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Edible insects as an alternative protein source: Nutritional composition and global consumption patterns

Tonna Ashim Anyasi [a,c,*], Parag Acharya [a,c], Chibuike C. Udenigwe [b]

[a] Food and Markets Department, Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent ME4 4TB, UK
[b] School of Nutrition Sciences, Faculty of Health Sciences, University of Ottawa, Ottawa ON K1H 8M5, Canada
[c] Medway Food Innovation Centre, Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent ME4 4TB, UK

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ABSTRACT

Insects are emerging as a viable alternative protein source due to shifting global consumption patterns and environmental concerns associated with meat production. Despite their nutritional benefits, insects from the orders Coleoptera, Hemiptera, and Lepidoptera are yet to be widely accepted as dietary ingredients globally. This review examines regions of the world where insects are traditionally consumed and the current trends in global consumption patterns. It presents the complex and essential nutrients inherent in the different edible insect orders, potential insect-derived products, their role in ensuring food security as well as food safety concerns. Historically, tropical and some temperate regions of Asia, Africa, North America (including Mexico), South America, and Oceania have incorporated insects into their diets. Edible insects are rich in complex and essential nutrients, including chitin, high quality amino acids, vitamins, minerals, fatty acids, phenolic compounds and flavonoids. Chitin, a dietary fibre in edible insects, offers antimicrobial, cholesterol-lowering properties and serves as an excipient in medicinal compounds. However, the varying amino acid profile of different insect species pose challenges in meeting the human dietary requirements. Nonetheless, innovative insect-derived food products such as meat substitutes and composite baked products are gaining acceptance, thereby positioning edible insects as a sustainable alternative protein source in diets.

1. Introduction

Insects can be described as the most varied clusters of multicellular organisms accounting for >70 % of all living species on earth (Scaraffia and Miesfeld, 2012; Raheem et al., 2019). Insects are members of the phylum Arthropoda, subphylum Hexapoda, and they are known to be the largest group of Arthropods on earth (Bullard et al., 2002; Giribet and Edgecombe, 2019). In addition, they are recorded to have the fastest evolutionary trend among other groups (Gaunt and Miles, 2002; Garambois et al., 2024), drifting into almost every ecological niche excluding the benthic region (Kelemu et al., 2015; Eggleton, 2020). For about 400 million years, there has been recorded existence of insects in the planet resulting in insects becoming one of the earliest land animals (Misof et al., 2014; Eggleton, 2020). The number of living insect species are known to be in the range of 2.5–10 million, with a length of <1 mm – 20 cm as well as features that led to their diversity and continuous existence including their short life cycle, and ability to colonise new ecological zones (Raheem et al., 2019; Eggleton, 2020). Factors that contribute to its growth include nutrition, temperature, population density (which influences its size), fertility and lifespan (Mirth and Riddiford, 2007; Koyama and Mirth, 2018; Hawkey et al., 2021). Based on their developmental pattern, insects can be divided into holometabolous having complete metamorphosis; hemimetabolous having incomplete metamorphosis; and ametabolous described as wingless insects (Eggleton, 2020; Hawkey et al., 2021).

In recent years, the use of edible insects as a sustainable source of nutrients has shown some degree of progress due to increased consumer acceptance and regulatory advances by some countries (Liceaga, 2022; Bhattarai et al., 2024; Devi et al.; 2024). There is a growing trend in the interest and consumption patterns of edible insects in Western countries where they had previously received low interest. Edible insects are now present in the US, Canada and Europe, apart from the efforts to ensure their continuous production in many developing countries (Vantomme et al., 2014; Liceaga, 2022). As a result, thousands of insect species are consumed by a sizeable percentage of the human population around the world (Raheem et al., 2019; Omuse et al., 2024). Jongema (2012)

* Corresponding author.
E-mail address: T.A.Anyasi@greenwich.ac.uk (T.A. Anyasi).

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reported that Wageningen University's Laboratory of Entomology's record of insects across the globe registered 2163 species described in the literature as being consumed by humans. Accordingly, several orders of insects are mostly consumed in diets for humans worldwide (Fig. 1). These include Blattodea, Coleoptera, Diptera, Ephemeroptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, Megaloptera, Odonota and Orthoptera (Tanga and Ekesi, 2024). Among the listed orders, the three most consumed by humans are Coleoptera (26 families and 661 species), Hemiptera (27 families and 222 species) and Lepidoptera (36 families and 396 species), while, on a family level, Scarabaeidae (247 species), Cerambycidae (129 species), and Dytiscidae (55 species) from Coleoptera, Saturniidae (109 species), Hepialidae (47 species), and Sphingidae (36 species) from Lepidoptera, and Cicadidae (70 species), Pentatomidae (31 species), and Belostomatidae (17 species) from Hemiptera.

Edible insects contain important nutrients including proteins, fatty acids, and essential micronutrients (minerals and vitamins) which compares favourably to nutrients obtained from plants and animals (Oonincx and Finke, 2021; van Huis et al., 2021; Oliveira et al., 2024; Tanga and Ekesi, 2024). Apart from their nutritional value, insects affect the environment positively because of their role in waste biodegradation and as pollinators of plants. Furthermore, rearing edible insects is known to be less expensive than conventional livestock rearing; beside emittance of less greenhouse gases, insect farming requires less land and water (Nowak et al., 2016; Liceaga, 2022; Lange and Nakamura, 2023). Edible insects are commonly obtained by farming in commercial facilities or laboratories, as by-products of an industrial activity, or directly from their natural habitat. In their utilization as feed, production of edible insects ensures mitigation of environmental pollution and the conversion of waste products into high-nutrient feed that can serve as an alternative to the costly animal feed ingredients (Payne et al., 2016; van Huis et al., 2021).

Considered mostly as pests and nuisance to plant and animal health, edible insects are known to contribute greatly to food security (Dzerefos and Witkowski, 2014; Bulak et al., 2020; Wantulla et al., 2023) and compares favourably to conventional meat in terms of nutritional content. Premalatha et al. (2011) opined that it is an irony that yearly, billions are spent globally to rescue crops that supplies <14 % plant proteins while destroying insects, which are more valuable in terms of their protein composition (Belluco et al., 2013). Raheem et al. (2019) showed that edible insects are consumed not only for their nutritional value, but also for their characteristic flavour. However, this contradicts the consumption patterns of some urban and Western societies, which view edible insect consumption as repulsive (Reed et al., 2021; Liceaga et al., 2022). This review therefore explores regions of the world where edible insects are traditionally consumed, the edible insect orders consumed in these regions and the current trends in global consumption patterns. The review describes the essential nutrients inherent in the different edible insect orders, the potential insect-derived products, their role in ensuring food security as well as food safety concerns arising from insect consumption. Insights from this work will contribute to current shift in the existing consumption patterns, cultural norms, acceptability and perceptions regarding edible insects as food, as well as further promote their application in food products.

