prefer to remove the legs (corresponding to 17% of body weight) (15).

Additionally, some insects can be fed by human and animal waste (organic side stream) and agricultural and food industry by-products (20, 21). This is an alternative way to make use of food waste. The greenhouse gas emissions by insects are likely to be lower than that of conventional livestock. The CO_2 emissions for the production of 1 kg of beef cattle, pork and chicken are equivalent to 14.8 kg, 3.8 kg and 1.1 kg, respectively (22). Mealworms, crickets and locusts can produce up to 100 times less greenhouse gas than beef cattle and pigs (15). The literature estimates that insect farming is less land-dependent than conventional livestock farming and requires less water (15). The water requirement per gram of protein of cattle is 16.8 g whereas crickets require only 0.7-0.8 g (23).

Furthermore, edible insects can be used as protein replacement in feeds for traditional livestock (e.g., cattle and poultry) and for aquaculture, replacing fishmeal. This also helps to preserve fish for human consumption (15, 24).

Social benefits of traditional collection and rearing of edible insects

Insects can be collected in the wild or reared. Minimal technical skills and financial investments are required for basic harvesting and rearing equipment making it an ideal activity for vulnerable groups, including women and landless people in urban and rural areas (15). Some species of edible insects can be collected early in the morning or in the evening making this activity compatible with other income-generating or routine activities (15). Collection of wild insects or small-scale rearing can offer an important income diversification strategy. It can improve the household diet as a good source of protein and provide income through the selling of excess production as street food (25). Improving the nutrition of populations could increase economic productivity and allow resources to be spent on improving access to education or health services (26). Interest in edible insect farming has rapidly increased, even in countries not traditionally involved in harvesting and collecting wild insects, and insect-based food products are also growing their market share (24).

Nutritional Benefits of using edible insects to address food insecurity

Most widely consumed protein food sources are not as nutrient-dense as edible insects. Edible insects provide a complete protein source, rich in essential amino acids, fibre and other micronutrients such as calcium, iron, zinc (Table 1), and vitamins (B_1, B_2 and B_{12}). However, more than 50% of these vitamins are lost after heat treatment of edible insects (27).

Most edible insects can provide energy and protein requirements (28) because they contain a high quantity of these nutrients compared to conventional meat sources (Table 1). For instance, 100 g of the house cricket (*Acheta domesticus*) can provide 120% of the RDI for protein and 446 Kcal of energy compared to 44% of protein and 122 Kcal from 100 g beef, and 32% of protein and 167 Kcal from 100 g of chicken. As such, edible insects are promising food sources for addressing global malnutrition because they contain high-quality protein and essential nutrients (29). Edible insects are also a better source of polyunsaturated fatty acids (healthy fats) compared to conventional livestock such as chicken and cattle (30, 31). For example, house crickets, mealworms and black soldier flies contain 0.8-13%; 1.2-13% and 0.5-10% of omega 3 fatty acids, respectively (32). They are also rich in omega 6 fatty acids: 29%, 27% and 10% in house crickets, mealworms and black soldier flies, respectively. Additionally, the oleic acid content of most edible insects ranged from 12%-30% of the total fatty acid content (32).

Table 1. Energy content (kcal/100 g dry matter), protein, fat, carbohydrate (Carbs), fibre content (g/100 g dry matter) and calcium, iron and zinc content (mg/100 dry matter) of selected commonly consumed edible insects, compared to conventional meat (beef and chicken).

Selected commonly consumed edible insects versus beef and chicken (references)	Energy	Protein	Fat	Carbs	Fibre	Calcium	Iron	Zinc
Caterpillar Westwood (*Cirina forda*) **(33)**	435.54	74.4	14.3	2.4	6.0	37.2	6.0	4.3
Mealworms (*Tenebrio molitor*) **(33)**	410.52	65.3	14.9	3.9	20.2	63.6	6.01	12.7
House cricket (*Acheta domesticus*)**(29)**	446.46	75.8	12.9	6.8	6.6	184.3	4.7	21.7
Beef (lean meat) **(34)**	121.6	27.9	2.7	0.0	0.0	4.5	1.7	5.7
Chicken (whole meat) **(35)**	167	20.0	9.7	0.0	0.0	13	1.1	1.0

Incorporating edible insects into the diet could help reduce micronutrient deficiencies

Edible insects are good sources of iron, calcium, zinc and fibre (1, 36, 37). WHO estimated in 2016 that approximately one in three women of reproductive age had anaemia globally (38). Compared with conventional meat such as beef and chicken, edible insects are good sources of iron, and their consumption has the potential to address problems with iron deficiency (Table 1). Edible insects are also good sources of calcium (Table 1); 26% of calcium and 19% of iron of the recommended intake can be met with a 100 g of *A. domesticus* compared to 1% of calcium and 7% of iron from 100 g of beef and 2% of calcium and 4% iron from 100 g of chicken (39).

