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Review Article

Exploring the various orders of edible insects in the Kingdom of Saudi Arabia as a safe and sustainable food alternative: A comprehensive review

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Abstract
The global population is predicted to reach 9.3 billion by 2050, increasing food production substantially and posing significant food security risks, particularly for low-income countries. The widening food security gap necessitates innovative, sustainable solutions. In response, promoting edible insects as a viable food source gained momentum, addressing malnutrition and food insecurity. The Kingdom of Saudi Arabia, one of the world's largest countries, has many edible insects. As a result of its unique challenges, Saudi Arabia explores insects as a vital source for enhancing food security, such as Crickets, Mealworms, Black Soldier Flies, Buffalo's, Grasshoppers, Ants, Silkworms, and Cicadas. The Kingdom's commitment to Vision 2030, focusing on sustainable development, underscores the importance of incorporating insects into agricultural processes and food manufacturing. Despite the promising nutritional benefits, challenges such as potential toxicity, pesticide residues, heavy metals, and allergic reactions require careful consideration. Collaborative efforts involving the public and private sectors, universities, and large-scale breeding laboratories are essential to realize the full potential of edible insects. This review article delves into the nutritional value of edible insect orders found in the Kingdom, examining protein, lipid, carbohydrate, nucleic acid, mineral, and vitamin content. The review emphasizes the need for extensive research to understand the nutritional composition of diverse insect species in Saudi Arabia.

Keywords: Edible insects, Food sustainability, Insects, Insect orders, Kingdom of Saudi Arabia

INTRODUCTION

By 2050, the world is estimated to require 60 % in food production to sustain a population of 9.3 billion (FAO); however, adhering to a business-as-usual farming approach would strain our natural resources (United Nations, 2015). Consequently, the gap in food security between high-income and low-income nations is expected to widen, highlighting the urgent need for socioeconomic enhancements and improved global food access (Premalatha *et al.,* 2011). Despite recent advancements in food technology, many countries continue to grapple with food security challenges, including access, affordability, equitable distribution, and safety (Kumareswaran *et al.,* 2022). Moreover, regions experiencing rapid population growth are projected to confront these challenges more acutely (United Nations, 2015). Recognizing the impending food security crisis, the FAO initiated the exploration of insect-based food sources in 2013, aiming to address global food insecurity (Sun-Waterhouse *et al.,* 2016).

For thousands of years, edible insects have been acknowledged as valuable nutritional resources capable of combating malnutrition and supporting food security in vulnerable regions (Backwell and d'Errico, 2001; Huis *et al.,* 2013; Rothman *et al.,* 2014; Ayieko *et al.*, 2016; Hawkey *et al.,* 2021; Lange and Nakamura, 2021). Faced with unprecedented food security and sustainability challenges, European Union (EU) legislators have extensively revised regulations governing edible insects, feed production, and marketing (Vauterin *et al.,* 2021). These products, targeting insects for use as food, are subject to regulation under the Novel Foods (NF) classification (EU) (Scaffardi and Formici, 2022).

In light of this, the Kingdom of Saudi Arabia stands out as one of the world's largest countries with significant edible insect populations. Addressing its unique challenges, Saudi Arabia identifies various insect orders to enhance food security, including crickets, mealworms, black soldier flies, and cicadas. Generally, there are eight orders of edible insects suitable for consumption, such as Order Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Lepidoptera, Odonata, and Orthoptera as in Fig. 1 (Pal and Roy, 2014; Melgar‐Lalanne *et al.,* 2019), which are found in Saudi Arabia (Abdel-Dayem *et al.,* 2020; Gharsan and Alghamdi, 2024; Zeya *et al.,* 2024; Sharawi, 2023; Husain *et al.,* 2023; Seizmair, 2023; Waldhauser *et al.,* 2023; Yaman, 2009). The outline of the different orders of edible insects found in Saudi Arabia and their edible phases are shown in Tables 1-8.