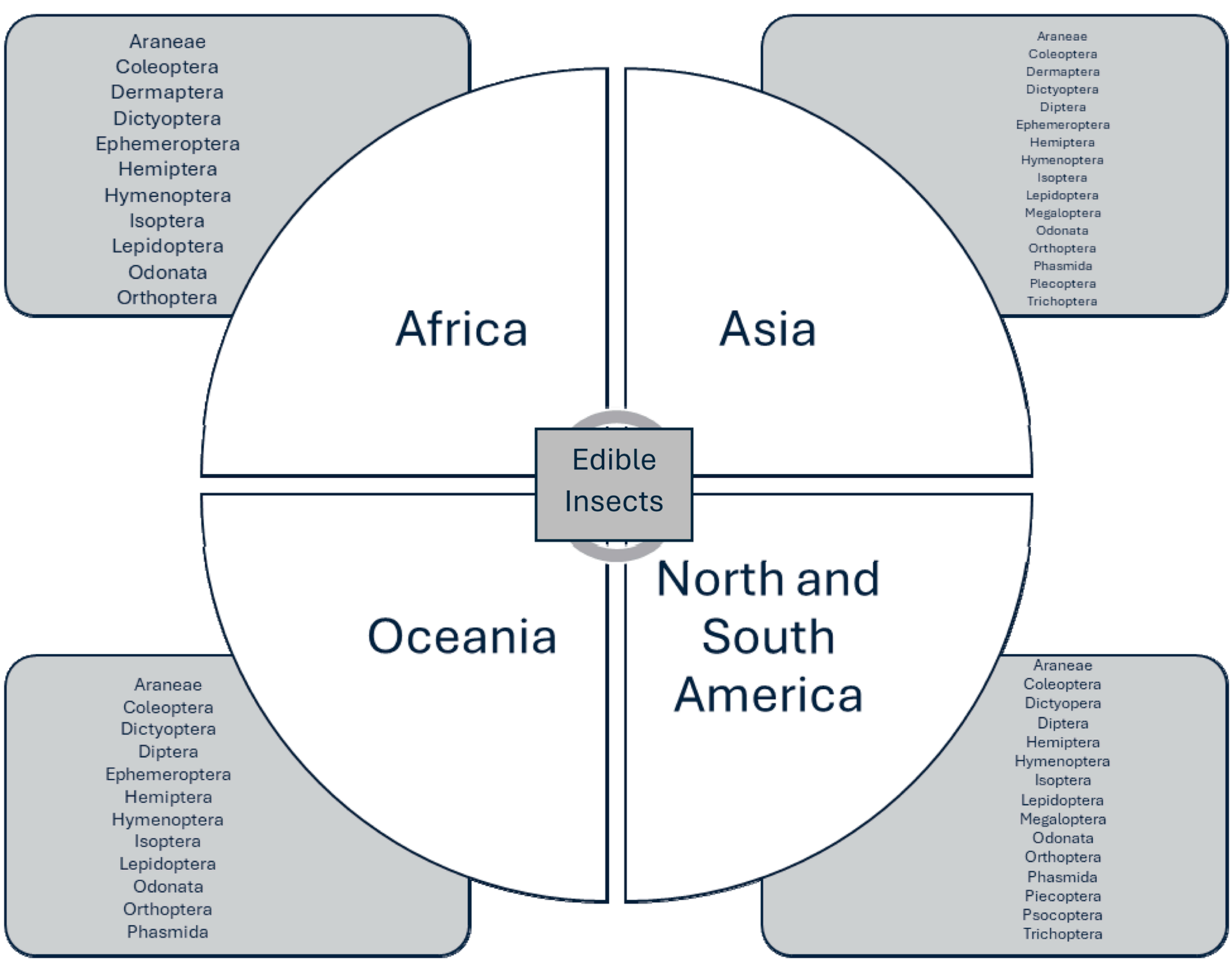

Fig. 1. Edible insect orders consumed in different regions of the globe. Information source: Raheem et al. (2019); Omuse et al. (2024).

2. Insects as food

The Codex Alimentarius Commission defined food as "any substance, whether processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance which has been used in the manufacture, preparation or treatment of 'food' but does not include cosmetics or tobacco or substances used only as drugs" (FAO and WHO, 2025). This implies that safety is a priority when classifying a substance as food, however, not all insects can be consumed as food (Rumpold and Schluter, 2013a,b). While reservations exist in some regions of the world in classifying insects as food, insects are now seen as a potential alternative protein source especially with their ease in rearing and sustainability (Belluco et al., 2018). Even though insects are finding applications as food with an increasing global acceptance, this is not fully evident in the West where attitude towards food is mostly characterised by refusal due to psychological rather than logical perspective (Belluco et al., 2013). Conversely, there is extensive acceptance and experience of insect consumption in Africa, Asia and South America (Belluco et al., 2018; Tang et al., 2019; Abril et al., 2022; Granados-Echegoyen et al., 2024). Current insect application includes meals and food products for human consumption and health promotion, food for insectivores, and its use as feed for animals.

Generally, insects undergo metamorphosis at different stages of their growth, but some can be harvested for food at different developmental stages (Payne et al., 2016; Tanga and Ekesi, 2024). Tanga and Ekesi (2024) showed that about 1600 – 2300 species of insects, at different developmental stages, are consumed as local delicacies across Africa, Australia, Americas and Asia. These edible insects form an important aspect of the nutrient requirements apart from the added economic benefits they provide to the society (Hawkey et al., 2021). Edible insects contain a large amount of high quality and digestible proteins (7 – 91 % d.w.) when compared to several plant proteins (Ramos-Elorduy et al., 1997; van Huis, 2016; Akhtar and Isman, 2018; Loveday, 2019; Tanga and Ekesi, 2024), fat, vitamins, minerals and bioactive compounds including flavonoids (Hawkey et al., 2021; Mishyna and Glumac, 2021; Tanga and Ekesi, 2024). Thus, they can serve as a protein source in populations that do not consume meat protein sources such as beef, pork and poultry products (Yhoung-Aree et al., 1995). Similarly, edible insects are reported to contain different fatty acid profiles including the polyunsaturated fatty acids such as alpha-linolenic acid and eicosapentaenoic acid (Yang et al., 2006; Hawkey et al., 2021). The proximate composition of edible insects is affected by factors such as gender (Sönmez and Gülel, 2008), developmental stage (McClements et al., 2003), food source (Ramos-Elorduy et al., 2002; Oonincx and van der Poel, 2011), rearing temperature (Sönmez and Gülel, 2008), daylight duration (Shearer and Jones, 1996; Koc and Gulel, 2008) and humidity (Han et al., 2008; Ali et al., 2011; Nedvěd and Kalushkov, 2012). Other variables that could affect the chemical composition of edible insects include light intensity, spectra composition, assessment methods and modes of processing (Rumpold and Schluter, 2013a; Finke and Oonincx, 2014; Kourimská and Adámková, 2016).

Consumption of insects is hinged on two basic factors: efficiency and biodiversity. Vogel (2010) stated that cattle consume 8 g of food/g of weight gain when compared to insects that consume 2 g. A major reason attributed for this difference is the poikilothermic nature of insects which makes them use less energy for regulating their body temperature (Premalatha et al., 2011). Furthermore, the productiveness, high adaptability, rapid growth rate and short lifespan of insects add to their efficiency and potential as a major source of human diet and food products (Shockley and Dossey, 2014). In terms of biodiversity, over 2000 edible insects are currently in use (Ramos-Elorduy, 2009; Vogel, 2010; Jongema, 2012; Tanga and Ekesi, 2024), and between 4–30 million insect species are found in places occupied by humans (Dossey, 2010). Due to this diversity, insects have the potential to be a leading contributor to food security in the future when compared to other vertebrates (Shockley and Dossey, 2014). Tuma et al. (2020) and Eggleton (2020) observed that the total biomass of insects is approximately 200 Mt of carbon, which is way less than that of plants, described to be a thousand times more (Bar-On et al., 2018).

3. Global consumption patterns of edible insects

Globally, over 2100 edible insects have been identified in various regions of Asia, Africa, Oceania, North, and South America (Feng et al., 2018; Kipkoech et al., 2023). Asia accounts for over 900 insect species, the highest among all continents, followed by North America (529), Africa (464), South America (300) and Oceania (107) (Fasogbon, 2020; Omuse et al., 2024). Approximately 30 % of the world's population, across over 113 countries, include edible insects in their diets, with Africa, Asia, and Latin America (Table 1) having a documented history of consumption (van Huis et al., 2013; Tao and Li, 2018; Omuse et al., 2024). Edible insects are consumed in 48 countries in Africa where the DRC, Cameroon, and Zambia lead in its consumption. In Asia, edible insects are consumed in about 52 countries and Thailand, India, and China are countries leading in its consumption (Omuse et al., 2024). Furthermore, edible insects are consumed in approximately 15 countries in South America and Brazil, Ecuador, and Colombia lead in its consumption. In Oceania, Australia, Papua New Guinea, New Zealand, New Caledonia, and the Solomon Islands are countries where edible insects are consumed (Omuse et al., 2024).

Insects such as ants, beetles, bees, caterpillars, cicadas, crickets, grasshoppers, plant hoppers, locusts, true bugs, and termites are eaten with over 1000 insect species consumed at different developmental stages as traditional foods worldwide (Raheem et al., 2019). However, the size and number of edible insects in tropical and temperate regions affect consumption patterns. In the tropics, insects gather in large numbers and can be harvested in significant proportions, whereas in temperate zones, insects hibernate during cold winters, stalling their growth and development (Raheem et al., 2019). In Africa, each country has unique entomophagy practices that vary across regions. Ramos-Elorduy (2005) noted that Africa is one of the world's most important hotspots of edible insect biodiversity with 524 species reported from 34 African countries. About 22 insect species, including moths, beetles, grasshoppers, crickets, termites, and bees, are consumed in Nigeria, while nine edible insects, such as palm weevil larvae, termites, crickets, and grasshoppers, are mostly consumed in Ghana (Anankware et al., 2016; Raheem et al., 2019). Approximately 87 % of people in Southern Cameroon consume grasshoppers as food (Ngoute et al., 2021; van Huis, 2022) while the mopane worm is highly consumed in Southern Africa, with about 9.5 billion mopane caterpillars harvested annually (Raheem et al., 2019).

In Asia, edible insects are consumed, with some used as health food in China. Approximately 324 insect species in China are used as food and feed, with about 20 species, including bees, beetles, bamboo caterpillars, crickets, dragonflies, silkworms, and wasps, regularly consumed (Feng et al., 2018; Zhu and Begho, 2022). Although grasshoppers are the most consumed edible insect in Japan, entomophagy is generally declining (Raheem et al., 2019). Thailand consumes over 194 edible insect species, including beetles, crickets, grasshoppers, bees, wasps, leafhoppers, and planthoppers (Raheem et al., 2019). However, urban migration and a shift to a more Westernized diet have led to a decline in insect consumption in Asia (Van Huis, 2013; Raheem et al., 2019). In Europe, the consumption of insects remain largely unexplored and not widely accepted, although Belgium imports about three tonnes of mopane worms annually (Caparros Megido et al., 2016; Raheem et al., 2019). Factors such as habitat, climatic conditions, and fauna influence the biogeographical distribution of edible insects globally (Govorushko, 2019).

3.1. Consumption frequency of edible insects

Edible insects are integrated into diets in diverse ways across the

Table 1
Edible insect distribution across different regions of the world.

