Current Research in Food Science 7 (2023) 100596

Contents lists available at ScienceDirect

Current Research in Food Science

journal homepage: www.sciencedirect.com/journal/current-research-in-food-science

A review on edible insects in China: Nutritional supply, environmental benefits, and potential applications

Xueying Lin[a], Feifan Wang[a], Yuting Lu[a], Jiarui Wang[a], Jingwen Chen[a], Yingxin Yu[b], Xiaoyu Tao[a], Ying Xiao[a,**], Ye Peng[a,*]

[a] *Faculty of Medicine, Macau University of Science and Technology, Taipa, Macao SAR, 999078, China*

[b] *Guangdong-Hong Kong-Macao Joint Laboratory for Contaminants Exposure and Health, Guangdong Key Laboratory of Environmental Catalysis and Health Risk Control, Institute of Environmental Health and Pollution Control, Guangdong University of Technology, Guangzhou, 510006, China*

ARTICLE INFO

Handling Editor: Professor A.G. Marangoni

Keywords:
Edible insects
Food safety
Nutrition
Sustainability
Environmental benefits

ABSTRACT

This review explored the potential of edible insects to address the challenges of malnutrition and food security. Although grain production in China has met the Food and Agriculture Organization standards, the shortage of protein supply is still a big issue. Moreover, expanding livestock farming is considered unsustainable and environmentally unfriendly. Edible insects have become an alternative with higher sustainable and ecological properties. There are 324 species of insects currently consumed in China, and they have high nutritional value, with a rich source of protein and unsaturated fatty acids. Insect farming provides numerous benefits, including green feeds for livestock, poultry, and aquaculture, sustainable organic waste management, as well as industrial and pharmaceutical raw materials. The food toxicological evaluations conducted in China indicated that edible insects are safe for general consumption by the Chinese, but allergies and other related food safety issues should not be ignored. Consumer acceptance is another barrier to overcome, with different schemas between China and Western countries. More research on the potential functions of edible insects and their product development may enhance their acceptance in China. Overall, incorporating edible insects into our diet is a promising solution to address challenges related to protein supply and food security. To ensure safety and sustainability, appropriate legislation, quality regulations, large-scale insect farms, and acceptable processing techniques are necessary. Moreover, more scientific research and social awareness are required to promote the culture and utilization of edible insects in China.

1. Introduction

It is estimated that the global population will exceed 10 billion by 2050, making food security one of the greatest health and social challenges of the 21st century (UN, 2019). The Food and Agriculture Organization (FAO) defines food security as the physical, social, and economic access of all people to sufficient, safe, and nutritious food that meets their dietary needs and preferences for an active and healthy life (FAO, 2021). It suggests that food security comprises four key points: availability, stability, access, and utilization (Schmidhuber, 2007). Unfortunately, the current level of food production is insufficient to meet the needs of the large population. Meanwhile, human exploitation of natural resources has exceeded a range of planetary boundaries, which has endangered the stability and maintenance of ecosystems from biomes to the entire planet, affecting the biodiversity on Earth (Willett et al., 2019). Such impacts are exacerbated by climate change and soil degradation, with profound consequences for global food security.

Food security is an important strategic issue to all countries, and it is even more critical to China specifically due to its large population size. China is one of the world's most populous countries and is expected to hold 1.4 billion people in 2050, which takes approximately 14% of the world's population. However, climate change and human development could lead to a serious crisis of food security in China. A recent study with the combination of the shared socioeconomic pathways and the global gridded crop model found that China is at risk of food shortages in the 21st century (Chen et al., 2021). Protein is an essential nutrient element, and consuming sufficient protein is vital for human health and wellness. Protein supply in China is now considerably far below the

* Corresponding author. Faculty of Medicine, Macau University of Science and Technology, Taipa, Macao SAR, China.
** Corresponding author.
E-mail addresses: yxiao@must.edu.mo (Y. Xiao), pengye@must.edu.mo (Y. Peng).

https://doi.org/10.1016/j.crfs.2023.100596
Received 21 June 2023; Received in revised form 14 September 2023; Accepted 14 September 2023
Available online 16 September 2023

standard for health goals, which is considered a big threat to food security in this country.

Domestic protein production in China is characterized with poor capacity and low self-sufficiency. In 2015, the self-sufficiency rate of edible protein in China was 73.1% (Zheng et al., 2015). Thus, China highly relies on imports to fill the gap in the supply of protein-rich foods, especially meat and meat products, and imports are growing yearly. In 2023, China is expected to import 6.45 million tons of meat, up 5.2% from the previous year (MARA, 2023). Additionally, the ongoing shift from plant-based to animal-based diets exerts great pressure on animal-based protein supply (Chen et al., 2019). The demand for high-quality protein requires more resources, such as feed, land, and water, to raise larger numbers of livestock. This, in turn, leads to more land for cultivation and more water resources for use. Agricultural expansion has become an undesirable and unsustainable option due to China's current strained land relations and freshwater resource shortage. Malnutrition, on the other hand, is a significant problem that needs to be addressed in China. Like many low- and middle-income countries, China is facing the burden of undernutrition as well as overweight and obesity in a term (Piernas et al., 2015). An unbalanced food supply and poor diet quality can all lead to micronutrient deficiencies and result in an alarming increase in obesity and diet-related non--communicable diseases (Willett et al., 2019). In this context, alternative food and feed resources have to be developed to address the dual challenges of malnutrition and food insecurity in an ever-changing global environment.

FAO views insects as a potentially sustainable food source, thus insects can be considered as a major option to improve food security and ameliorate malnutrition in China (Hartmann et al., 2015). Insects have been consumed in China for more than 2000 years, with much of the insect farming industry established in rural areas of China, which brings a steady income to local people. In the past 20 years, many studies on edible insects have been carried out worldwide, including the culture of insectivores, the identification of edible insects, nutritional value, breeding and reproduction, as well as food development. All tested insects provide rich levels of protein, fat, vitamins, and minerals, despite subtle differences in micronutrients. Therefore, fortification and enrichment of foods by edible insect powders might be a food-based approach to address malnutrition (Adegboye et al., 2021). Additionally, compared to the cost and environmental consumption required for protein production from livestock, insect proteins have been found to exhibit environmental benefits for global sustainability. Therefore, this paper aims to review the current research on edible insects in China, covering aspects including nutritional value, environmental sustainability, food safety, applications, and consumer acceptance. In the present review, the Web of Science, ScienceDirect and Scopus were accessed for the period from 2013 to March 2023, using search terms/keywords including edible insects, insectivorous, food security, nutrition, safety, willingness, acceptability, China that support this review. Two to three of these keywords were used in each search. Relevant book chapters were also searched to provide additional factual material. Over 2100 articles were initially screened from databases, with weakly correlated and duplicate articles being excluded based on papers' titles and abstracts, resulting in 381 articles. After a more in-depth evaluation of the content, we included a total of 103 publications in this review.

2. Edible insect resources in China

The consumption of edible insects has a significant historical background in China, with a history that dates back over 2000 years (Su et al., 2023). In antiquity, silkworm pupae were a prevalent dietary staple (Feng et al., 2018). Despite the global shift in dietary patterns, the consumption of insects remains prevalent in various regions of China (Liu et al., 2019). Numerous instances in ancient Chinese literature illustrate prevalent types of edible insects, along with methods for gathering and preparing them. In recent years, there has been a significant expansion in scientific research on edible insects, encompassing various areas such as species identification, nutritional assessment, new agricultural methods, and cultural exploration pertaining to human-insect interactions.

Over 1900 distinct species of insects are deemed suitable for human consumption globally, which are classified under the orders *Coleoptera* (31%), *Lepidoptera* (18%), *Hymenoptera* (14%), *Orthoptera* (13%), *Hemiptera* (10%), *Isoptera* (3%), *Odonata* (3%), *Diptera* (2%), and *Miscellaneous* (5%) (Kinyuru et al., 2015). As mentioned above, 324 documented species of insects in China are classified into 11 orders, with the dominant orders being *Lepidoptera*, *Coleoptera*, and *Hymenoptera*, which comprising 37.65%, 18.21%, and 15.43% of the total, respectively, as shown in Fig. 1 (Adeoye et al., 2014; Su et al., 2023). The most widely consumed insects include bees, wasps, silkworms, crickets, bamboo caterpillars, dragonflies, and beetles. Within them, silkworm chrysalis is highest consumed insects in multiple regions in China, serving as a popular delicacy (Garofalo et al., 2019). The percentage of edible insects consumed in China and the major cooking ways are summarized in Fig. 1.