EDIBLE INSECTS AND VISION 2030 OF SAUDI ARABIA

According to Mancini *et al.* (2022), previously edible insects can undergo various processes such as roasting, frying, baking, defatting, and drying before being transformed into powder or oil. These whole insect products are typically presented following local, cultural, or exotic cooking styles and spices to enhance consumers' affordability (Boukid *et al.,* 2022). For instance, in Al-Qassim Province, Saudi Arabia, Crickets, locusts, and grasshoppers are consumed whole. Despite being considered a niche product, insect powder is gaining traction among consumers for use in their recipes. It serves as a partial substitute for other ingredients, thereby impacting the nutritional value of the food. Additionally, fats or oils derived from insects can potentially replace animal-vegetable fats in food formulations, offering an alternative to conventional butter, margarine, and table oils (Tzompa-Sosa *et al.,* 2021; Mancini *et al.,* 2022). Recent research by Boukid *et al.* (2022) revealed that since 1996, 236 insect-based products have been launched in the global market. With the implementation of legal frameworks and increased consumer awareness of their benefits, more insect-based foods are expected. One of the edible insect benefits, their lipids primarily consist of triacylglycerol, with fatty acids like linoleic acid, palmitic acid, lauric acid, and

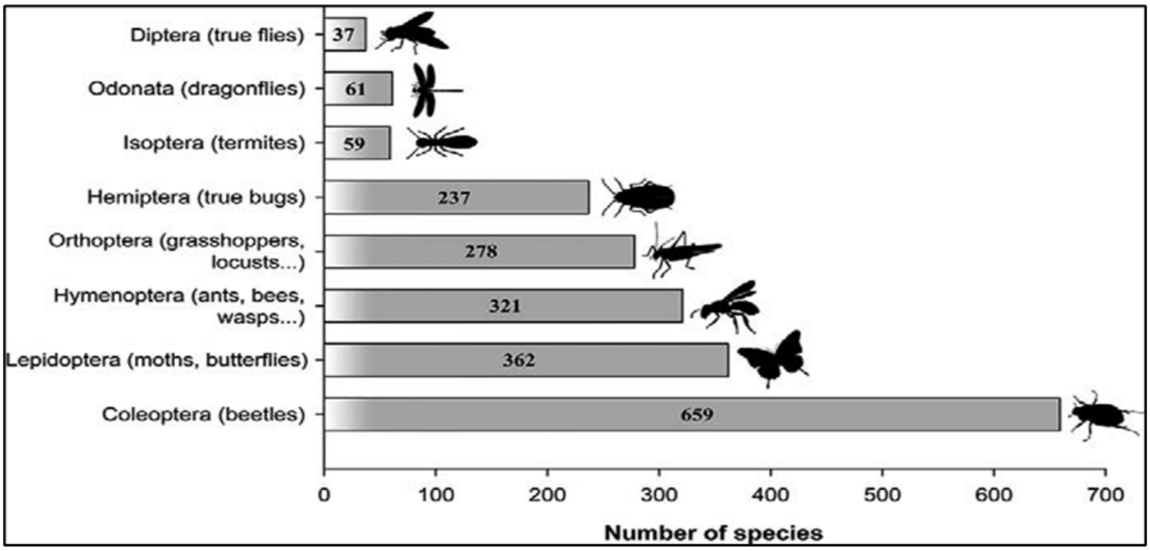

Fig. 1. *General eight orders of edible insects (Fiebelkorn et al., 2020*

Table 1. Edible Odonata insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Enallagma sp.	*Coenagrionidae*	Nymphs and adult stages	Chakravorty *et al.,* 2011; Samraoui *et al.,* 2010
Ictinogomphus rapax	*Gomphidae*		Chakravorty *et al.,* 2011; Prasad, 1996
Sympetrum sp. *Urothemis sp.* *Diplacodes sp.*	*Libellulidae*		Chakravorty *et al.,* 2011; Schneider and Krupp, 1993

Table 2. Edible Orthoptera insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Chondacris rosea	*Acrididae*	Adult stages	Chakravorty *et al.,* 2011; Danhassan et al., 2018
Heiroglyphus sp.			Chakravorty *et al.,* 2011
Schistocerca sp.			Chakravorty *et al.,* 2011; Maxwell-Darling, 1937
Leptysma sp.			Chakravorty *et al.,* 2011; Asiry et al., 2022
Gryllotalpa sp.	*Gryllotalpidae*		Chakravorty *et al.,* 2011; Gorochov, 1993
Schizodactylus monstrosus	*Schizodactylidae*		Chakravorty *et al.,* 2011; Ghoneim, 2019
Conocephalus sp. *Chloracris brullei*	*Tettigoniidae*		Chakravorty *et al.,* 2011; Mitsuhashi, 2016