Continent	Region	Country	Insect order	Edible insect species
Europe	Europe general		Orthoptera Acrididae	*Locusta viridissima*
			Blattaria Blattellide	*Ectobios lapponicus*
			Coleoptera Meloidae	*Lytta vesicatoria*
			Hymenoptera Formicidae	*Formica major, F. minor*
	South Europe		Orthoptera Acrididae	*Gryllus aegyptius, G. lineola, G. locust, G. tataricus*
	Lapland		Hemitera-Homoptera Psyllidae	*Chermes* sp.
North America	North America General		Coleoptera Bruchidae	*Algarobius* spp., *Mimosestes* spp
West indies			Orthoptera Acrididae	*Oedipoda corallipes, Xanthipus corallipes zapotecus*
			Coleopter Cerambycide	*Macrodontia cervicornis, Stenodontes damicornis*
			Curculioide	*Rhynchophorus palmarum*
			Orthoptera Acrididae	*Oedipoda corallipes*
South America	South America General		Isoptera Termitidae	*Termes arborum*
	Amazonia		Isoptera Termitidae	*Termes flavicole*
			Anoplura Pediculidae	*Pediculus humanus*
			Coleoptera Bruchidae	*Caryoborus serripes*
				Pachymerus cardo
			Chrysomelidae	*Speciomerus giganteus*
			Curculionidae	*Rhynchophorus cruentatus*
				R. palmarum
			Dynastidae	*Dynastes hercules*
				Megaceras sp
				Megasoma actaeon
			Hymenoptera formicidae	*Atta cephalotes*
			Polybiidae	*Polybia* spp.
		Bolivia-Brazil	Hymenoptera Apidae	*Trigona jati*
		Bolivia/Peru/Brazil/Colombia	Coleoptera Curculionidae	*Rhynchophorus palmarum*
			Isoptera Termitidae	*Nasutitermes corniger*
			Coleoptera Curculionidae	*Rhynchophorus palmarum*
		Brazil/Colombia	Hymenoptera Formicidae	*Atta sexdens*
			Anopluran Pediculidae	*Pediculus humanus*
		Brazil/Guyana	Coleoptera Curculionidae	*Rhynchophorus palmarum*
		Brazil/Venezuela	Diptera Simuliidae	*Simulium rubithorax*
			Hymenoptera Formicidae	*Atta sexdens*
		Colombia/Peru	Coleoptera Curculionidae	*Rhynchophorus palmarum*
		Colombia/Venezuela	Coleoptera Curculionidae	*Anthonomus* spp., *Rhynchophorus palmarum*
			Dynastidae	*Podischnus agenor*
			Lariidae	*Caryobruchus scheelaea*
			Neuroptera Corydalidae	*Corydalus* spp.
			Trichopteran Hydropsychidae	*Leptnema* spp.
			Hymenoptera Polybiidae	*Polybia ignobilis*
			Polistidae	*Mischocyttarus* spp.
Africa	Africa General		Orthoptera Acrididae	*Acorypha clara*
				Caloptenopsis nigrovariegata
				Eyprepocnemis plorans
				Gastrimargus determinatus
				Heteracris coerulescens
				Pycnodictya flavipes
			Catantopidae	*Catantops melanostichus*
				Diabolocantatops axillaris
				Exoporpacris modica
				Oxycantatops congoensis
				Parapropacris notate
				Phaeocantatops decorates
			Gryllacrididae	*Gryllacris africana*
			Gryllidae	*Acheta smeathmanni*
				Gymnogryllus leucostictus
			Hemiacrididae	*Acanthoxia gladiator*
				Hieroglyphus daganensis
				Mazaea granulosa
			Tettigoniidae	*Anabrus simplex*
				Anoedopoda erosa
				Conocephalus spp.
				Pseudorhynchus lanceolatus
			Isoptera termitidae	*Cubitermes* spp.
				Termes smeathmanni
			Hodotermitidae	*Microhodotermes* spp.
			Mantodea Hymenopodidae	*Pseudoharpax virescens*
			Mantidae	*Epitenodera houyi*
				Mantis religiosa
				Miomantis paykullii
				Psedoharpax virescens
				Sphodromantis centralis
			Anoplura Pediculidae	*Pediculus humanus corporis*
			Hemiptera-Homoptera Cicadidae	*Andropogon gayanus*

Source: Mitsuhashi (2017).

globe. Anagonou et al. (2023) showed that edible insects including crickets, grasshoppers and termites, form a significant part of the local diet especially in rural parts of the Republic of Benin. These insects are typically consumed as snacks or side dishes, often roasted or fried, and sometimes incorporated into sauces served with staple foods like maize or cassava (Anagonou et al., 2023). Similarly, Matandirotya et al. (2022) and Akullo et al. (2025) reported that termites and grasshoppers are a popular delicacy in Uganda and can be consumed fried or roasted as snacks and as side dishes in Kenya. Mopane worms (larvae of emperor moth) are a popular food in Zimbabwe, Botswana, Mozambique, Angola and in rural parts of South Africa where they are often dried or cooked in tomato-based sauce (Hlongwane et al., 2021; Matandirotya, et al., 2022). Tang et al. (2019) stated that silkworm pupae are consumed as popular delicacies in China, Japan, Thailand and Vietnam. *Chapulines* as well as *Vinitos* seasoned with chili and onion are consumed as snacks or side dishes in Mexico (Granados-Echegoyen et al., 2024), while *Chicatanas* (ants) constitute part of traditional diets in Colombia and Brazil (Abril et al., 2022). Wilkinson et al. (2018) showed that witchetty grubs (*Endoxyla leucomochla*) are a traditional food source and delicacy for Aboriginal Australians where they are consumed with honey ants (*Myrmecocystus mexicanus*) and Bogong moths (*Agrotis infusa*) in a diet referred to as "bush tucker". While edible insect consumption is gaining interest in Canada, the United States, United Kingdom and other Western countries, it is not yet a staple in these countries. However, edible insects including crickets and mealworms are increasingly used as ingredients in various food products such as protein bars, snacks, pasta and burgers in Western countries (Vantomme et al., 2014; Liceaga, 2022).

4. Nutritional value of edible insects

As shown in Table 2, the edible parts of insects are reported to contain essential macro- and micronutrients, including proteins, carbohydrates, fatty acids, free amino acids, minerals and vitamins (Rumpold and Schlüter, 2013b; van Huis, 2013; Sun-Waterhouse et al., 2016, 2016; Nongonierma and FitzGerald, 2017). The caloric contents of edible insects are comparable to that of meat (fresh wt. basis) except for pork which is high in fat (Sirimungkararat et al., 2010). Edible insects can be used as a sustainable alternative food and feed source, especially when compared to fish and meat. This has been attributed to their low breeding space requirement and high feed conversion efficiency, aside their high rate of reproduction (Rumpold and Schluter, 2013b).

4.1. Edible insect carbohydrate

In edible insects, carbohydrates are reported to be present mostly as chitin in contrast to other carbohydrates, and at a concentration of 0.5 – 51.6 % (DM) (Ramos-Elorduy et al., 2002; Lorenz and Anand, 2004; Tanga and Ekesi, 2024). However, Ramos-Elorduy et al. (2002) reported a carbohydrate content of between 1 and 7 % in yellow mealworm larvae with the carbohydrate concentration in the insect largely dependent on the diet provided. Furthermore, Lorenz and Anand (2004) reported that the free carbohydrate content in fat body of female species of the field cricket (*Gryllus bimaculatus* De Geer) was 0.5 % (DM). In addition, 0.3 % carbohydrate content was also reported for the fresh weight of the field insect (Finke and Oonincx, 2014) while Tanga and Ekesi (2024) reported a carbohydrate content of between 5.0 – 51.6 % (DM) for seven insect orders. The presence of chitin in high concentrations ($\geq$ 10 %) equally makes edible insects a veritable source of fibre (van Huis et al., 2013; Hawkey et al., 2021). Edible insects contain substantial amounts of fibre, mostly in the exoskeleton and described as a combination of different compounds such as chitin, sclerotized proteins and chitin-bound compounds (Finke, 2007). Edible insect fibres are often taken to be synonymous with chitin which is structurally like cellulose; they both do not have a direct nutritional value in humans (Finke and Oonincx, 2014). However, fibres present in edible insects can act as replacement for plant carbohydrates, thus potentially bringing about a reduction in glycaemic load (Belluco et al., 2013). Chitin, a linear polymer of β-(1,4)-linked 2-amino-2-deoxy-β-D-glucopyranose and 2-acetamido-2-deoxy-β-D-glucopyranose residues (EFSA Panel on Nutrition et al., 2021a), is predominantly present in the exoskeleton of invertebrates, algae, fungi and protozoa. Caloric value of chitin varies and is dependent on the insect type. However, Finke (2007) showed that the chitin content varies from 2.7 – 49.8 mg/kg (FW) and 11.6 −137.2 mg/kg (DM) in seven different insect species. Total metabolism of the estimated values of insects cannot be done by humans especially as the calories brought about by chitin oxidation are not totally released for utilization in humans. Chitin is reported to occur in the insect cuticle in association with proteins, lipids, minerals and other components (Kramer et al., 1995). As a food ingredient, the amount of chitin is limited because it is present only in the insect exocuticle (Finke and Oonincx, 2014).

