frontiers | Frontiers in Sustainability

TYPE Opinion
PUBLISHED 16 January 2023
DOI 10.3389/frsus.2023.1112950

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Sustainable Consumption, a section of the journal Frontiers in Sustainability

RECEIVED 30 November 2022
ACCEPTED 03 January 2023
PUBLISHED 16 January 2023

CITATION
Lange KW and Nakamura Y (2023) Potential contribution of edible insects to sustainable consumption and production.
Front. Sustain. 4:1112950.
doi: 10.3389/frsus.2023.1112950

Potential contribution of edible insects to sustainable consumption and production

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KEYWORDS

edible insects for food, food production and consumption, responsible consumption and production, sustainability, food security

Introduction

The world population has been estimated to increase to over nine billion people by 2050 (United Nations, 2019), with the demand for animal-derived protein expected to rise at an even higher rate (Godfray et al., 2010). Population growth in China has been associated with a significant increase in meat consumption (Al-Ali et al., 2018). The required rise in global meat production predicted in 2014 over the following 35 years was 72% (Wu et al., 2014). However, animal-derived food, including beef, pork and poultry, is becoming increasingly expensive, in both economic and environmental terms, and has increasingly been associated with depletion of resources, emission of greenhouse gases, pollution and health issues. In the everyday life of the future, meat cannot be consumed on the scale it is today.

The constant growth of the world's population, food insecurity in some world regions as well as an increasing demand for and rising cost of animal protein will require a significant increase of food production and will place an unprecedentedly heavy burden on limited natural resources. This will pose a major challenge for the agricultural food industry, which needs to account for not only demographic and economic factors, but also issues related to a range of natural resources, such as energy, land and water (Calicioglu et al., 2019). Environmental sustainability will become a key issue, since unsustainable patterns of consumption and production are causally related to the current planetary crises of biodiversity loss, pollution and climate change. The United Nations Sustainable Development Goal #12 of ensuring sustainable consumption and production patterns entails the transformation of energy and materials to maintain or even improve human wellbeing without negatively impacting environmental resources (United Nations, 2022). In the context of achieving environmentally sustainable food security worldwide, edible insects as a future food for humans have become an issue of increasing interest (Lange and Nakamura, 2021b). While insect consumption may provide various benefits, the narrative of edible insects as a solution to resource challenges and hunger may be misleading. Thus, the present opinion piece argues that the presence of high-quality protein and various micronutrients as well as potential environmental and economic benefits may render edible insects globally a food for the future and an environmentally sustainable solution to malnutrition and food insecurity. However, scaling up the farming of insects, including more efficient breeding and ecologically friendly rearing methods, may not necessarily result in sustainability or more food resources for all. Edible insect products in a global market may become novel ingredients used to provide new snacks for overfed consumers.

Insects as food source

Insects are one of numerous food sources that have been consumed throughout the history of human development (Pager, 1976; Backwell and d'Errico, 2001). Edible insects have been an important source of protein, fat and micronutrients in otherwise plant-based diets (Rothman et al., 2014), and insect eating is, to various degrees, common in all primates (McGrew, 2014). Today, the eating of insects remains popular in many regions worldwide (mainly Central and South America, sub-Saharan Africa and Southeast Asia), with regular consumption of edible insects estimated to form part of traditional diets of more than two billion people (van Huis et al., 2013).

Edible insects are a promising source of macronutrients and micronutrients. The available evidence suggests a high nutritional value of insects, since they are rich in protein, fat, vitamins, minerals and fibre (Lange and Nakamura, 2021a). The amount of protein and various types of lipids in insects depends primarily on species, type of diet and stage of metamorphosis (van Huis et al., 2013). The protein content of insects is in the same range as that of beef and pork (40–75 g/100 g dry weight) (Istituto Nazionale della Nutrizione, 1989). Insect consumption can contribute to the total intake of protein and various amino acids and may therefore enhance nutritional quality in the human diet (Bukkens, 1997). Most species of edible insects, such as yellow mealworm beetle, black soldier fly, housefly and house cricket, meet the amino acid content (e.g., phenylalanine, tyrosine, tryptophan, threonine and lysine) recommended by the World Health Organisation (World Health Organization, 2007). The total fat content of insects has been found to range from 2 to 62% (Williams et al., 2016). The fatty acid profile of insects is similar to that of animal fats and vegetable oils (Tzompa-Sosa and Fogliano, 2017). Compared to beef and pork, however, insects are particularly rich in unsaturated fatty acids, with some insect species containing up to 75% of total fatty acid content (Rumpold and Schlüter, 2013; Tzompa-Sosa et al., 2014). The composition of omega-3 polyunsaturated and some other fatty acids in mealworms is comparable to that found in fish and higher than that in pig and cattle. The omega-6/omega-3 fatty acid ratio can be influenced by diet (Lange and Nakamura, 2021b). Edible insects are also an important dietary source of fibre, since the exoskeleton of many insects consists of chitin. Edible insects appear to be a promising source of food bioactives, such as minerals, polyunsaturated fatty acids and fibre, and may be able to provide a wide range of food supplements and functional food ingredients for specific purposes. However, in view of the very large number of edible insect species and the many factors affecting their nutrient and bioactive content, generalisable conclusions concerning their nutritional value and potential health-promoting properties cannot be drawn.