Table 3. Edible Hemiptera insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Tibicen pruinosus *Cyclochila virens*	*Cicadidae*	Adult stages	Chakravorty et al., 2011; Mitsuhashi, 2016
Halyomorpha picus	*Pentatomidae*		Chakravorty et al., 2011; Tselikh, 2016
Nezara viridula			Chakravorty et al., 2011; Asiry et al., 2022

Table 4. Edible Hymenoptera insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Vespa sp. *Vespa orientalis*		Adult stages	Chakravorty *et al.,* 2011; Ahmad, 2023
Apis cerana	*Vespidae*	Larval and pupal stages	Chakravorty *et al.,* 2011; Alqarni et al., 2011
Apis sp.		Adult stages	Chakravorty *et al.,* 2011; Ahmad, 2023
Xylocopa sp.	*Xylocopidae*	Larval and adult stages	Chakravorty *et al.,* 2011; Hannan et al., 2012
Oecophylla smaragdina	*Formicidae*		Chakravorty *et al.,* 2011; Mashaly *et al.,* 2018

Table 5. Edible Coleoptera insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Sternocera sp.	*Buprestidae*	Adult stages	Chakravorty *et al.,* 2011; Bílý *et al.,* 2011
Dorcus sp.	*Lucanidae*	Larval and adult stages	Chakravorty *et al.,* 2011; BartoLozzi *et al.,* 2016
Polyphylla sp.			Chakravorty *et al.,* 2011; Ahmed, 2023
Catharsius sp.	*Scarabaeidae*	Adult stages	Chakravorty *et al.,* 2011; Abdel-Dayem *et al.,* 2020
Allomyrina dichotoma			Chakravorty *et al.,* 2011; Ayaad *et al.,* 2015

Table 6. Edible Diptera insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Chaoborus	*Chaoboridae*	Larval stages	Chen *et al.,* 2009; Alharbi, 2019
Musca domestica	*Muscidae*		

Table 7. Edible Isoptera insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Macrotermes annandalei	*Termitidae*	Adult stages	Chen *et al.,* 2009; Alajmi *et al.,* 2019
Macrotermes barneyi	*Termitidae*		
Macrotermes acrocephalus	*Termitidae*		
Odontotermes formosanus	*Termitidae*		
Odontotermes yunnanensis	*Termitidae*		
Coptotermes formosanus	*Rhinotermitidae*		

stearic acid being predominant (Amberg and Fogarassy, 2019; Almeida *et al.,* 2020; Dos Santos Aguilar, 2021; Franco *et al.,* 2021; Chain *et al.,* 2024). Chitin, a polysaccharide covering the insect exoskeleton, ranks among the most abundant biopolymers after cellulose. Its derivative, chitosan, has attracted significant attention due to its versatile applications (Hahn *et al.,* 2020). In line with the National Transformation Program 2020 and Vision 2030, ensuring food security is a pivotal objective. The Kingdom of Saudi Arabia has initiated strategies to address challenges such as resource scarcity and food shortages, aiming to strengthen food systems and enhance research and innovation capabilities. This vision emphasizes collaborative efforts to integrate insects into agricultural practices and food production, harnessing the Kingdom's natural resources. However, drawing generalizable conclusions about edible insects' nutritional value and health benefits remains challenging due to the wide variety of species and complex factors influencing their nutrient

Table 8. Edible Lepidoptera insect species found in Saudi Arabia

Scientific name	Family	Edible phase	References
Chinese caterpillar fungus	*Ophiocordycipitaceae*	Larval stages	Chen *et al.,* 2009; Al Yousef *et al.,* 2015
Chilo fuscidentalis	*Crambidae*	Larval stages	
Bombyx mori	*Bombycidae*	Larval stages	

content.