Although chitin and its metabolites have been shown to possess antioxidant, anticancer and anti-inflammatory properties (Park and Kim, 2010), its antinutritional activities through its affinity to various macromolecules limits their accessibility for digestion in the gut (Hawkey et al., 2021). However, chitin can be partially digested due to the presence of acidic mammalian chitinase and chitotriosidase catalytic chitinases (Belluco et al., 2013; EFSA Panel on Nutrition et al., 2021a). It has further been observed that the limited expression of chitinase genes leading to loss of catalytic efficiency in some parts of the globe is due to low chitin intake in western diets (EFSA Panel on Nutrition et al., 2021a).

4.2. Edible insect proteins

As the search for meat protein replacement continues, edible insects are very much investigated as possible entrants (Vogel, 2010; Belluco et al., 2013). Annual red meat consumption in countries such as The Netherlands in Europe has been estimated to be around 39.2 kg per capita while that of the United States is placed at 48 kg (excluding bones) per capita. The increased prevalence of some communicable diseases has been associated with the consumption of animal-derived proteins such as meat products (Belluco et al., 2013). Thus, due to the high level of meat consumption in Europe, nutritional guidelines have been developed to bring about a decrease and partial substitution of proteins from meat origin with those from other sources such as pulses, grains and fish (Gerbens-Leenes et al., 2010; Aiking, 2011; Belluco et al., 2013). Though fish serves as a good alternative for substitution of meat protein as it imparts great health benefits due to its n-3 polyunsaturated fatty acid composition, fish however serves as a means of exposure of methylmercury, a neurotoxin to humans and pregnant women (Mahaffey et al., 2011; Belluco et al., 2013). Other sources of proteins include meat free dishes such as eggs, cheese and dairy products (de Boer and Aiking, 2011). Rahman et al. (2024) showed that insects possess higher protein per gramme compared to animal sources: 63 % cricket powder compared to 25.6 % beef, 26.3 % milk powder and 39 % chicken. Variations in the protein content of different edible insects has been attributed to the stage of insect development and specie type (Rumpold and Schlüter, 2013a; van Huis, 2016; Akhtar and Isman, 2018). Aside being a good source of protein, it was observed that the protein present in crickets were found to be equal or of higher quality to that of soybean when administered to newly weaned rats at all levels of intake (Rumpold and Schlüter, 2013a,b). The high quality of insect proteins can be mainly attributed to their amino acid profile. As a matter of fact, the nutritional value of protein is determined by digestibility of protein fractions as well as amino acid composition.

The amino acids of dietary proteins are classified as dispensable (non-essential) or indispensable (essential). The essential amino acids, which includes histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine, cannot be synthesized

Table 2
Proximate composition (%) of raw and processed edible insects.

Order	Species	Common name	Stage of consumption	Mode of Processing	Moisture	Crude Protein	Crude Fat	Fiber	Ash
Lepidoptera	*Agrotis infusa*	Bogong moth	Larva	Roasting	49.2	52.7	39.0	5.3	NA
	Anaphe panda	African moth	Larva	Removal of intestinal contents and hair	73.9	45.6	35.0	6.5**	3.7
	Anaphe venata	African moth	Larva	Dried without hairs	6.6	60.0	23.2	3.2	NA
	Ascalapha odorata	Black witch moth	Larva	Whole raw	56.0	15.0	NA	12.0**	6.0
	Bombyx mori	Silkworm	Larva	Whole raw	82.7	53.8	8.1	6.4*	6.4
	Bombyx mori	Silkworm	Pupa	Whole raw, dried	18.9	60.0	37.1	NA	10.6
	Callasomia promethea	Silk moth	Larva	Whole raw, freeze dried	4.5	51.7	10.5	11.3**	7.2
	Catastica teutila	Pure banded dartwhite moth	Larva	Whole raw	60.0	19.0	NA	7.0**	7.0
	Chilecomadia moorei	Tebo worms	Larva	Whole raw	60.2	15.5	29.4	1.4	1.2
	Conimbrasia belina	Mopani worms	Larva	Dried, intestinal contents removed	62.0	16.0	NA	11.4**	7.6
	Galleria mellonella	Waxworm	Larva	Whole raw	58.5	34.0	60.0	8.1*	1.4
	Heliothis zea	Corn earworm	Larva	Whole raw	77.4	18.2	NA	NA	NA
	Hyalophora cecropia	Cecropia moth	Larva	Whole raw, freeze dried	2.6	56.2	10.5	15.1**	6.1
	Imbrasia epimethea	African moth larva	Larva	Smoked and dried	7.0	62.5	13.3	NA	4.0
	Imbrasia ertli	African moth larva	Larva	Boiled/roasted; dried and salted, viscera removed	9.0	52.9	12.2	NA	15.8
	Imbrasia truncate	African moth larva	Larva	Smoked and dried	7.3	64.7	16.4	NA	4.0
	Manduca sexta	Carolina sphynx moth	Larva	Whole raw, freeze dried	4.7	60.7	17.3	8.8*	8.5
	Nudaurelia oyemensis		Larva	Smoked and dried	7.0	61.1	12.2	NA	3.8
	Porthetria dispar	Gypsy moth	Adult with eggs	Whole raw	68.6	80.0	44.6	8.0	NA
	Pseudaletia unipuncta	Army worm	Larva	Whole raw, freeze dried	2.0	55.5	15.2	5.1**	7.0
	Spodoptera eridania	Fall army worm	Larva	Whole raw, freeze dried	4.5	57.3	14.6	7.4**	10.3
	Spodoptera frugiperda	Fall worm army	Larva	Whole raw, freeze dried	3.6	59.3	11.7	12.4**	11.6
	Usta terpischore	African moth	Larva	Boiled/roasted; dried and salted, viscera removed	9.2	48.6	9.5	NA	13.0
	Xyleutes redtenbacheri	Carpenter moths	Larva	Whole raw	43.0	48.0	NA	6.0**	2.0
	Hylesia frigida					42.0	10.0	NA	NA
	Arsenura armida	Giant silk moth				52.0	8.0		
	Phasus triangularis	Moth				15	77		
Coleoptera	*Callipogon barbatus*				41.0	34.0		23.0**	2.0
	Oileus rimator	Beetle	Whole raw	Larva	26.0	36.0		15.0**	3.0
	Passalus punctiger	Beetle	Whole raw	Larva	26.0	44.0		15.0**	3.0
	Rhyncophorus ferrugineus	Red palm weevil		Larva	70.5	20.7	44.4		
	Rhynocophorus palmarum	Red palm weevil	Whole raw	Larva	71.7	25.8	38.5		2.1
	Rhynophorun phoenicis	Red palm weevil	Frying, incised	Larva	10.8	22.8	46.8		2.7
	Scyphophorus acupunctatus	Agave weevil	Whole raw	Larva	36.0	52.0		6.0**	1.0
	Tenebrio molitor	Mealworm beetle	Whole raw	Adult	63.7	65.3	14.9	20.4*	3.3
	Tenebrio molitor	Mealworm beetle	Whole raw	Larva	61.9	49.1	35.0	6.6*	2.4
	Zophobas morio	Darkling beetle	Whole raw	Larva	57.9	46.8	42.0	6.3*	2.4
	Acheta domesticus	House cricket	Whole raw	Adult	69.2	66.6	22.1	10.2*	3.6
	Acheta domesticus	House cricket	Whole raw	Nymph	77.1	67.2	14.4	9.6*	4.8
	Blatella germanica	German cockroach	Whole raw	NS	71.2	78.8	20.0	NA	4.3
	Blatta lateralis	Turkestan cockroach	Whole raw	Nymphs	69.1	19	10	2.2	1.2
	Brachytrupes sp.	Cricket	Fresh, blanched. Inedible parts removed		73.3	47.9	21.3	13.5	9.4
	Crytacanthacris tatarica		Fresh, blanched. Inedible parts removed		76.7	61.4	14.2	17.2**	4.7
	Gryllotalpa africana	Mole cricket	Fresh, blanched. Inedible parts removed		71.2	53.5	21.9	9.7**	9.4
	Oxya verox		Whole raw, dried		29.8	64.2	2.4		3.4
	Oxya yezoensis		Whole raw		65.9	74.7	5.7		6.5
	Sphenarium histro	Grasshoppers	Whole raw	Nymphs and adults	77.0	4.0		12.0**	2.0
	Zonocerus sp.	Grasshoppers	Whole raw		62.7	71.8	10.2	6.4**	3.2
	Sphenarium purpurascens Ch	Grasshoppers	Whole raw		NA	75.9	6.02	7.1	4.8
	Taeniopodaques B	Horse lubber grasshopper			NA	71.1	5.9	10.6	9.6
	Melanoplus femurrubrum D	Red-legged grasshopper			NA	74.7	5.2	10.0	6.7
	Schistocerca	Bird grasshoppers				62.5	16.0	10.1	7.0
Isoptera	*Cortaritermes silvestri*	South American termites	Whole raw	Worker	77.8	48.6	6.9		8.5
	Macrotermes bellicosus	African termites	Raw, dewinged	Alate	6.0	34.8	46.1		10.2
	Macrotermes subhyalinus	African termites	Fried, dewinged	Alate	0.93	8.8	46.5		6.6

(continued on next page)

Table 2 (*continued*)