Edible insects are excellent sources of zinc (Table 1). The recommended zinc intake based on moderate bioavailability for pregnant women in the third trimester of gestation is the highest among all age groups (39). Yet a 100 g of *A. domesticus* can supply 217% of the recommended zinc intake (39) for this group compared to 57% from a 100 g of beef and 10% from a 100g of chicken (Table 1).

Synthetic micronutrient interventions aimed at preventing malnutrition and morbidity due to inadequate nutrient intakes (40) are not always sustainable due to the high cost of these nutrients. Whereas edible insects are sustainable sources of nutrients and can be employed in a food-based dietary prevention strategy to improve population nutritional health (41). For example, a 100 g of bread and cookies enriched with 10% house cricket powder has been found to provide 41% and 17% of the Recommended Dietary Iron Intake compared to 19% and 11% iron from a 100 g of the control bread and cookies respectively (41).

A recent cluster randomised trial in Cambodia tested if two local foods (moringa and cricket) combined with nutritional education (NE) improved child nutritional status and dietary intake. The study included three experimental groups: cricket plus NE, moringa plus NE and NE alone. There was no significant difference in the child nutritional status in the two intervention groups compared to NE alone. However, children consuming either of the two local foods (cricket or moringa) were more likely to fulfil their energy, iron, and zinc requirements and were healthier (42).

Another promising piece of evidence was discovered in an animal experimental study that compared a cricket diet with peanut-based and milk-based diets in recovery from protein malnutrition, growth, metabolism and immune function in mice (43). The cricket-based diet performed equally well as the peanut- and milk-based diets in body weight recovery, but there were significant differences in immune and metabolic markers among the different diets. The authors observed that mice in the milk and peanut diets had triglyceride levels comparable to controls, whereas triglyceride levels remained significantly lower in the cricket diet group. This result is particularly interesting because the per cent of energy from total fat was greater in the cricket diet (24%) compared to the milk (20%) or peanut (19%) diets (43).

The fortification and enrichment of food products with edible insect powder is potentially a sustainable food-based approach to address global malnutrition. For example, 100 g of bread enriched with 10% house cricket (*Acheta domesticus*) powder contains 15.8 g of protein, 1.4

mg of iron, and 82.1 mg of phosphorus compared to 9.5 g of protein, 0.9 mg of iron and 143.1 mg of phosphorus (41). Additionally, bread and cookies enriched with 10% house cricket powder had comparable texture and sensory parameters as the control products; however, sensory scores were significantly lower at 15% cricket powder inclusion in both products. In a Kenyan study, biscuits enriched with 10% house cricket powder contain a higher amount of protein, unsaturated fats, vitamin B12, vitamin A, zinc and iron compared to those enriched with milk (44).

Health benefits of edible insects

Chitin is a naturally occurring cellulose-like polysaccharide of glucosamine found in cell walls of fungi and arthropod exoskeletons (e.g., insects and shellfish) (45, 46). Edible insects are not only a good source of high-quality bioavailable animal protein, they are also rich in chitin. Chitin is insoluble dietary fibre, with potential prebiotic properties associated with health benefits including improved human gut microbiome composition and functional capacity (47). The anti-inflammatory property of *Gryllus bimaculatus* (known as two-spotted cricket) has been reported to reduce the risk of developing diabetes, chronic inflammatory diseases, fatty liver and hyperlipidemia (48-50). The active constituent is thought to be the polysaccharide 'Glycosaminoglycan'. Notwithstanding, bioactive peptides and peptide fractions in insect hydrolysates also express some antioxidant activities in addition to their anti-inflammatory characteristics (18, 51-53). A recent study aiming to identify antihypertensive, anti-glycaemic, and anti-inflammatory peptides derived from the in vitro gastrointestinal digests of cricket protein hydrolysates demonstrated the bioactive potential of edible cricket peptides, especially as angiotensin-converting enzyme inhibitors (54).

Furthermore, there is evidence suggesting that a high-protein diet improves metabolic and inflammatory markers and aids weight loss (55, 56). Food products with a high-quality protein content can contribute to a food-based dietary strategy aimed at reducing the prevalence of chronic dietary-related conditions such as obesity, hypertension and diabetes (41, 57).

Potential uses of food products enriched with edible insects to alleviate diet-related diseases

Food products enriched with edible insects are found in several countries and are sold as premium products (8, 58). For example, recently in Thailand, food companies are producing pasta enriched with 20% cricket powder. Other types of food products enriched with edible insect powder and whole dried insects are being produced by the Health Information Standards Organisation (HISO), which follows the Good Agriculture Practice (GAP) and Good Manufacturing Practice (GMP) guidelines in Thailand. Similarly, this new product development trend has been observed to a small extent even in Western countries such as the USA, Canada and UK (58).