3. Environmental benefits

Insect-based foods production offers several environmental advantages including lower water usage, reduced greenhouse gas emissions, and superior feed conversion ratio. The environmental destruction caused by agricultural production has been a great concern. Food production significantly accelerates greenhouse gas emissions, while the livestock supply chain contributes even more to global greenhouse gas emissions and anthropogenic nitrogen emissions (Bekuma et al., 2019; Uwizeye et al., 2020). Furthermore, chemicals such as fertilizers and pesticides have been overused over the past few decades. Excessive use of chemical fertilizers causes multiple environmental problems, such as water pollution, soil acidification, nitrogen deposition, and greenhouse gas emissions (Zhu and Begho, 2022).

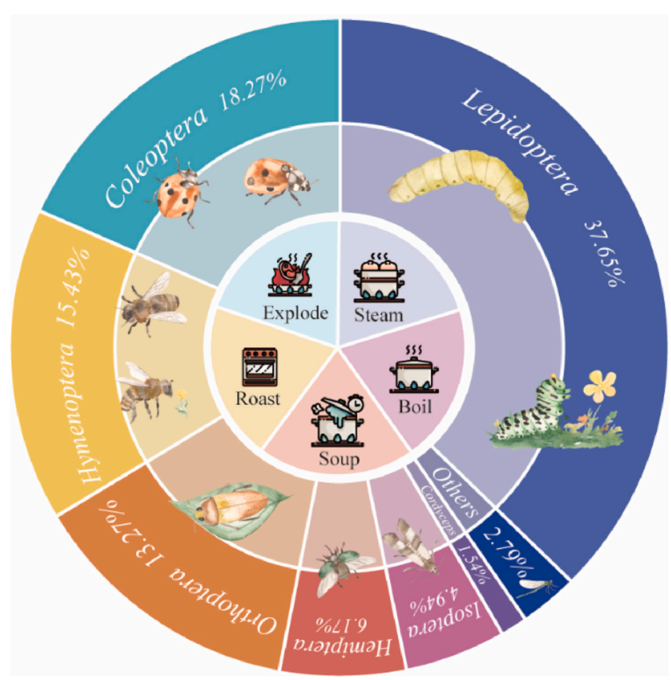

Fig. 1. The total 324 species of insects in 11 orders associated with food and feed in China can be summarized as the 8 groups with estimated consuming percentages.

3.1. Water and feed usage

Over the past 30 years, the per capita consumption of beef and pork in China has grown sevenfold and fourfold, respectively. (Zhu and Begho, 2022). If current and future protein needs in China are to be met, the increasing protein supply in China will lead to continued deforestation, environmental degradation, and natural resource appropriation. Therefore, replacing meat protein with insect protein has the potential to minimize meat consumption and natural resource exploitation in order to safeguard the environment.

One of the environmental benefits of raising insects is that they require less water and land compared to cattle farming. China has been identified by the United Nations as one of the 13 water-poor countries (Song et al., 2022). Agriculture, as a major water user, takes more than 62% of Chinese total water consumption, with animal product production being the biggest culprit (MWR, 2021). Insects require less water than other farmed animals to produce an identical amount of protein. For example, beef and chicken require 16.8 g and 5.2 g of water per gram of protein, respectively, while cricket production requires only 0.7–0.8 g of water per gram of protein (Mason et al., 2018). Furthermore, insects have a better feed conversion rate, making them more economical than conventional livestock. For instance, chicken, pig, and cow require 2.5, 5, and 10 kg of feed, respectively, for each additional kilogram of weight (Smil, 2002). While crickets only need 1.7 kg of feed for each kilogram of weight increase (Huis et al., 2013). Conventional livestock and insects differ considerably in terms of the proportion of their body weight that is edible. The edible weight percentage of chickens and pigs is 55%, which is higher than the 44% edible weight percentage of cattle (Smil, 2002). Insects are usually eaten whole, and only 3% of a cricket's body weight is indigestible, with edibility ranging from 80 to 97% depending on people's eating habits (some people prefer to remove the legs, which is equivalent to 17% of their body weight) (Nakagaki and Defoliart, 1991).

3.2. Low greenhouse gas emissions

Insects have gained attention as a "climate-smart food source" due to their substantially lower greenhouse gas emissions compared with large livestock (Govorushko, 2019). The current livestock industry is one of the leading contributors to greenhouse gas emissions. According to Life Cycle Analysis (LCA), 9% of the world's carbon dioxide, 35–40% of methane, and 65% of nitrous oxide production are associated with the entire production process of animal products (Steinfeld et al., 2006). In China, cow and pig breeding accounts for the majority of direct greenhouse gas emissions from animal food (64%), with 172 Mt CO_2e (metric tons of carbon dioxide equivalent) and 120 Mt CO_2e, respectively, in 2007 (Zhu and Begho, 2022). The production of 1 kg of beef, pork, and chicken results in the emission of 14.8 kg, 3.8 kg, and 1.1 kg of CO_2, respectively (Fiala, 2008). In contrast, mealworms, crickets, and locusts produce much lower greenhouse gas emissions per kg of mass gain, equivalent to 1% of livestock greenhouse gas emissions (Oonincx et al., 2010). Therefore, incorporating insects as a source of animal protein could significantly reduce greenhouse gas emissions associated with food production.

4. Nutritional value: Insect proteins and fatty acids content

Insects are known to have proteins as their primary nutritional components, which are present in significant amounts. One study showed that the protein content of insects' dry weight ranges from 7% to 91%, with the majority falling around 60% (Mintah et al., 2020). The digestibility of insect protein can reach up to 75%–98%, which is marginally lower than that of animal protein i.e., 95% for eggs, 98% for beef, and 99% for casein, but significantly higher than most plant protein (Komatsu et al., 2023). The present study found that the digestibility rates of fresh termites (90.5%), green locusts (82.3%), and brown locusts (85.7%) were relatively low (Kröncke and Benning, 2022). Comparing with them, the protein digestibility of dried bees and soybean moths is much higher, with 94.3% and 95.8%, respectively (Xia et al., 2012). Being attributed to the structural and compositional similarity of insect proteins to those from other animals, insect protein exhibits favorable interaction with digestive enzymes in the human body in the absence of cellulose encapsulation (Miguéns-Gómez et al., 2020). As a result, the digestive system of human can efficiently break down and absorb the nutrients from insect protein, making it a viable and sustainable source of dietary protein for humans. Insects possess a favorable amino acid composition. As an illustration, stink bugs that are fit for human consumption comprise several essential amino acids, such as lysine and tryptophan, which are frequently deficient in cereals or legumes (Huang et al., 2019; Rodríguez-Rodríguez et al., 2022). What's more, a study compared the level of amino acids, including essential amino acids, in the meat of different animal species and edible insects. The data therein indicated that both meat and edible insects are sources of complete animal protein containing all essential amino acids in its composition with the content of individual nutrients in both insects and meat varying significantly. *Bombyx mori* and *goose carcasses* are the insect and meat species, respectively, with the lowest levels of all essential amino acids (Orkusz, 2021).

It is widely known that unsaturated fatty acids exhibit great benefits for human body. Insects contain a prevalence of unsaturated fatty acids ranging from 43% to 79%, which is close to that in poultry and fish (Musundire et al., 2016). Among unsaturated fatty acids, the level of polyunsaturated fatty acids is found higher in insects, comparing with poultry and fish. The polyunsaturated fatty acids found in insects primarily consist of linoleic acid, arachidonic acid, and eicosapentaenoic acid. Monounsaturated fatty acids (MUFAs) are composed of palmitoleic acid and oleic acid (accounting for 60% of the total fatty acids content). Another research revealed that insects have lower cholesterol content compared with that of commonly consumed foods (Yi, 2015). For example, the cholesterol levels in locusts are approximately 66 mg/100 g, which is comparable to the levels found in beef and pork at approximately 70 mg/100 g. In contrast, eggs have a significantly higher cholesterol content of 479.5 mg/100 g (Nowakowski et al., 2022). The beneficial effects of MUFAs on blood lipid profile, blood pressure, insulin sensitivity, and glycemic control are widely recognized. Moreover, there exists significant evidence indicating that the intake of MUFA may have an impact on various aspects and roles associated with the endothelium. The observed effects encompass the enhancement of endothelium-dependent vasodilation and the attenuation of the ability of oleic-enriched low-density lipoprotein to induce the adhesion and chemotaxis of monocytes. Conversely, a diet enriched with MUFA has been shown to reduce the prothrombotic environment by altering platelet adhesion, coagulation, and fibrinolysis (Twining et al., 2018).