Order	Species	Common name	Stage of consumption	Mode of Processing	Moisture	Crude Protein	Crude Fat	Fiber	Ash
	Nasutitermes corniger	Central American tree termite	Whole raw	Soldier	69.6	58.0	11.2	34.8*	3.7
	Nasutitermes corniger	Central American tree termite	Whole raw	Worker	75.3	66.7	2.2	27.1*	4.6
	Procornitermes araujoi		Whole raw	Worker	78.1	33.9	16.1		3.5
	Syntermes ditus		Whole raw	Worker	79.7	43.2	3.4		17.1
Hymenoptera	*Apis mellifera*	European honeybee	Whole raw	Adult female	65.7	60.0	10.6		17.4
	Apis mellifera	European honeybee	Whole raw	Adult male	72.1	64.4	10.5		17.8
	Apis mellifera	European honeybee	Whole raw	Larva	76.8	40.5	20.3	1.3*	3.4
	Atta Mexicana	Leaf-cutter ant	Whole raw	Reproductive adult	46.0	39.0		11.0**	4.0
	Olecophylla smaragdina	Weaver ant	Fresh, blanched. Inedible parts removed		74.0	53.5	13.5	6.9**	6.5
	Oecophylla virescens	Green tree ant/ weaver ant	Inedible parts removed		78.32	41.0	26.7	NA	6.0
	Polybia sp.	Wasp	Whole raw	Adult	63.0	13.0		15.0**	6.0
	Trigon sp.		Whole raw		NA	28	41	NA	NA
	Parachartegus apicallis				NA	55	NA	NA	NA
	Brachygastra azteca	Paper wasp			NA	63	24	NA	NA
	Brachygastra melifica	Mexican honey wasp			NA	53	30	NA	NA
	Vespula squamosa	Southern yellow jacket			NA	63	22	NA	NA
	Polistes instabilis	Paper wasp			NA	31	62	NA	NA
Diptera	*Copestylum anna* and *Copestylum haggi*		Whole raw	Larva	37.0	31.0	NA	15.0**	8.0
	Drosophila melanogaster	Common fruit fly	Whole raw	Adult	67.1	56.3	17.9	NA	5.2
	Hermetia illucens	Black soldier fly	Dried, milled	Larva	3.8	47.0	32.6	6.7**	8.6
	Musca autumnalis	Face fly/autumn house fly	Dried, milled	Pupa	51.7	11.4	28.9	NA	NA
	Musca domestica	Common house fly	Dried, milled	Pupa	61.4	9.3	11.9	NA	NA
	Edessa petersii		Whole raw	Nymphs and adults	37.0	42.0	NA	18.0**	2.0
	Euchistus egglestoni		Whole raw	Nymphs and adults	35.0	45.0	NA	19.0**	1.0
	Pachilis gigas		Whole raw	Nymphs and adults	64.0	22.5	NA	7.5**	3.5
	Hoplophorion monograma	Treehopper	Whole raw	Nymphs and adults	64.0	14.0	NA	18.0**	3.0
	Umbonia reclinata		Whole raw	Nymphs and adults	29.0	33.0	NA	13.0**	11.0
	Callipogon barbutus				NA	41	34	NA	NA

*Acid detergent fiber; ** crude fiber; NA, not available; NS, not specified. Source: Bukkens (1997); Ramos-Elorduy et al. (1997); Finke (2007); Finke (2013); US Department of Agriculture (2015); Williams et al. (2016); Tanga and Ekesi (2024).

in humans from natural precursors in sufficient amounts that meet the basic metabolic needs (Belluco et al., 2013). Edible insects possess high concentrations of isoleucine, leucine, phenylalanine, tyrosine and glycine, and amino acids such as phenylalanine, threonine and aspartic acid were reported to be in higher amounts in edible insects when compared to other plant and animal protein sources (Akhtar and Isman, 2018). Majority of edible insects can thus be grouped as high-value protein sources due to their high essential amino acid contents (Belluco et al., 2013).

Proteins from edible insects are mostly digestible (77 – 98 %), although insects with varying concentration of exoskeleton due to their growth stage, could limit the digestibility of proteins because of the influence of chitin (Belluco et al., 2013; Soetemans et al., 2019). For example, Soetemans et al. (2019) showed that protein isolate from honey bees administered to weanling rats demonstrated higher digestibility of 94 % when compared to 71 % digestibility from the whole bee. Therefore, the removal of chitin can enhance the edible insect protein quality to a level similar to that obtained from vertebrates (Belluco et al., 2013; Soetemans et al., 2019; Sindermann et al., 2021). Mishyna and Glumac (2021) showed that chitin can be removed through different extraction procedures during the processing of food ingredients.

4.2.1. Protein quality of edible insects

As proteins from different species have different amino acid compositions, the protein quality of edible insects should be analysed in relation to dietary staples (van Huis, 2013). Protein quality can be measured by their digestibility and profile of essential amino acid. The protein quality also differs depending on whether the whole insect or isolated insect protein is used. Boye et al. (2012) stated that "the amino acid score (AAS) is the ratio of amino acid content in 1 g of a target protein to that of a reference protein". Aside its use in protein quality evaluation, AAS demonstrates the ability of dietary proteins to meet the amino acid need of individuals (Gaudichon, 2024). The AAS is principally based on the indispensable amino acid (IAA) content of dietary protein and further includes other digestibility factors such as the protein digestibility corrected amino acid score (PDCAAS) or the digestible indispensable amino acid score (DIAAS) (Gaudichon, 2024). Insect species such as *Acheta domesticus, Tenebrio molitor, Zophobas morio* and *Hermetia illucens* have shown high AAS with varying first limiting amino acid among adult and children (Table 3). The high AAS in these insect species further demonstrates that these insects are a good source of high-quality proteins in humans (Oonincx and Finke, 2021). Edible insect proteins can therefore supply in satisfactory amounts, the essential amino acid requirements of humans (WHO, 2007) as they contain essential amino acids of higher or comparable levels to products of plant and animal origin. Nongonierma and FitzGerald (2017) showed that insect protein isolation follows the general procedure which includes homogenisation, defatting, solubilisation, isoelectric precipitation, resolubilisation and drying. There may be a need to remove the chitin first by using enzymatic processing but, the parameters chosen depends on the insect type, matrix and intended use of the products.

Table 3
Dietary protein quality of edible insects.

Insect species	Amino acid score	Protein digestibility corrected amino acids score	First limiting amino acid	Reference
Acheta domesticus (lab reared)	0.48	0.84	Leucine	van Huis et al. (2021)
Acheta domesticus (commercially reared, FD)	0.88	0.82	Methionine + cystine	van Huis et al. (2021)
Acheta domesticus (adults/nymphs)	113	ND	Methionine + cystine	Oonincx and Finke (2021)
Alphitobius diaperinus	124.75	ND	Leucine	Perez-Santaescolastica et al. (2023)
Blaptica dubia	118.54	ND	Leucine	Perez-Santaescolastica et al. (2023)
Bombyx mori	94	81	Leucine	Ochiai et al. (2024)
Cirina forda	0.51	0.42	Methionine + cystine	van Huis et al. (2021)
Galleria mellonella	111.02	ND	Leucine	Perez-Santaescolastica et al. (2023)
Gryllus assimilis	0.91	0.73	Threonine	van Huis et al. (2021)
Gryllus bimaculatus	87	72	Tryptophan	Ochiai et al. (2024)
Hermetia illucens	111	ND	Methionine + cystine	Oonincx and Finke (2021)
Holotrichia parallela	0.87*/1.00**	0.86*/0.89**	Threonine	van Huis et al. (2021)
Locusta migratoria	111.3	ND	Lysine	Perez-Santaescolastica et al. (2023)
Macrotermes nigeriensis	0.47	0.42	Methionine + cystine	van Huis et al. (2021)
Melanoplus foedus	0.54	0.46	Isoleucine	van Huis et al. (2021)
Sarmia ricinii prepupae	0.99	0.86	Leucine	van Huis et al. (2021)
Tenebrio molitor (larvae)	0.39	0.86	Methionine + cystine	van Huis et al. (2021)
Tenebrio molitor (NH)	0.94	86.4	Methionine + cystine	Poelaert et al. (2018)
Zophobas morio (adults/larvae)	99	ND	Methionine + cystine	Oonincx and Finke (2021)
Zophobas morio	159.28	ND	Methionine + cystine	Perez-Santaescolastica et al. (2023)

* From crude protein content; **From net protein content; FD = Freeze dried; NH = No heat; ND = Not determined.

The availability of essential amino acids for use by the body depends hugely on its supply through the diet (Akhtar and Isman, 2018). Diets deficient in essential amino acids can be complemented with edible insects. For instance, in countries such as Kenya, Angola, Zimbabwe and Nigeria where maize and yam are consumed as a staple, edible insects such as termites are used as supplements in the diet which are mostly deficient in tryptophan and lysine (Akhtar and Isman, 2018). As stated by van Huis (2013), lysine commonly limited in cereals can be enhanced in a diet by introducing the termite *M. bellicosus*. Similarly, lysine and leucine also limited in yam, taro and sweet potato tubers can be complemented by the introduction of the larvae of *Rhynchophorus bilineatus* to the meal (van Huis, 2013). Furthermore, edible insect caterpillars are used in the Democratic Republic of Congo for complementing meals that are lysine deficient.