NUTRITIVE VALUE OF SOME EDIBLE INSECTS

Protein content

The Kingdom of Saudi Arabia, spanning 2,149,690 square kilometers and inhabited by 35,993,994 people (Fiaz *et al.,* 2018; Worldometers, 2022), harbors a substantial number of edible insects due to its climatic conditions. The protein content of these insects varies widely based on their types and developmental stages (Kouimská and Adámková, 2016), with an average protein content of around 56%. For instance, caterpillars, the larvae of moths and butterflies, contain approximately 50-60 grams of protein per 100 grams of insect body weight, the red palm weevil (*Rhynchophorus ferrugineus*)(Colioptera: Curculionidae), now present in more than 60 countries and expanding into the Middle East, contains 23-36 grams of protein per 100 grams of insect body weight, Orthopterans exhibit a protein content ranging from 41-91 grams, ants from 7-25 grams, and termites from 35-65 grams per 100 grams of insect body weight. Wax moths (*Galleria mellonella*) (Lepidopteran: Pyralidae) boast a protein content of 38.4% based on dry matter (Bednaová, 2013; Dunkel and Van Huis, 2024). Yellow mealworms (*Tenebrio molitor*) (Coleoptera: Tenebrionidae), have a protein percentage of 50.7%, whereas African migratory locusts (*Locusta migratoria*) (Orthoptera: Acrididae) contain 62.2% protein (Bogusz *et al.,* 2024). Edible insects also contain several nutritionally valuable amino acids, particularly phenylalanine and tyrosine, which significantly contribute to their nutritional value (Kouřimská and Adámková, 2016; García-Vaquero and García, 2024). Furthermore, certain insects are rich in lysine, tryptophan, and threonine, along with other amino acids lacking in certain cereal proteins. For example, *Rhynchophorus* beetle larvae are renowned for their high lysine content (Promwee, 2023). Silkworm pupae have 100g of amino acids per 100g dry weight, while *Omphisa fuscidentalis* (Lepidoptera: Crambidae), a bamboo caterpillar, has the highest amino acid content among tested insects at 83g per 100g dry weight. House crickets (*Acheta domesticus*), and leaf crickets (*Tettigoniidae*), (from order Orthoptera) follow with 68.7g and 77.5g per 100g dry weight, respectively (Yeruva *et al.,* 2023). However, comparing nitrogenous substances measured in the exoskeleton with actual protein content may be challenging because some nitrogen is bound in the exoskeleton of insects (Klunder *et al.,* 2012; Zou *et al.,* 2023).

Lipid content

The fat content of edible insects varies widely from 10% to 60% of dry matter, with higher levels typically observed during the larval stage compared to the adult stage (Xiaoming *et al.,* 2010; Siddiqui *et al.,* 2024). This variability in lipid content is significant and depends on factors such as the type of lipid and various environmental influences (Kouřimská and Adámková, 2016). Certain insects, including caterpillars, palm weevil grubs (*Rhynchophorus* spec.), and termites (Isoptera), have been found to contain higher fat content compared to others (Conway *et al.,* 2024). For instance, caterpillars' fat content (Lepidoptera), ranges from 8.6 grams to 15.2 grams per 100 grams of insect body weight, while grasshoppers and related Orthoptera species exhibit lower fat content, ranging from 3.8 grams to 5.3 grams per 100 grams of insect body weight (Tzompa-Sosa *et al.,* 2014; Kouřimská and Adámková, 2016). Approximately 80% of the fat in insect bodies comprises triacylglycerols, serving as an energy reserve, especially during periods of high energy demand, such as prolonged flights (Ekpo *et al.,* 2009; Cheng *et al.,* 2024). Phospholipids, another important group of lipids, are responsible for cell membrane structure (Tzompa-Sosa *et al.,* 2014). Insect fat generally contains a small amount of phospholipids, usually less than 20%, depending on the life stage and species of the insect (Ekpo *et al.,* 2009; Tzompa-Sosa *et al.,* 2014; Hossain *et al.,* 2023). Insect fat is characterized by relatively high levels of C18 fatty acids, including oleic, linoleic, and linolenic acids, as well as palmitic acid in relative abundance (Tzompa-Sosa *et al.,* 2014; Kolobe *et al.,* 2023). Some insects, such as the termite *Macrotermes bellicosus* (Isoptera: Termitidae), and the caterpillar *Imbrasia* belina (Lepedoptera: Saturniidae), contain an average of over 3.6% cholesterol in their lipid fraction, making it the most abundant sterol found in insects (Ekpo *et al.,* 2009; García-Vaquero and García, 2024). Various sterols like campesterol, stigmasterol, and β-sitosterol may also be present in edible insects (Sabolová *et al.,* 2016; Mudalungu *et al.,* 2023). Notably, the oil extracted from *Rhynchophorus phoenicis* (Coleoptera: Curculionidae) is recognized for its high levels of unsaturated components, making it suitable for use as edible oil (Onzikou *et al.,* 2010; Promwee *et al.,* 2023). Consumption of silkworm caterpillars (*Bombyx mori*) (Lepedoptera: Bombycidae), can meet daily requirements for copper, zinc, iron, thiamine, and riboflavin in humans, effectively addressing riboflavin deficiencies (Hăbeanu *et al.,* 2023; Chen *et al.,* 2024).