5. Safety review of edible insects in the world and in China

The major insect safety hazards mainly include diverse allergens and contaminants, based on different species, growing environment, fodder, and processing conditions (FAO, 2021; Murefu et al., 2019). Food allergies affect approximately 5% of adults and may cause life-threatening reactions (Downs et al., 2016). Cross-reactivity of related proteins can cause allergies (Fels-Klerx et al., 2018). For example, allergies to shellfish (crustaceans) can trigger reactions when consuming edible insects, which are closely related to tropomyosin groups, α-amylase, and arginine kinase groups in insects (Barre et al., 2018). Proper food processing methods can help reduce cross-reactivity and the risk of allergies in edible insects, such as thermal processing and enzymatic hydrolysis (Pali-Schöll et al., 2019). Accumulation of heavy metals in insects is another threat to the safety of insect consumption, as seen with cadmium in black soldier fly and arsenic in yellow mealworm (Biancarosa et al., 2018; Fels-Klerx et al., 2016). Exposure to low concentrations of heavy metals can interfere with human metabolomics and induce death in individuals due to toxic effects (Alengebawy et al., 2021; Rai et al., 2019). Heavy metal accumulation could potentially be reduced through the regulated breeding of edible insects. Pesticides may also accumulate in insects due to their consumption of insecticide-sprayed plants (Imathiu, 2020). Thus, critical quality control of the level of contaminants in the substrate can help reduce the presence of most chemical contaminants in insects (EFSA, 2015). Human viruses cannot replicate within insects, therefore, the potential for zoonotic infections is considered low. However, zoonotic diseases and insect-specific viruses have the potential to exert pressure on large-scale insect farming. Intensive rearing of edible insects may lead to significant losses due to viruses and give rise to other health issues, such as microbial drug resistance (Lange and Nakamura, 2021). The carry of pathogenic bacteria can be a risk to human health if proper hygiene is not maintained (Imathiu, 2020). However, due to the wide variation in phylogeny among hosts, the prevalence of these pathogens is relatively low. By conducting effective heat treatment, the risk of transmitting these bacteria can be significantly reduced (EFSA, 2015).

In China, most insects are caught in the wild and people consume them only occasionally or during specific seasons, and insect-related food safety is not considered a widespread harm within Chinese society (Feng et al., 2018). As the concept of edible insect spreads, more attention needs to be paid to the safety of common edible insects in China as more people begin to consume them. It is worth noting that the Chinese Ministry of Health recognized the silkworm chrysalis as common food as early as 2004, which means that silkworm chrysalis has become an ordinary food resource in China. Furthermore, in 2016, the Guangxi Zhuang Autonomous Region promulgated a local food safety standard for edible frozen fresh silkworm pupae (DBS45/030–2016). However, most edible insects are still out of the authoritative list. Therefore, the neglect of potential insects needs to be addressed (Gao et al., 2018). More recently, procedures for the Toxicological Assessment of Food in China have provided methods for assessing and determining food safety indicators of insects (Feng et al., 2018). The results of food toxicological evaluations of insects, based on the most recent 2014 version (including acute toxicity tests, genotoxicity tests, and 28-day oral toxicity tests), suggested that insects traditionally consumed in China are safe (Gao et al., 2018).

However, individual food safety cases related to insects continue to raise concerns. Allergens are the main potential hazard identified for the Asian continent, contributing to 25% of the hazards identified in Asia (Murefu et al., 2019). In China, insects were the fourth most commonly reported allergenic offenders between 1980 and 2007, after pineapple, turtle, and crab. Of the cases of anaphylactic shock caused by insects during that time period, 27 were caused by locusts, 27 by grasshoppers, 5 by silkworm pupae, 1 by cicadas, 1 by bee pupae, 1 by bee larva, and 1 by *Clanis bilineata tsingtauica* Mell (Ji et al., 2009). In addition to allergen issues, other insect-related food problems are gradually being identified and reported. For example, crickets have been found to accumulate heavy metals in feeding trials (Bednarska et al., 2015; Diener et al., 2015). A food poisoning incident in Thailand suggests that consumption of fried insects, such as grasshoppers and pupae, can lead to histamine poisoning (Chomchai and Chomchai, 2018). Some insects also contain anti-nutrients, such as phytic acid, oxalic acid, tannin, and hydrogen cyanide. Some of these compounds can act as chelators, binding to nutrients, which can result in absorption disorders and affect the bioavailability of nutrients in insects. (FAO, 2021). Honey bee is an edible insect well-known to the Chinese. However, chitin, a long-chain polymer of N-acetylglucosamine found in honey bees, seems to possess 'anti-nutritional' properties that can lower the quality of insect proteins. It's probably because chitin is intimately linked to the protein in the cuticle of bees, and chitin is indigestible and lacks obvious nutritional value for monogastric animals, thus diminishing the digestion and absorption of proteins closely associated with chitin. (Ozimek et al., 1985).

Currently, research on the safety of insect in China is limited, people seem to be more interested in the nutritional value of insects than that of safety. As the above cases are considered a significant concern for food safety, insects deserve more attention and longer-term research. As more people begin to consume insects, the first step is to standardize the feeding of edible insects and manage the feeding process rigorously. Food safety rules governing conventional foods should extend to insect-based processing and storage. What's more, it is crucial to establish a more robust regulatory framework as well as test system to ensure the safety of insects. Although various contaminants can affect the food safety of edible insects, the potential hazards associated with insect consumption in China can be mitigated by controlling insect farming and production.

6. Welfare and benefits of edible insect farming

Recently, insect farming has attracted intensive attention in China, as indicated by rapidly increasing publications shown in Fig. 2a. However, we should be aware that the level of recognition and acceptance of insect farming is still not enough, comparing to some developed countries (Fig. 2b), to alleviate the tension situation of China's large population and limited agricultural land (Feng et al., 2018, 2020). Hence, it's essential to research more about scientific insect farming to provide more alternative nutrient sources. The following paragraphs of this section will list relevant welfare and benefits.

6.1. Cost-effective nutritional substitute or supplement for human

Today, innovative insect farming methods are being developed and implemented in many regions of China. For example, in certain southern Chinese cities, east Asian migratory locusts and Chinese rice locusts are now being reared in greenhouses to produce high-end specialty foods. This process involves professional management of the greenhouse construction and arrangement, as well as meticulous attention to factors, such as soil agglomeration, rainwater prevention, and pest control. Additionally, specific conditions must be maintained during the egg-hatching stage, including a mild temperature of 25–30 °C, low moisture of 10–15%, and ample sunshine for at least 12 h per day. Larvae to adult rearing also requires abundant food of monocotyledon leaves, millfeed, and other sources to ensure healthy growth. Proper greenhouse sanitation is crucial to prevent mildew and maintain high-quality yields. Moreover, in Yunnan province, residents are taking advantage of abundant bamboo resources to breed bamboo worms, which boast a crude protein content of up to 40% (of dry weight) and seven essential amino acids for the human body. These worms are characterized by their high yield and easy harvesting, with each shoot sacrificed bamboo producing 100–500 g of bamboo worm larvae. In the northeast of China, such as Raohe County, large black bee swarms are domesticated to produce more than 150 tons of nutrient-rich honey each year (Feng and Chen, 2000).

Despite the numerous insect species that are suitable for human consumption and nutritional supplementation, only a small fraction of them are currently being cultured, accounting for just 2% of all orders of edible insects. Several reasons contribute to this low level of utilization, including safety concerns, cultural customs, eating habits, and taste preferences (Feng et al., 2018; Gao et al., 2018; Zhao et al., 2021). As increasing attention is being paid to the potential of insects as a sustainable protein source and ongoing efforts to address these barriers, insect farming, and consumption will continue to grow in popularity in China.

