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Entomophagy: Insects as Food

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Abstract

Due to the increasing cost of animal proteins, food and feed insecurity, population growth, and increasing need for protein-rich food in the developed and less developed countries, alternative sources of protein-rich food are highly needed. Scientific research has shown that edible insects are a very rich source of proteins and other nutrients. Hence, insect consumption might help revolutionaries' food and feed insecurity and thus replace the conventional animal source. This work assesses the potential of insects as food for humans and feed for animals and gathers existing information and research on edible insects. The assessment is based on the most recent and complete data available from various sources and experts around the world, because lack of a complete data on edible insects reduces consumer confidence and limits integration of edible insect consumption with other food sources. Considering the nutritional, economic, and ecological advantages of edible insects over conventional livestock, much attention should therefore be given to their method of collection as this will help improve their availability. This could be achieved by improved conservation or by raising them as a minilivestock. Considering the economic, nutritional, and ecological advantages of this traditional food source, its promotion deserves more attention both from national governments and assistance programs.

Keywords: edible insects, entomophagy, minilivestock, food and feed security, conservation

1. Introduction

Entomophagy, the consumption of insects, is rooted in human evolutionary history [1]. Insects have played an important part in the history of human nutrition in Africa, Europe, Asia, and Latin America. Over 1900 species of insects are known worldwide to be part of human diets;

some important groups include grasshoppers, caterpillars, beetle grubs, winged termites, bees, worms, ant brood, cicadas, and a variety of aquatic insects [2]. It is interesting to know that more than two billion people consume insects on a regular basis, and insect eating provides a significant proportion of the animal proteins consumed in some regions [3]. Because entomophagy is widely practiced, and because it compares favorably with nutrient and environmental aspects of conventional livestock rearing, it has the potential to contribute substantially to reducing undernutrition among an expanding global population [3].

2. Diversity of edible insect species in the world

Insects have been in existence for at least 400 million years, making them among the earliest land animals. They diverged as members of one of the largest subphyla in arthropods more than 390 million years ago experiencing a rapid evolution and radiation that is considered faster than any other group [4]. The class insects are the largest animal group on earth and constitute as much as 80% of the animal kingdom. Because of the nutritional importance of edible insects and their huge availability, this has attracted their consumption by more than two billion people on a daily basis [5].

Over 1900 species of edible insects in 300 ethnic groups in 113 countries worldwide have been recorded by various authors to be part of human diet (**Table 1**) [6]. According to Van Huis et al. [3], 246 species of edible insects have been reported in 27 countries in Africa. Another study

Order	Species	Location
Lepidoptera	<i>Anaphe panda</i> (Boisduval)	DRC, Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Nigeria, Tanzania
	<i>Cirina forda</i> (Westwood)	DRC, Zambia, South Africa, Botswana, Burkina Faso, Nigeria, Mozambique, Namibia, Ghana, Togo, Chad
	<i>Dactyloceras lucina</i> (Drury)	DRC, Zambia, South Africa, Botswana, Burkina Faso, Nigeria, Mozambique, Namibia, Ghana, Togo, Chad
	<i>Gynanisa ata</i> Strand	DRC, Zambia, South Africa, Botswana, Burkina Faso
	<i>Anaphe venata</i> Butler	Zambia, Nigeria, Ivory Coast, Sierra Leone, Guinea, Liberia, Guinea Bissau
Orthoptera	<i>Acanthacris ruficornis</i> (Fabricius)	DRC, Zambia, South Africa, Botswana, Burkina Faso, Nigeria, Mozambique, Namibia, Ghana, Togo, Chad
	<i>Ruspolia differens</i> (Serville)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Malawi, Mali
	<i>Zonocerus variegatus</i> Linnaeus)	DRC, Zambia, South Africa, Cameroon, Zimbabwe, Kenya, Uganda, Tanzania, Malawi
Coleoptera	<i>Oryctes boas</i> (Fabricius)	DRC, Cameroon, Congo, CA Republic, Nigeria, Ivory Coast, Sao Tomé, Guinea, Ghana, Liberia
	<i>Rhynchophorus phoenicis</i> (Fabricius)	Thailand, Australia, Nigeria, Ivory Coast, Sierra Leone, Guinea, Liberia, Guinea Bissau DRC, Congo, Botswana