Environmental benefits of edible insects

Major environmental benefits of edible insect production are related to the relatively high feed-to-meat conversion rate, with insects converting plant proteins to insect proteins far more efficiently than other animals (Deroy et al., 2015). While crickets require <2 kg of feed for every 1 kg of bodyweight gain (Collavo et al., 2005), the average amount of feed required to produce an increase in bodyweight by 1 kg is 2.5 kg for chicken, 5 kg for pork and up to 10 kg for beef (Smil, 2002). A further advantage of insects as a food source is the high percentage of the animal that can be consumed. Up to 80% of a cricket is edible for humans, compared to 55% for pigs and chickens and 40% for cattle (Nakagaki and de Foliart, 1991).

With respect to sustainability, a major advantage of edible insects is the viability of farming them using organic food waste, such as compost, manure or vegetable waste not suitable for human consumption, which may decrease environmentally damaging contamination. The food waste used for rearing insects provides an attractive approach to closing the loop of the food value chain in a sustainable circular economy (Ojha et al., 2020). Using organic side streams as insect feed can also increase the profitability of insect farming (Offenberg, 2011). However, the use of this form of waste may result in a reduction in growth and nutrient efficiency (Smetana et al., 2016). Moreover, mortality rates of crickets may increase when organic waste is used as feed (Lundy and Parrella, 2015).

Edible insects appear to be more climate-friendly than cattle, pigs or chickens, since they require less space and water to grow and develop and cause fewer greenhouse gas emissions. Food production in its present form can be expected to result increasingly in deforestation, environmental degradation and greenhouse gas emissions. The large-scale facilities producing livestock and fish incur huge environmental costs (Tilman et al., 2002; Fiala, 2008). Land use, in particular, will become a critical factor. The raising of livestock, accounting for over 70% of agricultural land use worldwide (Food Agriculture Organization of the United Nations, 2009), will increasingly contribute to the environmental problems, since the decrease in land available for agriculture as a consequence of climate change is likely to exacerbate food insecurity (Lloyd et al., 2011; Premalatha et al., 2011).

The ever-increasing demands on water supply will threaten global biodiversity as well as agricultural output and food production. Up to 70% of freshwater is used worldwide for agriculture (Pimentel et al., 2004), with meat production requiring particularly large quantities of water. The volume of water required for producing 1 kg of meat has been estimated to be 2,300 L for chicken, 3,500 L for pork and 22,000–43,000 L for beef (Chapagain and Hoekstra, 2003; Pimentel et al., 2004). The amount of water needed to produce 1 kg of edible insects is thought to be considerably lower (van Huis et al., 2013).

Livestock rearing has been estimated to produce 18% of greenhouse gas emissions, which is higher than emissions produced by the transport sector (Steinfeld et al., 2006). Insects appear to emit substantially smaller amounts of greenhouse gases and ammonia than cattle or pigs. The emissions of carbon dioxide, methane and nitrous oxide resulting from the farming of edible insects have been found to be lower by a factor of 100 per kg of weight in comparison with cattle (Oonincx et al., 2010). Manure and urine (ammonia) also contribute to environmental pollution and cause nitrification and soil acidification (Aarnink et al., 1995). Ammonia emissions of edible insects compare favourably to pigs, with a tenfold difference (Oonincx et al., 2010).

Possible problems of sustainable edible insect production

Despite the wide range of potential benefits of insect consumption, the narrative of edible insects as the solution to malnutrition and hunger as well as to resource and climate challenges or even as "the last great hope to save the planet" (Martin, 2014) is misleading. While insects can provide nutritious and sustainable food for a growing population, they are not a panacea.

Various problems may be associated with the sustainable production of edible insects. While they were believed to be an inexhaustible natural resource in the past (Schabel, 2006), some populations of insects are currently under threat of extinction due to their collection by humans (Ramos-Elorduy, 2006). Since several edible insect species are predated on by other insects and animals, a decrease in their numbers may have adverse effects on other insect populations and a wide range of ecosystem functions. For example, collecting edible insects may threaten essential ecosystem services, such as pollination, composting and pest control (Losey and Vaughan, 2006). In order to preserve wild insect populations and to avoid overexploitation, with the number of collected insects exceeding the capacity for regeneration capacity (Cerritos, 2009), the use of edible insects as a sustainable food source requires large-scale insect farming (van Huis et al., 2013). Whether scaling up the production of edible insects, with associated requirements including feed, energy, processing and transportation will involve unforeseen environmental costs and will, in fact, prove to be more sustainable than traditional livestock rearing remains to be seen. Sustainability in this context may be a property of mass production rather than of organisms. The current destructive food production methods should not be replaced by equally harmful new production systems for insect-based foods. Future research is therefore required to compare the sustainability and environmental impacts of large-scale farming of edible insects with those of existing farming practices.