Carbohydrates

Carbohydrates serve as essential nutrients in the human body, fulfilling various functions such as being the primary source of heat, reducing the need for protein consumption, aiding in detoxification, and acting as fundamental building blocks. In the context of edible insects, chitin, predominantly found in their exoskeleton, is the main carbohydrate source (Van Huis *et al.,* 2013; Dunkel and Van Huis, 2024). The carbohydrate content in edible insects demonstrates significant variability, ranging from 2.7 mg to 49.8 mg per kg of fresh matter (Kouřimská and Adámková, 2016; Siddiqui *et al.,* 2024). Research indicates substantial amounts of polysaccharides in insects, suggesting their potential to enhance immune function (Gericke *et al.,* 2024). A study on seven different edible insect species for fiber content, a non-digestible type of carbohydrate, revealed that African migratory locusts (*Locusta migratoria*) (Orthoptera: Acrididae), had the highest fiber content, while Jamaican field crickets (*Gryllus assimilis*) (Orthoptera: Gryllidae), had the lowest (Bednářová *et al.,* 2013; Dunkel and Van Huis, 2024). For instance, dried caterpillars contain 16.9 grams of carbohydrates per 100 grams, providing an energy value of 430 kcal (Xiaoming *et al.,* 2010). Chitin, comprising over 90% of insect skin, varies in content among different edible insect forms, with species such as *Bombyx mori* dried pupa, de-fatted pupa, *Dendrolimus houi* pupa (Lepidoptera: Lasiocampidae), and adult exhibiting varying levels (Zhang et al., 2024). Certain species, like *Oryctes monoceros* (Coleoptera: Scarabaeidae) and *Gryllotalpa Africana* (Orthoptera: Gryllotalpidae), have been noted for their high carbohydrate levels (Kouřimská and Adámková, 2016). Notably, some Macrotermes species have higher carbohydrate content, such as *Macrotermes falciger* (Blattodea: Termitidae) (32.8% ± 0.7), while others, like *Gonimbrasia belina* (Lepidoptera: Saturniidae), have lower carbohydrate content (7.8% ± 0.5) (Siulapwa *et al.,* 2014). Banjo *et al.* (2006) reported carbohydrate content for the termite *Macrotermes bellicosus* and *Macrotermes notalensis* (Blattodea: Termitidae) were (43.3%) (42.8%), respectively.

Nucleic acids

In examining the nutritional composition of insects, this overview overlooks specific details concerning nucleic acids. Nevertheless, some authors have explored the presence of nucleic acids in insect excreta (Hoyt and Osborne, 1970). Previous studies have reported purines such as xanthine and hypoxanthine (Nelson, 1958). Notably, mealworms (*Tenebrio molitor*) (Coleoptera: Tenebrionidae), super worms (*Zophobas atratus*) (Colioptera: Tenebrionidae), and crickets (*Gryllus assimilis*) (Orthoptera: Gryllidae), exhibited significantly higher purine content ($P < 0.05$) compared to egg white (Bednářová *et al.,* 2014; Finke and Oonincx, 2024). A recent investigation by Sabolová *et al.* (2023) revealed notable purine and uric acid content variations among stored edible insects. Guanine and xanthine were identified as the primary purines across all samples, with their proportions significantly exceeding those found in meat samples from poultry and livestock (Patil *et al.,* 2023). Additionally, uric acid contents varied significantly between aquatic insects and terrestrial insects, such as silkworm pupa (*Bombyx mori*) (Wang *et al.,* 2023). In comparison to meat, edible insects demonstrated comparable or higher levels of total purine (ranging from 3.23 to 13.22 g/kg of edible insect dry matter vs 3.61 to 5.53 g/kg of meat dry matter) and uricogenic purines adenine + hypoxanthine (ranging from 1.55 to 8.86 g/kg of edible insect dry matter vs 2.97 to 4.91 g/kg of meat dry matter) (Sabolová *et al.,* 2023). While the developmental stage and species significantly influenced the uric acid content, the total purine content remained consistent across stages (Sabolová *et al.,* 2023).