Order	Species	Location
Hymenoptera	<i>Apis mellifera</i> (Linnaeus)	Mexico, Cameroon, Congo, CA Republic, Nigeria, Angola, Ivory Coast, Niger, Sao Tomé, Guinea
	<i>Carebara vidua</i> (Smith)	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi, Sudan, Kenya, South Sudan
	<i>Carebara lignata</i> Westwood	Zambia, South Africa, Zimbabwe, Botswana, Sudan, Mozambique, Namibia, South Sudan
Isoptera	<i>Macrotermes subhyalinus</i> (Rambur)	Zambia, Angola, Kenya, Togo, Burundi, Ivory Coast, Canada, the USA
	<i>Macrotermes falciger</i> (Gerstäcker)	Zambia, Zimbabwe, Burkina Faso, Burundi, Benin, Australia, the Netherlands
	<i>Macrotermes natalensis</i> (Haviland)	DRC, Cameroon, Congo, CA Republic, Nigeria, Burundi, South Africa, Zimbabwe, Nigeria, Malawi

Sources: Banjo et al. [8], Igwe et al. [9], Opara et al. [10], Kelemu et al. [11].

Table 1. Diversity and location of the most consumed edible insects in the world.

carried out 2 years later by Ramos-Elorduy noted that Africa is one of the most important hot spots of edible insect biodiversity in the world with 524 species recorded from 34 African countries [7]. These species are mostly of the orders Orthoptera, Lepidoptera, Coleoptera, Hymenoptera, and Isoptera. Below is a checklist of the most consumed edible insect species in the world and their orders and locations (**Figure 1**).

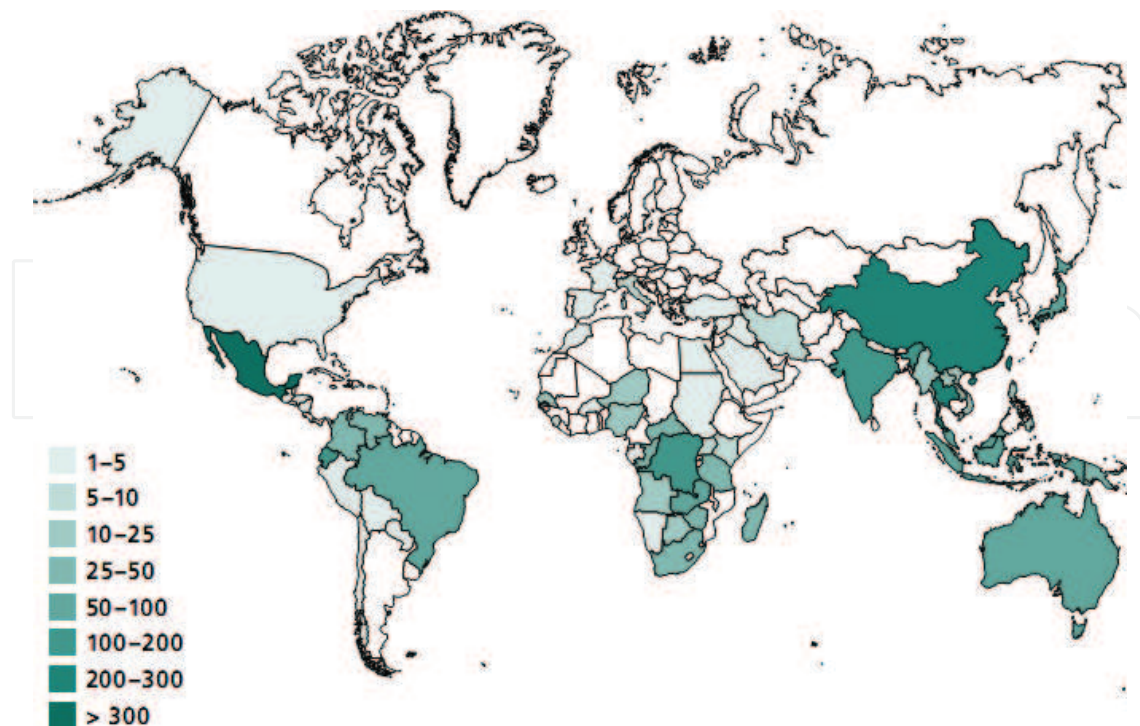


Figure 1. Recorded number of edible insect species, by country. Source: Centre for Geo Information, Wageningen University, based on data compiled by Jongema, 2012 [21]. Banjo et al, [8]; Igwe et al, [9]; Opera et al, [10]; Kelemu et al, [11].