Questions regarding insects as sustainable food source

Many questions regarding the use of edible insects as a sustainable food source remain to be answered. The future sustainability and environmental impact of large-scale rearing, harvesting and producing of edible insects is largely unknown and needs to be investigated in more detail in order to allow comparisons with traditional livestock raising and farming practices. In particular, suitable insect species and their requirements (feeding, housing, animal health and welfare) (Berggren et al., 2019) as well as processing, transport and storage conditions of insect-based foods need to be studied. Our knowledge of food safety in relation to insects for human consumption and of potential hazards of the intake of insects is limited. In common with other animal and plant-based foods, edible insects could be associated with various health risk factors, such as allergens, anti-nutritional compounds, food contaminants (e.g., mycotoxins, pathogenic microorganisms) and chemical residues (e.g., pesticides, heavy metals) (Lange and Nakamura, 2021b). This requires further consideration and research.

The potential socio-economic benefits of insect farming on improving food security in low-income countries requires further study. Once edible insects become a commodity in global markets, they may, like soy, serve as feed for livestock rather than food for humans and may therefore not benefit vulnerable populations. Cricket powder has become an ingredient of novel snacks for higher-income consumers, while low income individuals collecting and selling insects do not eat this nutritious food themselves. For example, increasing demand for insects from city-dwellers in Thailand led to the import of insects from bordering low-income countries with higher rates of malnourishment. Thus, the major source of protein of rural peasants in Cambodia, Laos and Myanmar is consumed mainly as snacks by well-fed urban people in Thailand (Müller et al., 2016).

A major obstacle to the inclusion of insects in human diets is consumer acceptance in western societies. The advantages of edible insects cannot be realised if people do not choose to eat them. In Europe and North America, insect consumption is viewed with feelings of disgust and is associated with a precarious and primitive lifestyle (Rozin and Fallon, 1987; Vane-Wright, 1991). Food disgust and aversion to insect consumption is mainly rooted in culturally determined food habits and can be attributed to prejudice (Mela, 1999). The question of whether people in western countries are willing to incorporate insects into their daily diet therefore depends on learning to tackle negative attitudes towards them by making edible insects available and educating the general public. Various approaches have been used to convince people that insects are palatable and thus influence consumer choices towards a favourable outlook on insects as a food source (Lange and Nakamura, 2021b). These include educational exhibitions in museums and zoos, combinations of educational talks and experience of insect eating, gastronomic activities, such as insect snacks and menus in bars and restaurants, as well as edible insect cookbooks. Experimental experience has confirmed the effectiveness of "bug banquets" in overcoming disgust towards edible insects (Lange and Nakamura, 2021b).

Furthermore, environmental sustainability appears not to be the main factor influencing acceptance and consumption of insect-based foods, but taste, price and availability (Berger et al., 2018; House, 2018). In consequence, the edible insect industry may forego sustainability measures, and the potential of insects as a sustainable food alternative might be diminished. In addition, the very high cost of cricket products, reflecting high demand and low supply, renders them currently an unlikely alternative to conventional protein sources.

In addition, the limited knowledge of food safety in relation to the use of insects in food production is likely to be a barrier to the introduction and promotion of edible insects as human food in western countries (Lange and Nakamura, 2021b). Risk factors to human health associated with the intake of edible insects include allergens as well as biological and chemical hazards. Both prevalence and concentration of contaminants in edible insects are influenced by species, stage of harvest, feed substrate and production methods. The use of hazard-free feed substrate is essential in improving the food safety of edible insects.

Conclusion

In summary, while food production will need to grow substantially in the future in order to meet the need for global food security, the environmental footprint of agricultural production systems has to be reduced dramatically. Amending diets by including edible insects in human consumption can markedly halt agricultural expansion for livestock production and may solve the dilemma of increasing population and consumption. Furthermore, edible insects could provide an eco-friendly and sustainable production approach and a nutritional profile beneficial to consumer health. The nutritional quality of edible insects appears to be equivalent or even superior to that of common animal-derived foods. Compared to cattle and pigs, insects have a faster growth rate, a higher feed-to-food conversion efficiency, lower requirements for space and water as well as lower emissions of greenhouse gas and ammonia. It seems ironic that we invest energy, land and water in growing lower-quality protein, which requires more input than insects. Money is spent worldwide to save crops containing only 14% plant protein by killing another food source (insects) whose protein content in dry insect matter can be as high as over 70% (Premalatha et al., 2011; Rumpold and Schlüter, 2013). Large-scale production of insect-based foods may help solve the looming global food insecurity problem and contribute to accomplishing the sustainable development goals set by the United Nations.

Author contributions

KL and YN made substantial contributions to the conception of the work, provide approval for publication of the content, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. KL drafted the work. YN revised it critically for important intellectual content. Both authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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