Minerals and vitamin content

Certain species of edible insects are rich in minerals such as potassium (K), sodium (Na), calcium (Ca), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), and phosphorus (P), as well as various vitamins including B group vitamins, A, D, E, K, and C (Kouřimská and Adámková, 2016; Siddiqui *et al.,* 2023). For instance, dung beetle *Oryctes* sp. (Coleoptera: Scarabaeidae) grubs, palm weevil grubs, and adult house crickets are documented with high calcium contents ranging from 61.3g/100g to 76g/100g dry weight (Banjo *et al.,* 2006; Onzikou *et al.,* 2010; Glazer *et al.,* 2023). Iron levels ranging from 27-29g/100g and 35.5g/100g dry weight have been observed in termites and caterpillars, respectively (Banjo *et al.,* 2006; Mabelebele *et al.,* 2023). Similarly, grasshoppers and the giant water bug *Lethocerus indicus* (Hemiptera: Belostomatidae) display maximum phosphorus contents of 226-238g/100g (Feng *et al.,* 2000; Singh *et al.,* 2023). High magnesium content (7.54-8.21g/100g) has been identified in grasshoppers and weevils (Banjo *et al.,* 2006; Ivanišová *et al.,* 2023). Eggs, larvae, and pupae of honeybees contain substantial amounts of vitamins A, B2, and C, with values of 12.44mg/100g, 3.24mg/100g, and 10.25mg/100g respectively (Dolganyuk *et al.,* 2023). Caloric intake from insects can reach up to 776.9kcal/100g, often surpassing those from soybean, maize, and beef (Dolganyuk *et al.,* 2023). Recent studies, such as those involving wheat buns enriched with the termite *Macrotermes subhyalinus* (Isoptera: Termitidae), have demonstrated superior attributes (e.g., size, color, texture, aroma) and higher nutritional contents, including riboflavin, niacin, folic acid, calcium, iron, and zinc, compared to ordinary bread (Kinyuru *et al.,* 2009; Siddiqui *et al.,* 2023).

Animals and humans' consumption of edible insects may indirectly contribute to reducing pesticide use. However, limited studies examine the sustainability of these insects as food sources, necessitating further investigation, especially in Saudi Arabia. Hygienically, it should be noted that certain insects may produce or contain toxic bioactive compounds, residues of pesticides, and heavy metals. Potential adverse human allergic reactions to edible insects pose a hazard. Therefore, a comprehensive assessment of numerous insect species is essential to ascertain their viability, particularly in Saudi Arabia. Generally, expanding the utilization of edible insects requires collaborative efforts between the public and private sectors, universities, the establishment of large insect breeding laboratories, thorough research on species in the Kingdom of Saudi Arabia, and decisive actions to integrate them into diverse food manufacturing processes to align with Vision 2030.

Conclusion

With the global population projected to reach 9 billion by 2050, addressing imminent food security challenges is crucial, especially for low-income nations facing climate change and population growth impacts. Bridging the gap between high- and low-income countries necessitates comprehensive socioeconomic advancements and improved food accessibility. In response, insect farming emerges as a sustainable solution, with the European Union leading regulatory reforms. Edible insects rich in protein, beneficial fats, and essential amino acids offer a promising remedy for malnutrition. Their versatility extends to insect-based products like powders and oils, diversifying food sources. The presence of different orders of edible insects in the Kingdom of Saudi Arabia and previous research on their nutritional contents supports reconsidering including these species within national transformation programs to ensure food continuity through safe food sources. Challenges persist, including the need for thorough studies on insect nutrition, toxic compounds, and allergens. Collaboration across sectors and robust research initiatives are vital for fully harnessing the potential of edible insects in diverse food processes. Embracing insect-based solutions represents a bold stride towards a more resilient and secure global food future amidst sustainability challenges.

Conflict of interest

The author declare that she has no conflict of interest.

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