3. Why eat insects?

Hunger and malnutrition is a serious problem in the ever-expanding human population. With the high rate at which the world population is growing, the world food supply should grow at the same rate, if not faster. Therefore, the search for new food sources including the identification and development of localized ethnic ones continues [3].

In most part of the world, particularly in Africa and Latin America, food resources are becoming increasingly scarce and the importing of foods is becoming more expensive. It is thus imperative to identify and develop indigenous food resources. To effectively respond not just to rapid population growth but also to other pressing challenges, researchers have turned their attention to insects not only because of their abundance, enormous biomass, and high-quality protein but also because of the time-honored practice among many culturally diverse peoples of Africa and Latin America of consuming live, roasted, and fried insects, providing them with a nutritious protein of good quality and high digestibility [12, 13]. The choice of insects as food is further strengthened by the fact that they also constituted rich sources of fat, vitamins, and minerals, especially iron and zinc [14].

4. Edible insects as food for humans and feed for animals

Insects are the most abundant and most diverse multicellular organisms on planet earth and are thought to account for about 80% of all species [15]. Numerous crops rely on them for pollination, and their importance extends into their other agricultural and human health benefit [16].

Over 1900 species of insects are known to be part of human diets, more than 2 billion people consume insects on a regular basis, and insect eating provides a significant proportion of the animal protein consumed in some regions [3, 17]. In fact, in many developing countries and among various cultures scattered throughout the world, insects remain a vital and preferred food and an essential source of protein, fat, minerals, and vitamins [18]. This is because some edible insects have been shown to have nutritional value that can be compared with meat and fish, while others have higher proportion of proteins, fat, and energy value [19]. This has become especially important as the need for alternative protein sources increases due to rapid urbanization in developing countries and the shifts in the composition of global food demand. Among the most important orders of insects consumed in the world are the Coleoptera, Hymenoptera, Isoptera, Lepidoptera, Odonata, and Orthoptera, and they are highly priced (**Figure 2**) [20]. Notable examples of these are the locusts, termites, worms, grasshoppers, caterpillars, palm weevils, and beetle grubs, among others.

Although insects were mainly recognized as pests affecting humans, plants, and animal health, insects play an essential role in minimizing food insecurity in addition to provide ecosystem services (such as pollination, waste degradation, and biological control). Insects also represent an important food source for a wide variety of animal species. Van Huis et al. outlined the important role of insects in assuring food and feed security. Below is a list of pictures showing the various edible insects consumed around the world (**Figure 3**) [3].

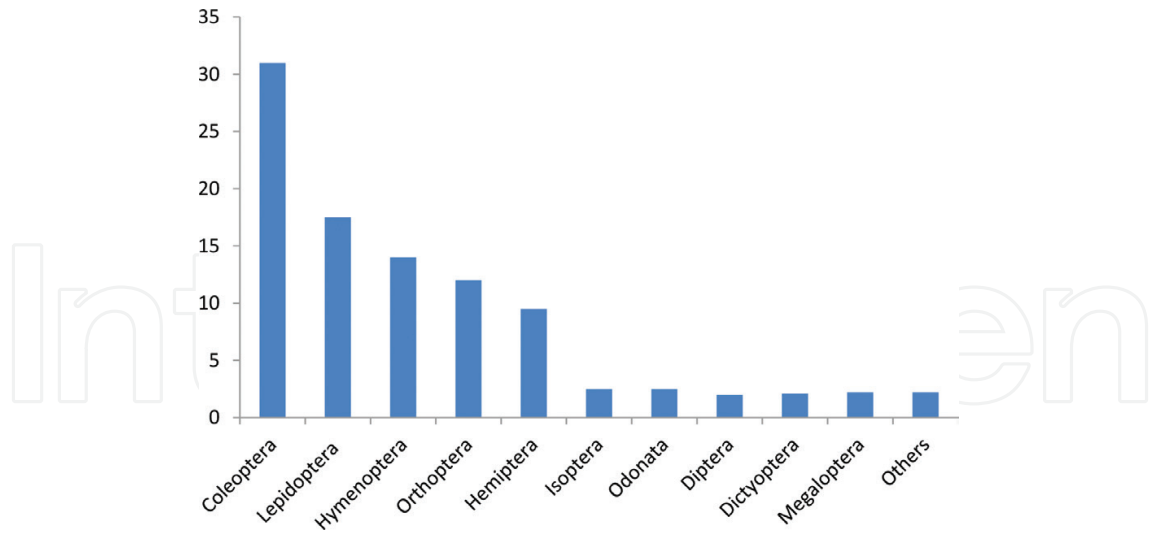


Figure 2. Number of insect species, by order, consumed worldwide. Source: Jongema [21].