6.2. Green feeds for livestock, poultry, and aquaculture

Farming edible insects with high protein content as a green ingredient for feed processing can be a sustainable solution in agricultural production. This approach can help reduce the consumption of corn and pasture dedicated to livestock, poultry, and aquaculture. Insects possess many advantages, including rapid growth rate, high feed conversion

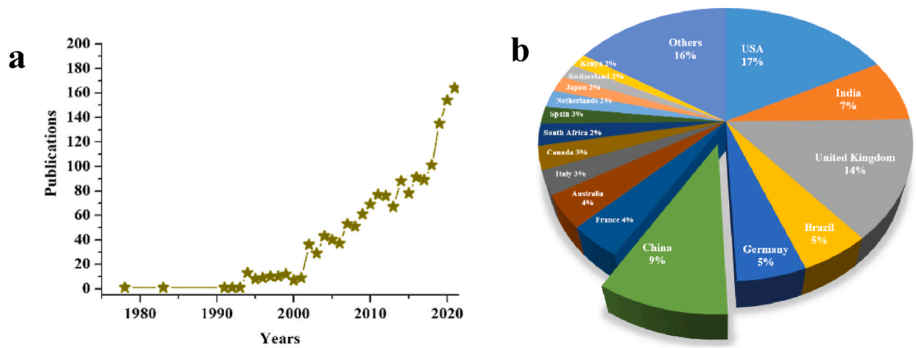

Fig. 2. Publications under the subject of insect farming, documented by Web of Science during the past years, **a**) variation in China and **b**) worldwide comparison among countries.

rate, and usage of organic waste as their feed, making them a cost-effective and sustainable source of feed for animals.

Several companies and individuals in China, such as those in Shandong and Hebei provinces, are engaged in feeding insects like yellow mealworms, locusts, and maggots with high-density breeding and high yield (Wang et al., 2013). The newly developed mealworms in Shandong Limin can breed four to six generations a year, far superior to only one generation of wild species (Wang et al., 2013). Adults are highly reproductive, and each can lay up to 30 eggs per day, spawning for 120–150 days. Besides, the company also developed its sustainable yellow mealworm industrial chain, including the production of worm eggs, worm dry, worm frass, mealworm high protein powder, mealworm pet food, yellow mealworm pupae vegetable, and various kinds of baby pheasants. Farming insects for feed is easily acceptable to the public, unlike eating insects directly. Moreover, using various organic wastes for insect products would reduce feed costs, stimulate aquaculture and livestock production, cut down land use for agriculture production, and lower the dependence on imported protein (Jensen et al., 2021). This approach is serving as an essential method to increase income in many remote rural areas of China.

6.3. *Sustainable organic waste management*

There are a lot of unnecessary biomasses produced during daily life and production. Improper treatment of these organic wastes will not only contaminate the environment but also cause energy waste. One sustainable organic waste management choice is to recycle these wastes through the bioconversion of some edible insects (Fig. 3). Insects are able to digest organic matter in wastes such as plant straw, excrements of poultry and livestock, and daily food waste, resulting in reduced energy and nutrition wasting. In addition to decomposing, transforming,

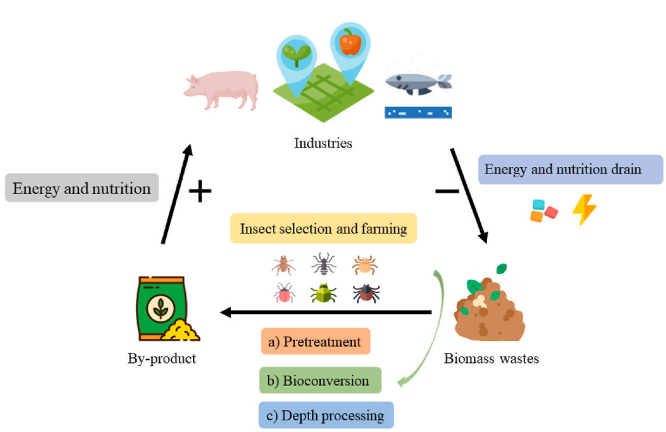

Fig. 3. A simple sustainable recycling economy depending on insect bioconversion.

and recycling organic waste in the environment, the completion of insect biotransformation can produce insect bodies and worm manure resources, which can be used as livestock protein feed and insect manure-based organic fertilizer. For example, black soldier fly can be used to convert organic waste into valuable products. The prepupae, pressed cake, and meal of black soldier fly are potential protein and energy sources for animal feed and feed ingredients due to their higher content of crude protein and energy than soybean meal and fishmeal. The black soldier fly-derived oil is a high-quality biodiesel with a high content of medium-chain saturated fatty acids of 67% (w%) and a low concentration of polyunsaturated fatty acids of 13%. The residual serves as green compost candidates for the growth of crops (Jucker et al., 2020; Li et al., 2021; Ragossnig and Ragossnig, 2021; Surendra et al., 2016; Zhang et al., 2021). Similarly, the bioconversion of swine manure using house fly provided value-added animal foodstuff with 56.9% protein and 23.8% total fat as dry matter, preventing waste products in an intensive animal production system from threatening public health (Wang et al., 2013). However, safety risks associated with bioconversions or waste management to both human beings and animals should be mitigated through rigorous security supervision, including quarantine and quality control measures.

6.4. *Industrial and pharmaceutical raw materials*

Insects offer a diverse array of important by-products that have been utilized in various industries, such as pharmaceuticals and textiles. Silkworms, which have been domesticated for centuries, produce silk as a valuable commodity that has played a significant role in ancient China's foreign trade and continues to be a crucial component in textile production and export (Wang et al., 2014). On the other hand, cochineal produces carminic acid, a red dye that is widely used in the food, pharmaceutical, and cosmetic industries (Bessa et al., 2020; Huis, 2013). Another example is the female Shellac worm, which secretes lac, a natural tree fat. This substance is an essential chemical raw material that finds applications in daily chemical industry, machinery, electronics, military industry, medicine, and food (Wang et al., 2014).

7. Consumer acceptance

Incorporating edible insects into food and feed products requires improvements in both the industrialization process and the promotion of consumer willingness. While some Western countries are still unfamiliar with insects as a food source, Chinese consumers have demonstrated relatively higher acceptance and willingness to purchase insect-based food (Castro and Chambers IV, 2019; Feng et al., 2018; Hartmann et al., 2015; Liu et al., 2019; Menozzi et al., 2017). However, despite this higher acceptance, the acceptance of insects in China is still not satisfactory, and it still lags behind other alternative meat products such as plant-based and cultured meat. The reasons underlying this phenomenon are multifaceted, including sensory and physical properties, health and environmental effects, past exposures, cultural norms, disgust, and new food neophobia.

7.1. Influencing factors of edible insect consumption in China

Various cross-cultural differences exist between Chinese and Western consumers when it comes to the factors affecting the acceptance of insect-based food. For most Westerners, physical properties such as taste, texture, odor, and appearance significantly shaped their willingness to eat insects (Dion-Poulin et al., 2021). Therefore, making it partially invisible can increase the acceptability of Westerners, but these physical properties do not appear to be a major factor for Chinese consumers (Hartmann et al., 2015; Schösler et al., 2012). Apart from that, there are also gender differences in the willingness to try insect-based foods across cultures; men in Western countries are more receptive, whereas the opposite is true in China (Castro and Chambers IV, 2019). Additionally, emphasizing extra health benefits of insects is found to increase the willingness to consume them among Chinese, but not among Germans (Hartmann et al., 2015). The possible reason is that the Chinese place a high emphasis on 'yang sheng', which refers to self-cultivation practices aimed at promoting personal health and longevity (Grunert et al., 2011; Huang et al., 2015).

In China, the acceptance of edible insects is influenced by various factors, such as age, gender, household size, household income, and knowledge base. Older individuals, who are more sensitive to health-related problems, are more attracted to the extra health benefits of insect-based food (Tańska et al., 2017), and thus, they tend to be more receptive to it. Additionally, individuals with better economic conditions are more likely to consume edible insects, probably because they have a greater ability to tolerate the risks associated with new foods (Hubar et al., 2020). Moreover, the acceptance level of insect-based food also has a positive correlation with an individual's knowledge base, as knowledge can help dispel stereotypes and misconceptions about insects, and emphasize their nutritional value (Liu et al., 2019).