In some communities, edible insects are traditionally processed using different techniques such as steaming, roasting, smoking, curing, grinding and frying in order to enhance their sensory and nutritional value and increase their shelf-life (58). To increase consumers' interest in and the acceptability of edible insects in Western countries, a number of processing techniques have been developed aiming at using insects as ingredients in a nonidentifiable form (e.g. powders) (58). Several studies have assessed the feasibility of incorporating edible insect powder in bread (41, 59), pasta (60, 61), cookies (41), biscuits (44), and snack fillings (62).

The study of fortified biscuits among Kenyan school children found good acceptability of the product (44). These authors and others have highlighted the need for a suitable product formulation that will enhance the enrichment of widely consumed food products with insect powder to improve the taste and increase the use of such food products (41, 44) (41). The idea behind edible insect food product development is to enhance consumer acceptability and increase access to nutrient-dense food products as some consumers are disgusted by whole dried and fried edible insects (58).

Given its affordable and less complex preparation process and wide availability, edible insect powder could potentially offer an added value to some indigenous, tailored nutrient-dense meals that can alleviate malnutrition and enhance the nutritional status of vulnerable populations living in food-insecure regions. (Examples include Amtewa meal (68), iAtta meal (69), and sCool meal (70).) Therefore, edible insects could be incorporated into the composition of these diets particularly in areas where insects are part of traditional meals (e.g., Kinshasa, DR Congo), to potentially enhance their impact on health outcomes. This sustainable fortification strategy can use locally grown insects via domestic low-tech food processing methods (e.g., drying, roasting and grinding) to enrich staple foods with essential macro and micronutrients for food-insecure families.

Potential challenges to edible insects

Asthma and allergies are more prevalent in people in Western countries living in hygienic environments compared to people in developing countries, which supports the hygiene hypothesis, that is that extremely clean environments fail to provide the necessary exposure to microbes required to mature the immune system (45). Early exposure to chitin in insects, parasites and fungi seem protective against allergies (45). However, some insects can trigger allergic reactions and even anaphylactic shock in some people (46).

In addition to allergies, the literature shows that heavy metals can be found in some insects (e.g., cadmium in black soldier fly and arsenic in yellow mealworm larvae) (46). Regarding infections, the literature shows that insect-specific viruses are deemed safe for humans (46). However, more studies are needed specifically for arthropod-borne viruses that can cause human diseases (e.g., dengue, chikungunya, West Nile disease, rift valley fever, and haemorrhagic fever). Insects also contain a plethora of other microorganisms including some human pathogenic bacteria. However, heat treatment is efficient in inactivating these. Although processing is a critical stage in determining the microbial quality of edible insects, the management of farming conditions should not be neglected, particularly to protect workers, and all processing procedures should be carried out under the standards of safe manufacturing practice (SMP) protocol (46).

Conclusions

As the world begins to plan its recovery from COVID-19 and prepares to achieve the Sustainable Development Goal of ending hunger by 2030, perhaps promoting edible insects as part of human diets has the potential to be part of the solution to address food insecurity. Edible insects can provide a source of income for vulnerable populations and a source of complete protein, vitamins, and minerals to the household diet. Furthermore, insect protein powder can potentially have a significant impact beyond the high-end or premium type of protein bar product if the food industry is able to make its price competitive compared to other traditional protein powders (whey and soybean). Insect powder could also be used in animal feed, reducing our dependence on corn and soybean and minimising the negative impacts on land utilisation and excessive use of fertiliser. Insect powder can be used as a fishmeal replacement to alleviate the pressure on fish stocks, which are rapidly declining. Insect powder can also be used in nutrition emergencies (e.g., droughts, floods, conflicts) as a shelf-stable source of nutrition in supplements or fortified food for hunger relief. As prices and stigma of eating insects, particularly in Westerner populations, are reducing, consumers may increasingly consider replacing their weekly steak with an insect burger.

To make edible insects as a sustainable high-quality animal protein a reality, there is a need for more research on food safety and human health benefits. There is also a need for investment in innovation for large-scale and cost-effective insect farming. Adding automation to some of the rearing procedures and optimising the feeding and processing conditions for producing high quality, safe and nutritious edible insects will enhance their contribution to sustainable nutrition. These can also lead to low-cost, appetizing and nutritious foods. These foods could meet the demands of a growing global population while alleviating environmental pressures on limited natural resources. Finally, more research should be promoted regarding the safety of their use for animal feed and human food.

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