Figure 3. Examples of edible insects.

5. Medicinal value of edible insects

Scientific validation of traditional wisdom in bioprospecting has assured greater significance. Edible insects have long been a significant dietary factor and remedy for illnesses in many regions of the world [22]. Traditional healers have used insects as medicine to treat various diseases in human beings and animals successfully. Some of these diseases include common fever, scabies, epilepsy, violent headaches, bronchitis, hemorrhage, and dog bite. Insects are also used to treat wound, to prevent gangrene, and to increase milk flow in lactating women, among others [23]. This treatment is finding modern usage in many hospitals. Also, chemicals produced by edible insects against self-defense have also been exploited by many researchers for the production of antibacterial and anticancer drugs. For instance, pierisin, a protein purified from pupa of cabbage butterfly, exhibits cytotoxic effects against human gastric cancer. Cecropin has also been reported to be cytotoxic against mammalian lymphoma and leukemia cells [22]. Despite the fact that edible insects have a high nutritional, economic, and medicinal value, they are often neglected. It is high time that scientists recognize this fact and begin to build on it given the benefits of these creatures to the environment and to human health.

6. Market value of edible insects

Many rural communities like those in Africa, Asia, and South America know that eating insects provides a valuable source of protein, minerals, and vitamins as well as a tasty snack and therefore must be in high demand. Crickets, grasshoppers, and locusts, for example, are a seasonal delicacy, while the giant water beetles are used in salads [22].

Considering the popularity of edible insects, it is not surprising that scores of species have been and are prominent items of commerce in the town and village markets of Africa and tropical and semitropical regions of the world [24]. In several areas in Africa, particularly in Zimbabwe, Nigeria, South Africa, Ivory Coast, and Zambia, many families make fairly good living from selling insects [25, 26]. These insects are mostly gathered from bushes and farmland by women and children (Figure 4), processed, and eaten or sold in school premises and



Figure 4. A picture showing women and children selling edible insects in local markets.

local and urban markets. Some of these insects are also processed and exported to shops and restaurants in cities in and out of the country [20, 27]. The commercialization of edible insects therefore provides significant income to many households in Africa. However, poorly understood and poorly organized market chains severely limit agribusiness in Africa. The market constraints encountered by farmers when attempting to diversify the production of edible insect business should therefore be documented.

7. Nutritional value of edible insects

The part played by insects in human nutrition cannot be underestimated [28]. Substantial evidence suggests that insects are a highly nutritious and healthy food source with high content of nutrients such as fats, proteins, amino acids, carbohydrates, vitamins, fibers, and minerals required by humans and animals [3]. However, the nutritional compositions of edible insects between and within species are highly variable depending upon the metamorphic stage, habitat, and diet of the insect as well as the preparation and processing methods applied before consumption [29]. Although the nutritional composition of some edible insects has previously been investigated in a number of countries, for example, India, the USA, Mexico, and Thailand, very few authors have reported a compiled nutritional composition of edible insects in the world. The lack of nutritional data on most edible insects may result in a reduction in consumer confidence and limits integration of insect consumption with other food sources. Hence, this work seeks to compile nutritional data of edible insects consumed in the world.

7.1. Dietary energy content of edible insects

With the growing world population, there are now more than 3.7 billion people suffering from malnutrition, mainly due to lack of protein and energy from food [30]. Also, new agricultural land is scarce to produce food for humans, and as such a greater proportion of people are eating resource-intensive animal protein than ever before. Livestock production is very expensive because it requires a large input of energy compared to the energy output [31]. These livestock also compete for nutrients and energy with humans.

Utilization of insects as a protein source could benefit insect conservation through habitat protection [32]. Insects are essential agents because they are able to exploit all organic sources in nature and are able to recycle organic waste and provide nutrients to farm animals and humans [33, 34]. Furthermore, edible insects have high quantities of polyunsaturated fat which provides majority of the energy for sustaining life. The energy contents of edible insects vary according to the species and region found and have also been found to be significantly higher than those of livestock and vegetables [19, 35]. Hence, edible insects may efficiently provide the necessary energy for the vital functions and survival of organisms.