From a psychological standpoint, neophobia, and disgust are the two main barriers to the adoption of edible insects (Fig. 4). For disgust, it is a food-related negative emotion when faced with offensive objects (Rozin and Fallon, 1987; Rozin et al., 2008). This negative emotional response stems from people's schema (Barsalou, 1992), which is an associative network formed in their minds when insects are mentioned. It is largely influenced by the socio-cultural environment as it is imparted by their parents' attitudes and social learning (Sandy and Scherer, 2009). In the case of edible insects, people from different cultures may relate to them differently due to their diverse schema (Huis et al., 2013; Looy et al., 2014). Chinese consumers tend to have more positive implicit associations, whereas, in Westerners' schema, insects are viewed as dirty, dangerous, and disgusting figures, such as stool, pathogens, and decaying substances (Kellert, 1993; Vanhonacker et al., 2013). They even tend to view entomophagy as a primitive practice, which threatens their self-esteem (La Barbera et al., 2018; Ramos-Elorduy, 1997). Therefore, the emotional reaction of Westerners is relatively negative, with a higher level of disgust, fear, and contempt (Amato, 2017; Gmuer et al., 2016; Hamerman, 2016). On the contrary, people from South and East Asia, including China, would not feel the same way (Huis, 2013). The feeling of disgust elicited by the food, together with people's interest in it, strongly influences our intention to try the food. This viewpoint helps us understand the role of disgust in explaining the cross-cultural differences in willingness to consume insect-based foods.

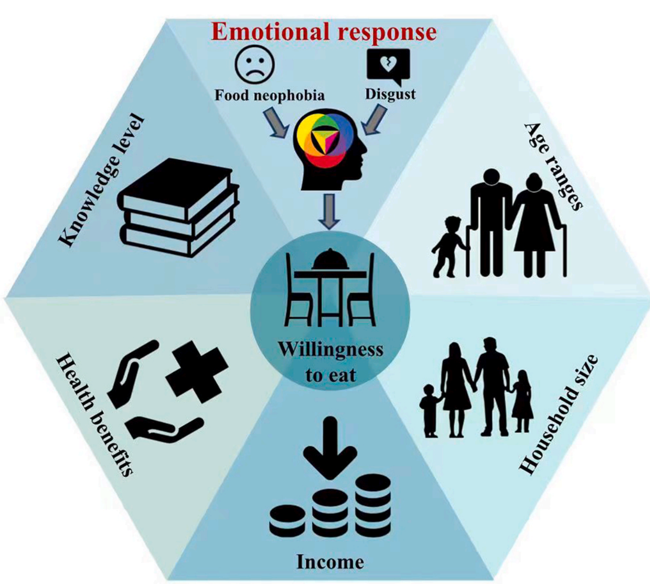

Fig. 4. Influencing factors of insects-based food acceptability in China.

Food neophobia level refers to the tendency to avoid unfamiliar foods. The degree of insect neophobia is highly influenced by people's cultural familiarity and individual characteristics. The idea of edible insects is more widely accepted in China because of the more than 2000-year history of entomophagy in this area (Feng et al., 2018). The Food Neophobia Scale (FNS)is a tool used to measure the tendency to develop food neophobia (La Barbera et al., 2018; Pliner and Hobden, 1992). Originally it was developed in Western countries but adjusted to better suit the Chinese context later (Zhao et al., 2020). Research has shown that Chinese individuals scored high on the FNS, suggesting that they have a significant fear of new foods. Interestingly, their overall level of neophobia towards insect-based foods, usually recognized as 'unconventional', is relatively low, owing to their high culture familiarity (Hanboonsong, 2010; Hartmann et al., 2015; Toti et al., 2020).

To stimulate insect consumption, merchandisers should target families with more children or higher incomes. Investigating additional health benefits of insect-based foods and seeking to increase public familiarity with the subject would also be helpful (Hartmann et al., 2015; Liu et al., 2019). Moreover, delivering the facts about edible insects can ameliorate bias on the food (Verbeke, 2015). Furthermore, food packaging can also affect the willingness to purchase: without the insect-like image, people are more likely to buy it (Pozharliev et al., 2023).

7.2. Research limitations and future focus

Research on the acceptance of insects as food is still limited and further studies are required. Another limitation is the relatively narrow range of research objects. Within the current research, most objects were college students. Other potential consumer groups were rarely taken into account, which made the data unable to fully reflect the purchase intention in the actual market. Besides, China has complex cultures, topography, and terrain, so taste preferences, insect farming, and eating habits vary greatly from region to region. Thus, studies on specific regions or areas, such as northern and southern China, cannot provide an overview of the whole picture of the Chinese population. It is suggested that more detailed studies are needed on this topic (Liu et al., 2019).

8. Conclusion and perspectives

The abundance and diversity of insect resources on Earth make them an invaluable biological asset. In China, edible insects have been traditionally consumed. More recent studies have revealed that many insect species possess excellent nutritional qualities, such as high protein content and polyunsaturated fatty acids. As the demand for protein-rich food sources continues to grow, the rich nutrients supplied by insects make them a viable solution to address malnutrition and food security concerns. Furthermore, edible insects have a low demand for soil and water resources, high feed conversion rates, and fewer greenhouse gas emissions, making them an ecologically significant protein source.

Therefore, they could alleviate the pressure on our current ecosystem to feed the growing protein demand. The local economy in China is already benefiting from the insect economy, indicating that insects are a promising resource with great potential in the Chinese market.

However, it is crucial to ensure that food prepared from insects is safe, legal, and accepted. Proper legislation and quality regulations must be established to ensure the safety of food and feed from insects. Large-scale insect farms must be implemented to minimize food safety issues and prevent contamination during the farming process. Mass insect farming can create a cost-effective industry. More widely acceptable processing techniques are necessary to produce high-quality, safe, and nutritious edible insect products. Besides, research should focus on identifying potential allergens and toxins and developing effective control measures. It is essential to have social awareness and promote the culture and utilization of edible insect resources in China, and this review aims to contribute to this goal.

In summary, insects have the potential to play a crucial role in China's food and agricultural industries. To promote their use while ensuring their safety, acceptance and sustainability. With the help of scientific research and social awareness, people can enhance the culture and utilization of edible insect resources in China, ultimately benefiting both the local economy and the global community.

CRediT authorship contribution statement

Xueying Lin: Supervision, Methodology, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Feifan Wang:** Conceptualization, Validation, Investigation, Writing – original draft. **Yuting Lu:** Validation, Investigation, Writing – original draft. **Jiarui Wang:** Validation, Investigation, Writing – original draft. **Jingwen Chen:** Visualization. **Yingxin Yu:** Writing – review & editing. **Xiaoyu Tao:** Writing – review & editing. **Ying Xiao:** Writing – review & editing, Visualization, Funding acquisition, Supervision, Project administration. **Ye Peng:** Writing – review & editing, Visualization, Funding acquisition, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgments

There is no conflict of interest associated with this manuscript. This review was supported by Guangdong-Hong Kong-Macao Joint Laboratory for Contaminants Exposure and Health (2020B1212030008) and Faculty Research Grants at Macau University of Science and Technology [FRG-22-111-FMD].

Additionally, the authors would like to express their gratitude to Ms. Esther X. Chen for her valuable revision suggestions and contributions to related illustrations.

References

Adegboye, A.R.A., Bawa, M., Keith, R., Twefik, S., Tewfik, I., 2021. Edible Insects Sustainable nutrient-rich foods to tackle food insecurity and malnutrition. World Nutrition 176–189. https://doi.org/10.26596/wn.202-1124176-189.

Adeoye, O.T., Oyelowo, O.J., Adebisi-Fagbohungbe, T.A., Akinyemi, O.D., 2014. Eco-diversity of edible insects of Nigeria and its impact on food security. J. Sci. Food Agric. 5 (2) https://doi.org/10.5296/jbls.v5i2.6109.

Alengebawy, A., Abdelkhalek, S.T., Qureshi, S.R., Wang, M.Q., 2021. Heavy metals and pesticides toxicity in agricultural soil and plants: ecological risks and human health implications. Toxics 9 (3). https://doi.org/10.3390/toxics.90300-42.

Amato, M., 2017. *Insects as Food: A Cross-Cultural Comparison of Consumers' Intention and Behaviour* (Unpublished Doctoral Dissertation). University of Naples Federico II.

Barre, A., Simplicien, M., Cassan, G., Benoist, H., Rougé, P., 2018. Food allergen families common to different arthropods (mites, insects, crustaceans), mollusks and nematods: cross-reactivity and potential cross-allergenicity. Rev. Fr. Allergol. 58 (8), 581–593. https://doi.org/10.1016/j.reval.2018.10.008.