4.3. Edible insect vitamins

Insects contain a large amount of vitamins and minerals (Finke, 2013; Hawkey et al., 2021), which are essential for biological processes in humans (Michaelsen et al., 2009; Adegbola et al., 2013; Kelemu et al., 2015). Edible insects such as Angolan caterpillar, *Usta Terpsichore,* have been found to contain thiamine (vitamin B_1) and riboflavin (B_2) while caterpillar species from Saturnidae were shown to contain riboflavin and niacin (Niacin) (Belluco et al., 2013). Most edible insects are rich in thiamine and riboflavin (Akhtar and Isman, 2018), with the thiamine concentration in the range of 0.1–4.0 mg/ 100 g dry wt. and riboflavin in the range of 0.11–8.5 mg/100 mg dry wt. (Bukkens, 2005). Edible insects are also reported to be good sources of vitamin E (Table 4).

4.3.1. Vitamin A content

Vitamin A is important because it plays important physiological roles in cell differentiation, reproduction, growth, immune response, and vision. There is a dearth of information on the vitamin A concentration of edible insects (Finke and Oonincx, 2014). Furthermore, most reported values of vitamin A (retinol) content of edible insects are low, with some cases reported to be as low as 300 μg retinol/kg dry matter (Finke, 2002; Punzo, 2003; Oonincx and van der Poel, 2011; Finke, 2013). Low amounts of vitamin A ranging from 0.11 – 0.19 mg/kg DM was reported in adult migratory locusts fed on different diets (Oonincx and van der Poel, 2011) while Finke (2013) reported non-detectable levels of <300 μg retinol/kg in the larvae of soldier flies, tebo worms, nymphs of turkestan cockroaches and in adult house flies. Although retinol was reported to be in low amounts in edible insects, carotenoid levels for wild bred insects were found to be in high concentrations; β-carotene is a precursor of vitamin A. Conversely, commercially bred insects were found to contain lower amounts of the carotenoids (Isaksson and Andersson, 2007; Eeva et al., 2010; Oonincx and van der Poel, 2011; Finke, 2013;).

4.3.2. Vitamin B content

Vitamin B reported to be present in wild and commercially bred edible insects include vitamin B_1 (thiamine, required for enzyme functioning needed for energy metabolism), vitamin B_2 (riboflavin, coenzymes required for nutrient metabolism), vitamin B_3 (niacin (Niacin), tissue respiration), vitamin B_5 (pantothenic acid, component of coenzyme A), vitamin B_6 (pyridoxine, involved in several metabolic processes e.g. amino acid metabolism), vitamin B_8, (biotin, carrier of carboxyl group in adenosine triphosphate reactions), vitamin B_9 (folic acid, DNA synthesis and one-carbon metabolism) and vitamin B_{12} (cobalamin, functions in reactions involving methyl donors) (Thurnham et al., 2000; Hawkey et al., 2021). Although thiamine is relatively unstable, it has been detected in several insects of African origin, including African palm weevil (Nigeria), Attacidae caterpillar (Democratic Republic of Congo), and insects from other regions of the world, including butterworms, superworms, Turkistan roaches, silkworm, mealworm larvae and waxworms. Riboflavin, on the other hand, was found in high concentrations (17.6–306.3 mg/kg dry matter) in most insect species, such as the Attacidae caterpillars, palm weevil larvae, termites and larvae of Saturniid species. A range of insect species including termites, species of lepidopteran larvae and palm weevil larvae consumed in Africa are known to contain niacin (Niacin) (Finke and Oonincx, 2014). Other B vitamins such as pantothenic acid, pyridoxine, biotin, folic acid and cobalamin have all been shown to be present in varying concentrations in either the wild or commercially grown edible insects (Finke,

Table 4
Vitamin profile of some edible insects (mg/100 g d.w.).

Order	Specie	Stage of consumption	Retinol	Beta-carotene	Thiamine	Riboflavin	Niacin	Pyridoxine	Folic acid	Pantothenic acid	Biotin	Cyanocobalamin
Lepidoptera	*Bombyx mori*		1580.0 IU/kg	<0.02	0.33	0.94	2.63	0.16	0.071	2.16	0.025	<1.2 μg/kg
	Galleria mellonella		<1000.0 IU/kg	<0.02	0.23	0.73	3.75	0.13	0.044	2.02	0.029	<1.2 μg/kg
	Comimbrasia belina		21.6 IU	1.71 IU	0.58	4.98	11.90	NA	NA	NA	NA	NA
	Comimbrasia belina (dried)		0.053	0.634	0.55	1.99	11.60	NA	NA	NA	NA	NA
	Nudaurelia oyemensis		32.0 μg	6.8 μg	0.21	3.40	10.10	54.0 μg	21.5 μg	9.50	32.0	0.015 μg
	Imbrasia truncate		33.0 μg	7.1 μg	0.32	5.50	11.80	151.0 μg	40.0 μg	11.00	48.5 μg	0.027 μg
	Imbrasia epimethea		47.3 μg	8.2 μg	0.21	4.30	11.80	86.0 μg	6.8μg	7.80	24.7 μg	0.016 μg
	Chilecomadia moorei	Larva	<300.0 μg	0.57	<0.01	64.50	33.60	3.29	0.83	26.50	0.46	–
Colodoptera	*Zophobas morio*	Larva	<1000.0 IU/KG	<0.02	0.06	0.75	3.23	0.32	0.006	1.94	0.035	0.42
	Tenebrio molitor	Giant larva	<1000.0 IU/kg	<0.02	0.12	1.61	4.13	0.58	0.117	1.45	0.0037	0.13
	Tenebrio molitor	Adult	<1000.0 IU/kg	<0.02	0.10	0.85	5.64	0.81	0.139	2.40	0.028	0.56
	Tenebrio molito	Larva	<1000.0 IU/kg	<0.02	0.24	0.81	4.07	0.81	0.157	2.62	0.030	0.47
Orthoptera	*Oxya verox*		356.0 μg	78.0 μg	0.34	7.84	10.00					
	Acheta domesticus	Adult	<1000.0 IU/kg	<0.02	0.04	3.41	3.84	0.23	1.50	2.30	0.017	5.37
	Acheta domesticus	Nymphs	<1000.0 IU/kg	0.02	0.02	0.95	3.28	0.17	0.145	2.63	0.005	8.72
	Blatta lateralis	Nymphs	<300.0 μg/kg	<0.20	0.9	15.60	43.80	3.10	1.11	37.00	0.37	–
Isoptera	*Termes* sp. Dried				0.03	6.07	5.90					
	Termes sp. Smoked				0.11	0.07	1.95					
	Termes sp. Fried				0.14	3.79	9.81					

Source: Bukkens (1997); Ramos-Elorduy et al. (1997); Finke (2007); Finke (2013); USDA National Nutrient Database (2015); Williams et al. (2016).

2002, 2013). Akhtar and Isman (2018) reported that crickets and cockroach nymphs provide 11 times more vitamin B_{12} than beef, seven times more than salmon and 59 times more than chicken. Soldier flies were also reported to supply 15 times more thiamine, nine times more riboflavin and two times more vitamin B_{12} than beef.

4.3.3. Vitamin C content

Vitamin C is mostly known for its antioxidant properties and role in the formation of connective tissues. Most species of edible insects contain low concentrations of vitamin C (Finke 2007, 2013). However, Banjo et al. (2006) reported a high vitamin C concentration of 102.5–163.8 mg/kg dry matter for honeybees. Similarly, adult house crickets and mealworms were reported to contain vitamin C similar in amount to those of honeybees (Finke, 2002; Banjo et al., 2006, 2007, 2013; Finke and Oonincx, 2014).

4.3.4. Vitamin D content

Vitamin D can be synthesized by most vertebrates that are exposed to the appropriate environmental conditions. Generally, adequate vitamin D content can be obtained in vertebrates through exposure to ultraviolet light (Ferguson et al., 1996; Oonincx et al., 2010; Finke and Oonincx, 2014). Unlike the others, vitamin D was not detected in most commercially bred and wild edible insects (Finke and Oonincx, 2014). However, other studies reported that black soldier fly larvae, butterworm larvae, yellow mealworms, rusty red roaches and house crickets contain 388–9341 IU vitamin D/kg dry matter (Oonincx et al., 2010; Finke, 2013).

4.3.5. Vitamin E content

Vitamin E plays functions as an antioxidant and in maintaining the functionality of lipid-soluble compounds in the body (Finke and Oonincx, 2014). Different concentrations of vitamin E have been reported in wild and bred edible insect species, including super worm beetles (17.8 IU/kg dm), mealworm (9.0 IU/kg dm), fruit flies (166.0 IU/kg dm), false katydids (164.0 IU/kg dm), house flies (29.7 mg α-tocopherol/kg), soldier flies larvae (6.2 mg α-tocopherol/kg) (Oonincx and Dierenfeld, 2012; Finke, 2013;), waxworms (13.3 IU/kg), silkworms (8.9 IU/kg) nymph crickets (9.6 IU/kg) and adult crickets (19.7 IU/kg) (Finke, 2002).