Ramos Elorduy et al. [36] analyzed 78 insects from Oaxaca State, Mexico, and determined that caloric content was 293–762 kcal per 100 g of dry matter as shown in **Table 2**.

Location	Common name	Scientific name	Energy content kcal/100 g fresh weight
Australia	Australia plague locust, raw	<i>Chortoicetes terminifera</i>	499
Australia	Green (weaver) ant, raw	<i>Oecophylla smaragdina</i>	1272
Canada, Quebec	Red-legged grasshopper, whole, raw	<i>Melanoplus femurrubrum</i>	160
The USA, Illinois	Yellow mealworm, larva, raw	<i>Tenebrio molitor</i>	206
The USA, Illinois	Yellow mealworm, adult, raw	<i>Tenebrio molitor</i>	138
Ivory Coast	Termite, adult, dewinged, dried, flour	<i>Macrotermes subhyalinus</i>	535
Mexico Veracruz State	Leaf-cutter ant, adult, raw	<i>Atta mexicana</i>	404
Mexico Hidalgo State	Honey ant, adult, raw	<i>Myrmecocystus melliger</i>	116
Thailand	Field cricket, raw	<i>Gryllus bimaculatus</i>	120
Thailand	Giant water bug, raw	<i>Lethocerus indicus</i>	165
Thailand	Rice grasshopper, raw	<i>Oxya japonica</i>	149
Thailand	Grasshopper, raw	<i>Cyrtacanthacris tatarica</i>	89
Thailand	Domestic silkworm, pupa, raw	<i>Bombyx mori</i>	94
The Netherlands	Migratory locust, adult, raw	<i>Locusta migratoria</i>	179

Source: FAO [37].

Table 2. Examples of energy content of different processed insect species, by regions.

7.2. Protein and amino acid composition of edible insects

Proteins are organic compounds consisting amino acids which are the building blocks and could be either essential or nonessential. Protein is the basis of all organism activity and constitutes many important materials such as enzyme, hormones, and hemoglobin. Proteins are the most abundant biological macromolecules, occurring in all cells and all parts of cells. Proteins also occur in great variety; thousands of different kinds, ranging in size from relatively small peptides to huge polymers with molecular weights in the millions, may be found in a single cell. Moreover, proteins exhibit enormous diversity of biological function and are the most important final products of the information pathways. Proteins are the molecular instruments through which genetic information is expressed. Therefore, ensuring a steady source of protein is very important in providing energy for humans and animals.

Insects are potentially an important energy efficient source of protein in humans (**Table 3**), either through a direct consumption or as food supplements for stock [17]. Many local communities in

the world, particularly in the Amazon region, attain about 8–70% of their dietary protein from insects [39]. The highest amount of crude protein is found in insects in the order Lepidoptera followed by Coleoptera, while the order Hymenoptera has the least. The high protein content is an indication that edible insects can be of value to man and animal ration and can eventually replace higher animal protein usually absent in the diet of rural dwellers in developing countries [8].

Insect order	Stage	Range (% protein)
Coleoptera	Adults and larvae	23–66
Lepidoptera	Pupae and larvae	14–68
Hemiptera	Adults and larvae	42–74
Homoptera	Adults, larvae, and eggs	45–57
Hymenoptera	Adults, pupae, larvae, and eggs	13–77
Odonata	Adults and naiad	46–65
Orthoptera	Adult and nymph	23–65

Source: Xiaoming et al. [40].

Table 3. Crude protein content, by insect order.

Xiaoming et al. [40] evaluated the protein content of 100 species from a number of insect orders. He showed that protein content was high and in the range of 13–77% of dry matter and that there was a large variation between and within the insect orders.

Edible insects have also been shown to have higher protein content, on a mass basis, than other animal and plant foods such as beef, chicken, fish, soybeans, and maize [41]. FAO compared protein content of insects, reptiles, cattle, and fish (**Table 4**) [42]. Results showed that the protein content of the selected insect species had higher protein contents than the fish and mammals. This strongly suggests that insects are an important source of protein and as such their consumption should be encouraged.