Barsalou, L.W., 1992. Cognitive Psychology: an Overview for Cognitive Scientists. Psychology Press. https://doi.org/10.4324/9781315807485.

Bednarska, A.J., Opyd, M., Żurawicz, E., Laskowski, R., 2015. Regulation of body metal concentrations: toxicokinetics of cadmium and zinc in crickets. Ecotoxicol. Environ. Saf. 119, 9–14. https://doi.org/10.1016/j.ecoenv.2015.04.056.

Bekuma, A., Tadesse, T., Galmessa, U., 2019. Review on negative impacts of livestock production on climate change and its mitigation strategies: a global issue. World Sci. News 115, 218–228. https://doi.org/10.3920/JIFF2015.0030.

Bessa, L.W., Pieterse, E., Sigge, G., Hoffman, L.C., 2020. Insects as human food; from farm to fork. J. Sci. Food Agric. 100 (14), 5017–5022. https://doi.org/10.1002/jsfa.8860.

Biancarosa, I., Liland, N.S., Biemans, D., Araujo, P., Bruckner, C.G., Waagbo, R., Torstensen, B.E., Lock, E.J., Amlund, H., 2018. Uptake of heavy metals and arsenic in black soldier fly (Hermetia illucens) larvae grown on seaweed-enriched media. J. Sci. Food Agric. 98 (6), 2176–2183. https://doi.org/10.1002/jsfa.8702.

Castro, M., Chambers IV, E., 2019. Willingness to eat an insect based product and impact on brand equity: a global perspective. J. Sensory Stud. 34 (2), e12486 https://doi.org/10.1111/joss.12486.

Chen, H., Wang, Li, Guan, Hao, 2019. A study on the arable land demand for food security in China. Sustainability 11 (17). https://doi.org/10.3390/su11174769.

Chen, L., Chang, J., Wang, Y., Guo, A., Liu, Y., Wang, Q., Zhu, Y., Zhang, Y., Xie, Z., 2021. Disclosing the future food security risk of China based on crop production and water scarcity under diverse socioeconomic and climate scenarios. Sci. Total Environ. 790, 148110 https://doi.org/10.1016/j.scitotenv.2021.148110.

Chomchai, S., Chomchai, C., 2018. Histamine poisoning from insect consumption: an outbreak investigation from Thailand. Clin. Toxicol. 56 (2), 126–131. https://doi.org/10.1080/15563650.2017.1349320.

Diener, S., Zurbrügg, C., Tockner, K., 2015. Bioaccumulation of heavy metals in the black soldier fly, Hermetia illucens and effects on its life cycle. J. Insects Food Feed 1 (4), 261–270. https://doi.org/10.3920/JIFF2015.0030.

Dion-Poulin, A., Turcotte, M., Lee-Blouin, S., Perreault, V., Provencher, V., Doyen, A., Turgeon, S.L., 2021. Acceptability of insect ingredients by innovative student chefs: an exploratory study. Int. J. Gastron. Food Sci. 24, 100362 https://doi.org/10.1016/j.ijgfs.2021.100362.

Downs, M., Johnson, P., Zeece, M., 2016. Chapter 9 - insects and their connection to food allergy. In: Dossey, A.T., Morales-Ramos, J.A., Rojas, M.G. (Eds.), Insects as Sustainable Food Ingredients: Production Processing and Food Application. Nikki Levy, London, England, pp. 255–272. https://doi.org/10.1016/B978-0-12-802856-8.00009-0.

EFSA Scientific Committee, 2015. Risk profile related to production and consumption of insects as food and feed. EFSA J. 13 (10), 4257. https://doi.org/10.2903/j.efsa.2015.4257.

FAO, 2021. Looking at Edible Insects from a Food Safety Perspective. Challenges and Opportunities for the Sector. FAO, Rome, Italy. https://doi.org/10.4060/cb4094.en.

Fels-Klerx, V.D., H, J., Camenzuli, L., van der Lee, M.K., Oonincx, D.G., 2016. Uptake of cadmium, lead and arsenic by Tenebrio molitor and hermetia illucens from contaminated substrates. PLoS One 11 (11), e0166186. https://doi.org/10.1371/journal.pone.0166186.

Fels-Klerx, V.D., H, J., Camenzuli, L., Belluco, S., Meijer, N., Ricci, A., 2018. Food safety issues related to uses of insects for feeds and foods. Compr. Rev. Food Sci. Food Saf. 17 (5), 1172–1183. https://doi.org/10.1111/1541-4337.12385.

Feng, Y., Chen, X., 2000. The nutritional elements analysis of bamboo insect and review on its development and utilization value. For. Res. 13 (2), 188–191.

Feng, Y., Chen, X.M., Zhao, M., He, Z., Sun, L., Wang, C.Y., Ding, W.F., 2018. Edible insects in China: utilization and prospects. Insect Sci. 25 (2), 184–198. https://doi.org/10.1111/1744-7917.12449.

Feng, Y., Zhao, M., Ding, W.F., Chen, X.M., 2020. Overview of edible insect resources and common species utilisation in China. J. Insects Food Feed 6 (1), 13–25. https://doi.org/10.3920/jiff2019.0022.

Fiala, N., 2008. Meeting the demand: an estimation of potential future greenhouse gas emissions from meat production. Ecol. Econ. 67 (3), 412–419. https://doi.org/10.1016/j.ecolecon.2007.12.021.

Gao, Y., Wang, D., Xu, M.L., Shi, S.S., Xiong, J.F., 2018. Toxicological characteristics of edible insects in China: a historical review. Food Chem. Toxicol. 119, 237–251. https://doi.org/10.1016/j.fct.2018.04.016.

Garofalo, C., Milanović, V., Cardinali, F., Aquilanti, L., Clementi, F., Osimani, A., 2019. Current knowledge on the microbiota of edible insects intended for human consumption: a state-of-the-art review. Food Res. Int. 125, 108527 https://doi.org/10.1016/j.foodres.2019.108527.

Gmuer, A., Nuessli Guth, J., Hartmann, C., Siegrist, M., 2016. Effects of the degree of processing of insect ingredients in snacks on expected emotional experiences and willingness to eat. Food Qual. Prefer. 54, 117–127. https://doi.org/10.1016/j.foodqual.2016.07.003.

Govorushko, S., 2019. Global status of insects as food and feed source: a review. Trends Food Sci. Technol. 91, 436–445. https://doi.org/10.1016/j.tifs.2019.07.032.

Grunert, K.G., Perrea, T., Zhou, Y., Huang, G., Sørensen, B.T., Krystallis, A., 2011. Is food-related lifestyle (FRL) able to reveal food consumption patterns in non-Western cultural environments? Its adaptation and application in urban China. Appetite 56 (2), 357–367. https://doi.org/10.1016/j.appet.2010.12.020.

Hamerman, E.J., 2016. Cooking and disgust sensitivity influence preference for attending insect-based food events. Appetite 96, 319–326. https://doi.org/10.1016/j.appet.2015.09.029.

Hanboonsong, Y., 2010. Edible insects and associated food habits in Thailand. In: Durst, P.B., Johnson, D.V., Leslie, P.B., Shono, K. (Eds.), Forest Insects as Food: Humans Bite Back. FAO, Bangkok, Thailand, pp. 173–182.

Hartmann, C., Shi, J., Giusto, A., Siegrist, M., 2015. The psychology of eating insects: a cross-cultural comparison between Germany and China. Food Qual. Prefer. 44, 148–156. https://doi.org/10.1016/j.foodqual.2015.04.013.

Huang, G., Grunert, K.G., Lu, D., Zhou, Y., 2015. Chinese urban consumers segmentation based on modified food-related lifestyle (FRL). J. Int. Consum. Market. 27 (4), 328–343. https://doi.org/10.1080/08961530.2015.1022922.

Huang, C., Feng, W., Xiong, J., Wang, T., Wang, W., Wang, C., Yang, F., 2019. Impact of drying method on the nutritional value of the edible insect protein from black soldier fly (Hermetia illucens L.) larvae: amino acid composition, nutritional value evaluation, in vitro digestibility, and thermal properties. Eur. Food Res. Technol. 245, 11–21. https://doi.org/10.1007/s00217-018-3136-y.

Hubar, S., Koulovatianos, C., Li, J., 2020. The role of labor-income risk in household risk-taking. Eur. Econ. Rev. 129, 103522 https://doi.org/10.1016/j.euroecorev.2020.103522.