4.4. Mineral content

Minerals, classified as macro-minerals and trace elements, are present in edible insects in varying concentrations. The macro-minerals include calcium, phosphorus and magnesium, which help in maintaining the skeletal structure of vertebrates; and chloride, potassium and sodium, which function as electrolytes and in maintaining acid-base balance in the body (Finke and Oonincx, 2014). The essential trace elements include iron, zinc, copper, manganese, iodine and selenium; they play different roles from oxygen transport to their function as co-factors of a several enzymes (Finke and Oonincx, 2014). Although most studies focused on the protein content of edible insects, significantly high amounts of minerals such as iron and zinc have been recorded in insect species (Michaelsen et al., 2009). Several edible insects also contain substantial amounts of trace elements copper, iron, manganese and zinc in sufficient amounts needed in diets (Oonincx and van der Poel, 2011; Oonincx and Dierenfeld, 2012). Akhtar and Isman (2018) reported that edible crickets supplies about 15 times more magnesium and three times more iron than beef. Similarly, soldier fly was reported to supply 71 times more calcium, and two times more magnesium and zinc than beef.

Deficiencies of micronutrients iron and zinc especially in developing countries are widespread and can be more detrimental in pregnant women and young children. Muller and Krawinkel (2005) stated that nearly two billion people are zinc deficient and about one billion have iron deficiency anaemia. Hence, consumption of edible insects that are rich in these minerals, such as termites and crickets, will contribute significantly to mitigating such nutrient deficiencies (van Huis, 2013). Though the exoskeleton of insects comprises protein and chitin, some insects such as the larvae of face fly (*Musa autumnalis* De Geer) and black soldier fly have been found to possess mineralized exoskeleton; calcium and other minerals are incorporated into the cuticle (Dierenfeld and King, 2008; Finke, 2013). Other insect invertebrates such as isopods and millipedes also consist of mineralized exoskeleton, thus making them a dietary source of calcium (Oonincx and Dierenfeld, 2012).

4.5. Energy value and fatty acid composition

The fat and energy content of edible insects vary from 7 to 77 g/100 g dry wt. (fat content) and 293–762 kcal/100 g dry wt. (caloric value) (Ramos-Elorduy et al., 1997; Kourimská and Adámková, 2016). The variation has been attributed largely to differences in the insect species and their feed sources (Belluco et al., 2013; Khanal, 2025) with the fat content higher in the larvae than the adult insects (Bednářová et al., 2013; Akhtar and Isman, 2018). Termites (4.9 – 61.1 %) and palm weevil larvae (42.2 – 55.0 %) were reported to have the highest fat content of the edible insects (Bukkens, 1997; van Huis, 2013), however, Khanal (2025) showed a crude fat content of 42.2 – 54.3 % (DM) for long-horned grasshoppers and 40.7 – 57.8 % (DM) for black soldier fly larvae. For edible insects to benefit humans, their content of different fatty acid types should cover a suitable range (Dietary Reference Levels for the Italian population – LARN –2012). This is important as edible insects such as termites and caterpillars are known to have high fat contents (Belluco et al., 2013). DeFoliart (1992) reported that some edible insects contain higher amounts of essential fatty acids, e.g. linoleic acid and linolenic acid, than meat. The most suitable dietary fat composition for humans is when the fat sources are in the ratio of meat (4): plant (5): fish (1) with a recommended ratio of 3:4:3 for saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids, respectively (Belluco et al., 2013).

Except for the order Hemiptera, most insect species are made up of unsaturated fatty acids which make up over 50 % of the total fatty acid composition in edible insects. The predominant saturated fatty acids in edible insects include palmitic acid (C16:0), which is present in larger quantities, and stearic acid (C18:0) (Yang et al., 2006). Similarly, the predominant unsaturated fatty acids found in edible insects include palmitoleic acid (C16:1), oleic acid (C18:1) and linolenic acid (C18:3) (Yang et al., 2006; Ekpo et al., 2009; Finke and Oonincx, 2014). As stated by Yang et al. (2006), the fatty acid composition of Chinese grasshopper (*Acrida cinereal* Thunberg) were 41 % linolenic acid and 12 % linoleic acid. However, Aguilar-Miranda et al. (2002) reported a fatty acid composition for yellow mealworm larvae as 25.5 % linoleic acid and 0.3 % linolenic acid, with oleic acid being the most predominant. These reports also showed that saturated and unsaturated fatty acid ratios of most edible insects are <40 %, which compares favourably with the values for poultry and fish. Generally, the fatty acid profile of edible insects is dependent on the species, developmental phase, food source and environmental factors (Finke and Oonincx, 2014). Other factors that affect the fat content in adult edible insects include behavioural differences and the rearing and growth environment (Finke and Oonincx, 2014).

Insect fat contents are generally estimated by determining the total weight of lipids, waxes and other fat-soluble molecules. Fat tissues obtained through dietary sources or produced from carbohydrates are normally used for energy storage in the body (Bender, 2002; Finke and Oonincx, 2014). In addition to being an energy source, fat also enhances the palatability of edible insects. Insect lipids are mainly stored in the fat body as their storage site (Finke and Oonincx, 2023). Oonincx and van der Poel (2011) showed that the adult weight of migratory locust (*Locusta migratoria* L.) varies due to the difference in their fat content. Thus, the fat content can serve as a means of estimating the weight of adult edible insects (Finke and Oonincx, 2014). Edible insects derived from aquatic sources contain less amount of polyunsaturated fatty acid compared to the terrestrial edible insects. Aquatic insects were shown to possess higher amounts of monounsaturated fatty acids whereas terrestrial insects were found to have higher polyunsaturated fatty acid especially omega-6 fatty acids, eicosatrienoic acid (C20:3) and eicosatetraenoic acid (C20:4) (Fontaneto et al., 2011; Finke and Oonincx, 2014). The observed dissimilarities in the total fat content of aquatic and terrestrial insects could be attributed to the diets of both groups of insects. Rearing terrestrial edible insects could therefore be more beneficial for obtaining essential polyunsaturated fatty acids in diets (Fontaneto et al., 2011; Belluco et al., 2013).

5. Insect-derived food products

One of the many contributions of insects in promoting food security is their role as pollinators. Insects are also used as biological control against the activities of plant pest. Presently, with the increasing knowledge of edible insects and their health benefits, there is a global demand for insect-based and edible insect-derived food products (Shockley and Dossey, 2014). Studies have shown that edible insects can be incorporated as flours or powders into food items such as snacks, bars, energy drinks, burgers and yogurt (Dossey, 2013; Kieronczyk et al., 2022; Tanga and Ekesi, 2024). Furthermore, Anyiam et al. (2024) and Santiago et al. (2024) showed the technofunctional properties of insect proteins including insect protein concentrate, isolate, flour, defatted flour and protein extract from eight different species. Insects can therefore be added in the formulation of cookies, thus imparting similar functionalities as milk powder (Homann et al., 2017; Roos, 2018). Table 5 shows the food applications of edible insect powders and their roles in enhancing the functional properties and nutritional value of the processed food products.

As several alternatives to vertebrate meat are being explored, edible insects are increasingly considered as one of the most sustainable options. Edible insect proteins are similar to meat proteins in functionality and sensory properties and can be used in formulating ready-to-eat food products such as sausages, hotdogs and chicken nuggets (Scholliers et al., 2020; Cho and Ryu, 2021; Santiago et al., 2024). Utilization of edible insects as canned foods and snacks has also been reported (Raksakantong et al., 2010). Furthermore, insects can be used as nutraceuticals (Table 6), nutritional supplements, fortification of insect-derived products with increased protein digestibility, carrier for medicinal compounds, water purification materials, wound healing, antimicrobial agents and plastic alternatives (Tharanathan and Kittur, 2003; Je and Kim, 2012; Shockley and Dossey, 2014; Mudalungu et al., 2021; Kieronczyk et al., 2022).

6. Food security and food safety concerns

The nutritional qualities of several edible insects are similar or better than those of livestock and many plants (Tanga and Ekesi, 2024). Khanal (2025) showed that edible insects including yellow mealworm larvae, migratory locusts, house crickets and lesser mealworm larvae have been approved for marketing either as dried or frozen ingredients by the European Union (EU) Commission. Although edible insects possess high fat content of between 1.6 – 77.0 % (DM) across the different stages of maturity (Tang et al., 2019; Rahman et al., 2024; Khanal, 2025), its relative abundance of unsaturated fatty acids compared to the saturated ones makes it a healthier choice in diets. Tang et al. (2019) stated that oleic acid a common and important monounsaturated fatty acid (MUFA) in human diet due to its role in blood pressure reduction and cardiovascular diseases, is the most abundant MUFA in insects. Thus, the consumption of edible insects especially in areas with food scarcity can enhance immensely, the nutritional status and health of the populace (Shockley and Dossey, 2014). With the growing concern pertaining global food insecurity, edible insects can be explored as a food source for addressing the rising economic, environmental and health challenges (Godfray et al., 2010; Premalatha et al., 2011). It should be noted that

Table 5
Food applications of edible insect powders.