Many studies have also shown that edible insects are important source of amino acids (tryptophan and lysine). The inclusion of these insect species in diets could be of immense benefit in complementing lysine-poor staple cereals [43–45], and a host of others were able to demonstrate that an insect species *Tenebrio molitor* had a significant amount of essential and nonessential amino acids compared to beef (**Table 5**).

7.3. Fat and carbohydrate composition of edible insects

Fats and carbohydrates are important nutritive elements in the human body. They are the main energy source in the body, can reduce consumption of proteins, and help for detoxification [38].

Edible insects are also a good source of carbohydrates. In fact, the carbohydrate content of edible insects ranged from 6.71% in sting bug to 15.98% in cicada [47]. Carbohydrates in insects

are formed mainly by chitin. Chitin is a macromolecular compound that has a high nutritional and health value. This chitin reduces serum cholesterol [48]. Also, recent report showed that considerable amounts of polysaccharide in edible insects might improve immune functioning of human body [49].

Animal group	Species and common name	Edible product	Protein content (g/100 g fresh weight)
Insect (raw)	Locusts and grasshoppers: <i>Locusta migratoria</i> , <i>Anacridium melanorhodon</i> , <i>Ruspolia differens</i>	Larva	14–18
	Locusts and grasshoppers: <i>Locusta migratoria</i> , <i>Anacridium melanorhodon</i> , <i>Ruspolia differens</i>	Adult	13–28
	<i>Sphenarium purpurascens</i> (chapulines, Mexico)	Adult	35–48
	Silkworm (<i>Bombyx mori</i>)	Caterpillar	10–17
	Palm worm beetles: <i>Rhynchophorus palmarum</i> , <i>R. phoenicis</i> , <i>Callipogon barbatulus</i>	Larva	7–36
	Yellow mealworm (<i>Tenebrio molitor</i>)	Larva	14–25
	Crickets	Adult	8–25
	Termites	Adult	13–28
Cattles	Turtles: <i>Chelodina rugosa</i> , <i>Chelonia depressa</i>	Flesh	25–27
		Intestine	18
		Liver	11
		Heart	17–23
		Liver	12–27
Fish (raw)	Finfish	Tilapia	16–19
		Mackerel	16–28
		Catfish	17–28
	Crustaceans	Lobster	17–19
		Prawn (Malaysia)	16–19
		Shrimp	13–27
		Mollusks	Cuttlefish

Sources: FAO [37, 42].

Table 4. Comparison of average protein content among insects, fish, reptiles, and cattle.

Fat is the most energy-dense macronutrient in food. It consists of triglycerides and three fatty acid molecules which are the backbone. Fatty acid can either be saturated, unsaturated, or essential. Dietary intervention and epidemiological studies showed that fatty acid intake

Amino acid	<i>T. molitor</i> g/kg dry matter	Beef g/kg dry matter
Essential		
Isoleucine	24.7	16
Leucine	52.2	42
Lysine	26.8	45
Methionine	6.3	16
Phenylalanine	17.3	24
Threonine	20.2	25
Tryptophan	3.9	-
Valine	28.9	20
Semi-essential		
Arginine	25.5	33
Histidine	15.5	20
Methionine + cysteine	10.5	22
Tyrosine	36.0	22
Nonessential		
Alanine	40.4	30
Aspartic acid	40.0	52
Cysteine	4.2	5.9
Glycine	27.3	24
Glutamic acid	55.4	90
Proline	34.1	28
Serine	25.2	27
Taurine	210	-

Sources: Finke [45], Oonincx [46].

Table 5. Average amino acid content in *Tenebrio molitor* and beef in g/kg dry matter.

played a key role in human health. Reduction in dietary saturated fatty acids can decrease factor VII coagulant activity, which was implicated as a risk factor of cardiovascular disease [50]. Scientific literature has shown that consumption of PUFAs has several health benefits to humans such as reduction of glucose tolerance, thus reducing risk of diabetes and blood pressure [51], and prevention of insulin resistance [52], decreasing thrombotic tendency by inhibition of thromboxane A₂ formation [53] and lowering blood pressure [51, 54]. Womeni et al. [55] investigated the content and composition of fat extracted from several insects (**Table 6**). They showed that their oils are rich in polyunsaturated fatty acids and frequently contain the essential linoleic and α -linolenic acids. The nutritional importance of these two essential fatty acids is well recognized, mainly for the healthy development of children and infants [56].