Huis, A.V., 2013. Potential of insects as food and feed in assuring food security. Annual Annu. Rev. Entomol. 58 (1), 563–583. https://doi.org/10.1146/annurev-ento-120811-153704.

Huis, A.V., Itterbeeck, J.V., Klunder, H., Mertens, E., Halloran, A., Muir, G., Vantomme, P., 2013. Edible Insects: Future Prospects for Food and Feed Security. FAO, Rome, Italy.

Imathiu, S., 2020. Benefits and food safety concerns associated with consumption of edible insects. NFS J 18, 1–11. https://doi.org/10.1016/j.nfs.2019.11.002.

Jensen, H., Elleby, C., Domínguez, I.P., Chatzopoulos, T., Charlebois, P., 2021. Insect-based protein feed: from fork to farm. J. Insects Food Feed. https://doi.org/10.3920/JIFF2021.0007.

Ji, K., Chen, J., Li, M., Liu, Z., Wang, C., Zhan, Z., Wu, X., Xia, Q., 2009. Anaphylactic shock and lethal anaphylaxis caused by food consumption in China. Trends Food Sci. Technol. 20 (5), 227–231. https://doi.org/10.1016/j.tifs.2009.02.004.

Jucker, C., Lupi, D., Moore, C.D., Leonardi, M.G., Savoldelli, S., 2020. Nutrient recapture from insect farm waste: bioconversion with hermetia illucens (L.) (Diptera: Stratiomyidae). Sustainability 12 (1), 362. https://doi.org/10.3390/su12010362.

Kellert, S.R., 1993. Values and perceptions of invertebrates. Conserv. Biol. 7 (4), 845–855. https://doi.org/10.1046/j.1523-1739.1993.740845.x.

Kinyuru, J.N., Mogendi, J.B., Riwa, C.A., Ndung'u, N.W., 2015. Edible insects—a novel source of essential nutrients for human diet: learning from traditional knowledge. Anim. Front. 5 (2), 14–19. https://doi.org/10.2527/af.2015-0014.

Komatsu, Y., Tsuda, M., Wada, Y., Shibasaki, T., Nakamura, H., Miyaji, K., 2023. Nutritional evaluation of milk-, plant-, and insect-based protein materials by protein digestibility using the INFOGEST digestion method. J. Agric. Food Chem. 71 (5), 2503–2513. https://doi.org/10.1021/acs.jafc.2c07273.

Kröncke, N., Benning, R., 2022. Self-selection of feeding substrates by Tenebrio molitor larvae of different ages to determine optimal macronutrient intake and the influence on larval growth and protein content. Insects 13 (7), 657. https://doi.org/10.3390/insects13070657.

La Barbera, F., Verneau, F., Amato, M., Grunert, K., 2018. Understanding Westerners' disgust for the eating of insects: the role of food neophobia and implicit associations. Food Qual. Prefer. 64, 120–125. https://doi.org/10.1016/j.foodqual.2017.10.002.

Lange, K.W., Nakamura, Y., 2021. Edible insects as future food: chances and challenges. J. Future Foods 1 (1), 38–46. https://doi.org/10.1016/j.jfutfo.2021.10.001.

Li, T.H., Zhang, C.R., Che, P.F., Ma, Y., Zang, L.S., 2021. Recycling of spent mushroom substrate and food waste: utilisation as feed materials for black soldier fly (Hermetia illucens (L.) Diptera: Stratiomyidae). J. Insects Food Feed 7, 409–417. https://doi.org/10.3920/JIFF2020.0105.

Liu, A.J., Li, J., Gomez, M.I., 2019. Factors influencing consumption of edible insects for Chinese consumers. Insects 11 (1). https://doi.org/10.3390/insects.11010010.

Looy, H., Dunkel, F.V., Wood, J.R., 2014. How then shall we eat? Insect-eating attitudes and sustainable foodways. Agric. Hum. Val. 31 (1), 131–141. https://doi.org/10.1007/s10460-013-9450-x.

. *China Agricultural Outlook*(*2023-2032*) Market Early Warning Expert Committee of the Ministry of Agriculture and Rural Affairs (MARA), 2023. China Agricultural Science and Technology press.

Mason, J.B., Black, R., Booth, S.L., Brentano, A., Broadbent, B., Connolly, P., Finley, J., Goldin, J., Griffin, T., Hagen, K., Lesnik, J., Lewis, G., Pan, Z., Ramos, J.M., Ranalli, M., Rojas, G., Shockley, M., Stull, V.J., Swietlik, D., 2018. Fostering strategies to expand the consumption of edible insects: the value of a tripartite coalition between academia, industry, and government. Curr. Dev. Nutr. 2 (8) https://doi.org/10.1093/cdn/nzy056.

Menozzi, D., Sogari, G., Veneziani, M., Simoni, E., Mora, C., 2017. Eating novel foods: an application of the Theory of Planned Behaviour to predict the consumption of an insect-based product. Food Qual. Prefer. 59, 27–34. https://doi.org/10.1016/j.foodqual.2017.02.001.

Miguéns-Gómez, A., Grau-Bové, C., Sierra-Cruz, M., Jorba-Martín, R., Caro, A., Rodríguez-Gallego, E., Beltrán-Debón, R., Blay, M.T., Terra, X., Ardévol, A., Pinent, M., 2020. Gastrointestinally digested protein from the insect *Alphitobius diaperinus* stimulates a different intestinal secretome than beef or almond, producing a differential response in food intake in rats. Nutrients 12 (8), 2366. https://doi.org/10.3390/nu12082366.

Mintah, B.K., He, R., Agyekum, A.A., Dabbour, M., Golly, M.K., Ma, H., 2020. Edible insect protein for food applications: extraction, composition, and functional properties. J. Food Process. Eng. 43 (4), e13362 https://doi.org/10.1111/jfpe.13362.

Murefu, T.R., Macheka, L., Musundire, R., Manditsera, F.A., 2019. Safety of wild harvested and reared edible insects: a review. Food Control 101, 209–224. https://doi.org/10.1016/j.foodcont.2019.03.003.

Musundire, R., Osuga, I.M., Cheseto, X., Irungu, J., Torto, B., 2016. Aflatoxin contamination detected in nutrient and anti-oxidant rich edible stink bug stored in recycled grain containers. PLoS One 11 (1), e0145914. https://doi.org/10.1371/journal.pone.0145914.

Ministry of Water Resource of the People's Republic of China (MWR), 2021. China Water Resources Bulletin 2020. China Water & Power Press, Beijing, China.

Nakagaki, B.J., Defoliart, G.R., 1991. Comparison of diets for mass-rearing Acheta domesticus (Orthoptera: gryllidae) as a novelty food, and comparison of food conversion efficiency with values reported for livestock. J. Econ. Entomol. 84 (3), 891–896. https://doi.org/10.1093/jee/84.3.891.

Nowakowski, A.C., Miller, A.C., Miller, M.E., Xiao, H., Wu, X., 2022. Potential health benefits of edible insects. Crit. Rev. Food Sci. Nutr. 62 (13), 3499–3508. https://doi.org/10.1080/10408398.2020.1867053.

Oonincx, D.G., van Itterbeeck, J., Heetkamp, M.J., van den Brand, H., van Loon, J.J., van Huis, A., 2010. An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS One 5 (12), e14445. https://doi.org/10.1371/journal.pone.0014445.

Orkusz, A., 2021. Edible insects versus meat-nutritional comparison: knowledge of their composition is the key to good health. Nutrients 13 (4), 1207. https://doi.org/10.3390/nu13041207.

Ozimek, L., Sauer, W., Kozikowski, V., Ryan, J., Jorgensen, H., Jelen, P., 1985. Nutritive value of protein extracted from honey bees. J. Food Sci. 50 (5), 1327–1329. https://doi.org/10.1111/j.1365-2621.1985.tb10469.x.

Pali-Schöll, I., Meinlschmidt, P., Larenas-Linnemann, D., Purschke, B., Hofstetter, G., Rodríguez-Monroy, F.A., Einhorn, L., Mothes-Luksch, N., Jensen-Jarolim, E., Jäger, H., 2019. Edible insects: cross-recognition of IgE from crustacean- and house dust mite allergic patients, and reduction of allergenicity by food processing. World Allergy Organ. J. 12 (1), 100006 https://doi.org/10.1016/j.waojou.2018.10.001.