Edible insect specie	Growth stage	Powder type	Applications	Functional properties	Reference
Gryllus assimilis	Adult	Cricket flour	Gluten-free bread	Bread exhibited decreased hardness and chewiness; more than twice the lipid content and a 40 % increase in protein content	da Rosa Machado and Thys (2019)
Alphitobius diaperinus	NS	Protein concentrate	Meat analog	Improved texture of insect-based meat analog	Smetana et al. (2018)
Tenebrio molitor and *Bombyx mori*	NS	Pretreated insect flour used as 10 % replacement for lean pork	Emulsion sausages	Firmer texture of emulsion sausages (than control) and increased protein and mineral levels. Observed colour changes in products	Kim et al. (2016)
Tenebrio molitor, Alphitobius diaperinus and *Acheta domesticus*	NS	Insect flour	Wheat bread	Observed increase in browning index and colour difference in bread crumb; reduced springiness and cohesiveness	Kowalski et al. (2022)
Locusta migratoria and *Tenebrio molitor*	NS	Insect powders	Muffins	Softer crumb with observed lower springiness, cohesiveness and chewiness	Cabuk (2021)
Tenebrio molitor	Larvae	Insect larvae powder	Meat analogs	There was observed increase in the WHC, protein digestibility and antioxidant property (DPPH) as insect powder increased. However, textural properties decreased with increase in larvae powder	Cho and Ryu (2021)
	NS	Insect protein	Jecky analogs	Improved texture of jerky analogs	Kim et al. (2022)
	Larvae	Insect powder	Bread	Increased protein content and essential amino acids	Roncolini et al. (2019)
	Larvae	Flour	Dry fermented sausages	Significant increase in protein, fibre and polyunsaturated fatty acid content. Decreased fat content	Hospital et al. (2025)
	Larvae	Flour	Frankfurters	Significant increase in protein, ash and pH	Choi et al. (2017)
Bombyx mori	Pupae	Pupae powder	Meat batters	The cooking loss of meat batter reduced while there was an observed increase in protein, fat, ash content and textural properties of hardness, chewiness and gumminess	Park et al. (2017)
	Pupae	Pupae and locust flour	Biscuits	Varying acceptable range in the spread ratios for biscuits from 7.8 – 11.6.	Akande et al. (2020)
Acheta domesticus	NS	Cricket powder	Pork pate	There was an increase in bound water due to a 6 % addition of insect powder. However, there was observed reduction in hardness and spreadability	Walkowiak et al. (2019)
	NS	Cricket flour	Meat analog	Reduction in tensile strength of meat anlogs	Kiiru et al. (2020)
	NS	Cricket protein	Tortillas and tortilla chips	Varying texture properties in combination with alcalase and flavourzyme; overall consumer acceptability;	Luna et al. (2021)
	NS	Cricket powder	Chapati	Increase in cricket powder resulted in increased water absorption capacity and dough- development time	Khatun et al. (2021)
	NS	Cricket flour (10 – 30 %)	Fortified snack pellets	Improved protein and fibre content; reduction in bulk density of pellet	Wójtowicz et al. (2023)
	Adult	Defatted cricket flour	Frankfurters	Significant increase in protein, zinc, calcium and manganese content but no observed change in fat content. Reduction in processing loss of reformulated frankfurters	Cavalheiro et al. (2023)
Hermetia illucens, Acheta domestica and *Tenebrio molitor*	Larvae (*H. illucens, T. molitor*), adult (*A. domestica*)	Flour, defatted flour (*H. illucens*)	Bread	Increased protein, fat and ash content.	González et al. (2019)
Phyllophaga rugosa and *Nudaurelia melanops*	Adult (*P. rugosa*), larvae (*N. melanops*)	Flour	Cup cakes	Improved protein content, high oil holding, swelling, emulsifying and antioxidant capacities	Aguilera et al. (2021)

NS, not specified.

growing and harvesting of edible insects can mitigate food insecurity and improve the livelihood among rural dwellers while protecting their environment compared to livestock production (Agea et al., 2008; Hope et al., 2009; Kelemu et al., 2015). However, for insects to be accepted as food globally, it must be known to be safe both epidemiologically and analytically (Belluco et al., 2018).

Regarding food safety concerns, SLU et al. (2018) opined that allergens have not been reported in crickets and in the order Orthopthera. However, Hassan et al. (2024) demonstrated the presence of allergens in edible insects including silkworm, mealworm, locusts, crickets and grasshopper. Allergic reactions due to sensitisation and cross-reactivity with other arthropods is based on the existence of proteins such as tropomyosin, arginine kinase, myosin light and heavy chain, and larval cuticle protein A1A, A2B and A3A occurring in different insect species as well as the high protein homologies shared among other arthropods (de Gier and Verhoeckx, 2018; SLU et al., 2018; Hassan et al., 2024). The allergen tropomyosin present in crustaceans, has also been reported in crickets, thereby triggering and increasing susceptibility to develop allergic reactions upon cricket consumption by those who are allergic to crustaceans (de Gier and Verhoeckx, 2018; SLU et al., 2018). Reports by the EFSA Panel on Nutrition et al. (2021b) further shows that yellow mealworm proteins are known to trigger harmful reactions in consumers who are allergic to shrimp. This was attributed to the cross-reactivity of the high protein homology between phylogenetically related organisms including shrimps, crabs and several insects as well as in organisms between different arthropod subphyla (Van Broekhoven et al., 2016; Belluco et al., 2018; de Gier and Verhoeckx, 2018; EFSA Panel on Nutrition et al., 2021b). A total of 73 proteins identified as pan-allergens in *L. migratoria* including arginine kinase, chitinase, glutathione S-transferase, hexamerin, serine protease, tropomyosine and trypsin were shown to develop cross-reactivity with other homologous proteins present in arthropods (Barre et al., 2021). Sokol et al. (2017) showed that ingestion of roasted grasshopper (chapulines) obtained from Mexico induced anaphylaxis in consumers allergic to crustaceans but who had no prior exposure to grasshoppers. Furthermore, ingestion of insects including locusts, fried grasshoppers and crickets were

Table 6
Pharmacologically tested substances/products derived from some insect species.

Insect species	Substance/products	Pharmacological effects
Acheta domestica L.	Iridoids	Antimicrobial, tonic, anti-inflammatory
	Cumarins	Anticoagulants
Allomyrina dichotomus L.	Dicostatin	Anticancer
Anoplius samariensis Pal.	Pompilidotoxin	Neurotoxic
Anterhynchium flavomarginatum micado Kirsch	Eumenine mastoparan AF	Peptides that act on degradation of mastocytes
Apis mellifera L.	Propolis	Anticancer, anti-HIV
Bombyx mori L.	Attacin, moricin, drosocin	Antibacterial
Catopsilia crocale (Cramer)	Isoxantopterin	Anticancer
Drosophila melanogaster Meigen	Defensin, diptericin	Antibacterial
Edessa cordifera Walker	Cumarin	Anticoagulants
	Alkaloids	Increase in muscle tone and contractility
Euschitus crenator S.	Tannins	Antitoxic, antitumoral, antiviral
Hyalophora cecropia L.	Cecropin A y B	Antibacterial
Lonomia obliqua Walter	"Lopap" protein	Antithrombotic
Lytta vesicatoria L.	Cantharidin	Vesicant
Phoenicia sericata (Meigen)	Allantoin	Antibacterial
Polybia occidentalis nigratella Oliv.	Saponins	Anti-inflammatory, antihepatotoxical
Prioneris thestylis Doubleday	Isoguanine	Anticancer
Pseudagenia (batozonellus) maculifrons Sm.	Pompilidotoxin	Neurotoxic
Sarcophagi peregrine (Robineau-Desvoidy)	Sarcotoxin IA, IB, IC, sapecin	Antibacterial
Sphenarium purpurescens Ch.	Iridoids, carotenoids	Anti-inflammatory, antimicrobial, activity of provitamin A
Tetragonisca angustula Latreille	Honey	Antibacterial

Source: Costa Neto (2005); Costa-Neto and Dunkel (2016).

implicated as the cause anaphylactic reactions in China and Thailand (EFSA Panel on Nutrition et al., 2021a). However, studies have shown that allergenicity of proteins in edible insects such as crickets, silkworms, mealworms, grasshoppers and buffalo worm can be affected by processing techniques such as microwaves, roasting, frying, boiling and enzymatic hydrolysis (Bose et al., 2021; Lamberti et al., 2021; Hassan et al., 2024).

7. Conclusions and future perspectives

The acceptability of edible insects is increasing globally as they are rich sources of essential nutrients, and are currently consumed in approximately 30 % of the world's population, across 113 countries. Consumption patterns differ across regions including Asia, sub-Saharan Africa and Latin America where edible insects constitute major parts of diets, delicacies, side dishes and snacks. With the approval of the marketing of mealworm larvae, migratory locusts, house crickets and lesser mealworm larvae as dried or frozen food ingredients by the EU Commission, Western societies are gradually showing interest in edible insect consumption especially in its application as functional ingredients in different food formulations. The protein, fat, mineral, vitamins and fibre content of edible insects makes it a healthy option when compared to diets from plant and animal sources. Aside its good amino acid profile, edible insect proteins demonstrated high AAS (indicating high-quality proteins in humans) in *A. domesticus, T. molitor, Z. morio* and *H. illucens* with varying first limiting amino acid among adult and children. Furthermore, the fat content of edible insects consist mainly of unsaturated fatty acids including MUFA compared to the saturated ones. However, evidence of allergens was shown to exist in some edible insect species. Although allergenicity of these insect proteins are affected by different processing techniques, there is need for caution in their use as food, especially in regions with no tradition of insect consumption.

Ethical statement

We hereby declare that no human nor animal subject was involved while conducting this literature review. Thank you

CRediT authorship contribution statement

Tonna Ashim Anyasi: Writing – review & editing, Writing – original draft, Project administration, Investigation, Data curation, Conceptualization. **Parag Acharya:** Writing – review & editing, Writing – original draft. **Chibuike C. Udenigwe:** Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization.

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.

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