Many recent studies have shown that edible insects are a rich source of fatty acids, particularly polyunsaturated fat [19, 57]. These fatty acids differ and depend on many factors such as species reproduction stages [58, 59] and season or life stage [59].

Edible insect species	Fat content (% of dry matter)	Composition of main fatty acids (% of oil content)	Type of fatty acid
African palm weevil (<i>Rhynchophorus phoenicis</i>)	54%	Palmitoleic acid 38%	MUFA
		Linoleic acid 45%	PUFA
Edible grasshopper (<i>Ruspolia differens</i>)	67%	Palmitoleic acid 28%	MUFA
		Linoleic acid 46%	PUFA
		α -Linolenic acid	PUFA
Termites (<i>Macrotermes</i> sp.)	49%	Palmitic acid	SFA
		Oleic acid	MUFA
		Stearic acid 9%	SFA
Saturniid caterpillar (<i>Imbrasia</i> sp.)	24%	Palmitic acid 8%	SFA
		Oleic acid 9%	MUFA
		Linoleic acid 7%	PUFA
		α -Linolenic acid 38%	PUFA
Variegates grasshopper (<i>Zonocerus variegates</i>)	9%	Palmitoleic acid 24%	MUFA
		Oleic acid 11%	MUFA
		Linoleic acid 21%	PUFA
		α -Linolenic acid 15%	PUFA
		γ -Linolenic acid 23%	PUFA

Source: Womeni et al. [55]. PUFA= Polyunsaturated Fatty Acids; MUFA= Monounsaturated Fatty Acids; SFA= Saturated Fatty Acids.

Table 6. Fat content and randomly selected fatty acids of several edible insect species consumed in Cameroon.

7.4. Mineral composition of edible insects

Minerals are known to play important metabolic and physiologic roles in the living system. Iron, zinc, copper, and manganese strengthen the immune system as antioxidant and cofactors of enzyme [60]. Similarly, magnesium, zinc, and selenium prevent cardiomyopathy, muscle degeneration, growth retardation, impaired spermatogenesis, immunologic dysfunction, and bleeding disorder [61]. Iron deficiency is a major problem in women's diets in the developing world, particularly among pregnant women, and especially in Africa [62]. Magnesium is needed for more than 300 biochemical reactions in the body. It helps to maintain normal muscle and nerve function, keeps the heart rhythm steady, and regulates blood sugar levels [63].

Analysis of normal elements showed that edible insects are rich in nutritious elements such as potassium and sodium (cricket nymph), calcium (adult cricket), copper (mealworm), iron (axayacatl), zinc (cricket), manganese (cricket), and phosphorus [3]. Therefore, edible insects

can supply the necessary nutritive elements for human body functions and could be consumed along with other food and animals rich in other essential minerals to further complement the diet of these insects. The mineral contents of some edible insects in Nigeria are shown in **Table 7**.

Insect species	Ca	P	Fe	Mg	Ash
<i>Megachile nigeriensis</i>	1.00*	14.90*	9.56*	60.96*	7.60*
<i>Macrotermes bellicosus</i>	21	136	27	0.15	2.90
<i>M. natalensis</i>	18	114	29	0.26	1.90
<i>Brachytrupes</i> spp.	9.21	126.9	0.68	0.13	1.82
<i>Circus aeruginosus</i>	4.40	100.2	0.35	0.09	2.10
<i>Z. variegatus</i>	42.40	131.2	1.96	8.21	1.20
<i>Argiope trifasciata</i>	61.28	136.4	18.2	6.14	4.21
<i>Anaphe infracta</i>	8.56	111.3	1.78	1.01	1.60
<i>Annona reticulata</i>	10.52	102.4	2.24	2.56	2.50
<i>Lepidoptera litoralia</i>	12.00	9.00	19.50	0.50	4.30
<i>A. venata</i>	8.57	100.5	2.01	1.56	3.20
<i>C. forda</i>	8.24	111.0	1.79	1.87	1.50
<i>A. mellifera</i>	15.4	125.5	25.2	5.23	2.20
<i>O. boas</i>	45.68	130.2	2.31	6.62	1.50
<i>Oryctes monoceros</i>	NA	NA	85.00	175.00	10.50
<i>Gymmelia lucens</i>	NA	NA	NA	NA	6.40
<i>R. phoenicis</i>	54.1	685.0	30.80	131.8	2.70
<i>Aphodius rufipes</i>	42.16	131.2	30.82	11.72	2.74

*mg/kg body weight; NA, not available.