Piernas, C., Wang, D., Du, S., Zhang, B., Wang, Z., Su, C., Popkin, B.M., 2015. The double burden of under- and overnutrition and nutrient adequacy among Chinese preschool and school-aged children in 2009-2011. Eur. J. Clin. Nutr. 69 (12), 1323–1329. https://doi.org/10.1038/ejcn.2015.106.

Pliner, P., Hobden, K., 1992. Development of a scale to measure the trait of food neophobia in humans. Appetite 19 (2), 105–120. https://doi.org/10.1016/0195-6663(92)90014-W.

Pozharliev, R., De Angelis, M., Rossi, D., Bagozzi, R., Amatulli, C., 2023. I might try it: marketing actions to reduce consumer disgust toward insect-based food. J. Retailing 99 (1), 149–167. https://doi.org/10.1016/j.jretai.2022.12.003.

Ragossnig, H.A., Ragossnig, A.M., 2021. Biowaste treatment through industrial insect farms: one bioeconomy puzzle piece towards a sustainable net-zero carbon economy? Waste Manag. Res. 39 (8), 1005–1006. https://doi.org/10.1177/0734242x211036949.

Rai, P.K., Lee, S.S., Zhang, M., Tsang, Y.F., Kim, K.H., 2019. Heavy metals in food crops: health risks, fate, mechanisms, and management. Environ. Int. 125, 365–385. https://doi.org/10.1016/j.envint.2019.01.067.

Ramos-Elorduy, B.J., 1997. The importance of edible insects in the nutrition and economy of people of the rural areas of Mexico. Ecol. Food Nutr. 36 (5), 347–366. https://doi.org/10.1080/03670244.1997.9991524.

Rodríguez-Rodríguez, M., Barroso, F.G., Fabrikov, D., Sánchez-Muros, M.J., 2022. In vitro crude protein digestibility of insects: a review. Insects 13 (8), 682. https://doi.org/10.3390/insects13080682.

Rozin, P., Fallon, A.E., 1987. A perspective on disgust. Psychol. Rev. 94 (1), 23. https://doi.org/10.1037/0033-295X.94.1.23.

Rozin, P., Haidt, J., McCauley, C.R., 2008. Disgust. In: Lewis, M., Haviland-Jones, J.M., Barrett, L.F. (Eds.), Handbook of Emotions. The Guilford Press, New York, pp. 757–776.

Sandy, D., Scherer, K., 2009. The Oxford Companion to Emotion and the Affective Sciences. The United Statesof America: Oxford University Press, Cambridge.

Schmidhuber, J., Tubiello, F.N., 2007. Global Food Security under Climate Change. PANS. https://doi.org/10.1073/pnas.0701976104.

Schösler, H., De Boer, J., Boersema, J.J., 2012. Can we cut out the meat of the dish? Constructing consumer-oriented pathways towards meat substitution. Appetite 58 (1), 39–47. https://doi.org/10.1016/j.appet.2011.09.009.

Smil, V., 2002. Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins. Enzym. Microb. Technol. 30 (3), 305–311. https://doi.org/10.1016/S0141-0229(01)00504-X.

Song, M., Tao, W., Shang, Y., Zhao, X., 2022. Spatiotemporal characteristics and influencing factors of China's urban water resource utilization efficiency from the perspective of sustainable development. J. Clean. Prod. 338 https://doi.org/10.1016/j.jclepro.2022.130649.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., Haan, C.d., 2006. Livestock's Long Shadow : Environmental Issues and Options. FAO, Rome, Italy.

Su, Y., Chen, J., Zhao, M., Liao, H., Zhao, M., Du, Y., Lu, M., 2023. Insects are a delicacy: exploring consumer acceptance and market demand for edible insects in China. J. Insects Food Feed 9 (3), 389–398. https://doi.org/10.3920/JIFF2022.0059.

Surendra, K.C., Olivier, R., Tomberlin, J.K., Jha, R., Khanal, S.K., 2016. Bioconversion of organic wastes into biodiesel and animal feed via insect farming. Renew. Energy 98, 197–202. https://doi.org/10.1016/j.renene.2016.03.022.

Tańska, M., Babicz-Zielińska, E., Chaillot, A., 2017. Attitudes of elderly people towards new and unfamiliar food. Handel Wewn 1 (366), 368–376.

Toti, E., Massaro, L., Kais, A., Aiello, P., Palmery, M., Peluso, I., 2020. Entomophagy: a narrative review on nutritional value, safety, cultural acceptance and a focus on the role of food neophobia in Italy. Eur. J. Invest. Health 10 (2), 628–643. https://doi.org/10.3390/ejihpe10020046.

Twining, C.W., Lawrence, P., Winkler, D.W., Flecker, A.S., Brenna, J.T., 2018. Conversion efficiency of α-linolenic acid to omega-3 highly unsaturated fatty acids in aerial insectivore chicks. J. Exp. Biol. 221 (3) https://doi.org/10.1242/jeb.165373 jeb165373.

United Nations (UN), 2019. World population prospects of the UN. In: (2019). Probabilistic Population Projections Rev. 1 Based on the World Population Prospects 2019 Rev. 1. Available online at: http://population.un.org/wpp/. (Accessed 12 June 2023).

Uwizeye, A., de Boer, I.J., Opio, C.I., Schulte, R.P., Falcucci, A., Tempio, G., Teillard, F., Casu, F., Rulli, M., Galloway, J.N., 2020. Nitrogen emissions along global livestock supply chains. Nat. Food 1 (7), 437–446. https://doi.org/10.1038/s43016-020-0113-y.

Vanhonacker, F., Van Loo, E.J., Gellynck, X., Verbeke, W., 2013. Flemish consumer attitudes towards more sustainable food choices. Appetite 62, 7–16. https://doi.org/10.1016/j.appet.2012.11.003.

Verbeke, W., 2015. Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. Food Qual. Prefer. 39, 147–155. https://doi.org/10.1016/j.foodqual.2014.07.008.

Wang, H., Zhang, Z., Czapar, G.F., Winkler, M.K., Zheng, J., 2013. A full-scale house fly (Diptera: muscidae) larvae bioconversion system for value-added swine manure reduction. Waste Manag. Res. 31 (2), 223–231. https://doi.org/10.1177/0734242x.12469431.

Wang, G., Jia, H., Cui, L., 2014. Current Situation of Insect Culture and Utilization in China. Protection Forest Science and Technology, pp. 61–62.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet (N. Am. Ed.) 393 (10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

Xia, Z., Wu, S., Pan, S., Kim, J.M., 2012. Nutritional evaluation of protein from Clanis bilineata (Lepidoptera), an edible insect. J. Sci. Food Agric. 92 (7), 1479–1482. https://doi.org/10.1002/jsfa.4730.

Yi, L.Y., 2015. A Study on the Potential of Insect Protein and Lipid as a Food Source. Wageningen University, Wageningen, Netherlands.

Zhang, J.B., Zhang, J., Li, J.H., Tomerlin, J.K., Xiao, X.P., ur Rehman, K., Cai, M.M., Zheng, L.Y., Yu, Z.N., 2021. Black soldier fly: a new vista for livestock and poultry manure management. J. Integr. Agric. 20 (5), 1167–1179. https://doi.org/10.1016/S2095-3119(20)63423-2.

Zhao, J.B., Gao, Z.B., Li, Y.X., Zhang, X.Y., Zou, L.Q., 2020. The food neophobia scale (FNS): exploration and confirmation of factor structure in a healthy Chinese sample. Food Qual. Prefer. 79, 103791 https://doi.org/10.1016/j.foodqual.2019.103791.

Zhao, M., Wang, C.Y., Sun, L., He, Z., Yang, P.L., Liao, H.J., Feng, Y., 2021. Edible aquatic insects: diversities, nutrition, and safety. Foods 10 (12), 3033. https://doi.org/10.3390/foods10123033.

Zheng, R., Mi, S., Zhou, Y., Deng, Z., Kong, X., Li, T., Yin, Y., 2015. Protein security and food security in China. Front. Agr. Sci. Eng. 2 (2), 144–151. https://doi.org/10.15302/j-fase-2015062.

Zhu, Y., Begho, T., 2022. Towards responsible production, consumption and food security in China: a review of the role of novel alternatives to meat protein. Future Foods 6, 100186. https://doi.org/10.1016/j.fufo.2022.100186.