Sources: Banjo et al. [8], Ifie and Emeruwa [64], Finke [45]; Paiko et al. [65]; Solomon and Pisca [66], Johnson [67].

Table 7. Mineral and ash (mg/100 g) contents in some edible insect species.

7.5. Vitamin composition of edible insects

Vitamins are a group of organic compounds that are necessary for metabolism in human bodies. Vitamins cannot be synthesized in the human body; they must be supplied constantly by food [38]. Vitamin C, also called ascorbic acid, serves as a reducing agent (an antioxidant), while vitamin B comprises of components of coenzymes. Vitamins K and A are required for normal blood clotting and proper vision, respectively. Many studies have shown that edible insects contain appreciable amounts of vitamins [9, 44]. The high vitamin content of edible insects presents them as a highly potentially good source of food supplement for malnourished people and animals. The vitamin contents of some insect orders are shown in **Table 8**. Each of the orders contains appreciably high amounts of vitamins A, B2, and C.

Order	N	Vitamin A		Vitamin B2		Vitamin C	
		Range	Mean	Range	Mean	Range	Mean
Isoptera	3	0.026–0.05	0.14	1.54–1.98	1.69	3.01–17.76	8.06
Coleoptera	3	0.086–0.125	0.11	0.08–2.62	1.64	4.25–7.59	5.75
Orthoptera	3	0.0–0.068	0.03	0.03–0.08	0.06	0.0–8.64	3.21
Lepidoptera	5	0.028–0.034	0.09	0.09–2.21	1.50	1.95–4.52	2.83
Hymenoptera	1				3.24		10.25

N, number of insect species in each order. Sources: Banjo et al. [8], Ifie and Emeruwa [64], Igwe et al. [9].

Table 8. Vitamin (mg/100 g) contents in some edible insects in Nigeria.

8. Edible insects as an engine for improving/replacing livestock rearing

Land, water, and energy resources are declining, so these resources need to be conserved and managed to produce more food [68]. Also, animal husbandry competes for these vital resources, as the land is occupied by the production of feed and cannot be used to produce more food for humans [32]. It is very expensive to carry out livestock farming. This is because they consume large amounts of energy than they produce [68]. For example, livestock consume 77 million tons of protein in feedstuff that is potential for human nutrition to produce 58 million tons of protein [69]. Insect culture, on the other hand, requires little areas [70]. Also, many of the edible insect species do not compete with human beings for food resources. Equally, insect farming requires little water, which is significant because water shortages already exist throughout the world and are likely to increase. Hence, insects are nick named “minilivestock” [71].

9. Environmental (ecological) opportunities of insect rearing

Insects deliver a host of ecological services fundamental to the survival of humankind. Utilization of insects as a protein source could benefit insect conservation through habitat protection [32]. Insects are essential agents feeding on organic matter in nature, and they efficiently exploit all organic sources. Insects also recycle organic waste and provide nutrients for farm animals [33, 34]. Many insect species are absolutely necessary to improve soil fertility. This is because insects play an important role in breaking down waste products until it is fit to be consumed by fungi and bacteria, thus releasing minerals and nutrients which become readily available in the soil for plant uptake, hence improving soil fertility. Animal carcasses, for example, are consumed by fly maggots and beetle larvae. Dung beetles—of which there are about 400 known species—also play a significant role in decomposing manure. Hence, insects could be used as efficient bio-transformers to convert abundant, low-cost organic wastes into animal biomass rich in proteins and suitable for use in animal nutrition [72].

10. Beneficial roles of insects for humans

Besides serving as sources of food, edible insects provide humans with a variety of other valuable products. A huge variety of insect species are known to have remarkable commercial and pharmaceutical values. For example, bees and silkworm have been shown to produce massive tons of honey and silk, respectively. These products can be sold in the local as well as in the international markets [72], while silkworms produce more than 90,000 tons of silk [73]. Also carmine, a red dye produced by scale insects of the order Hemiptera, is used to color foods, textiles, and pharmaceuticals. Resilin, a rubberlike protein that enables insects to jump, has been used in medicine to repair arteries because of its elastic properties [74]. In addition to this, other products produced by edible insects such as honey, propolis, royal jelly, and venom have been used in treating traumatic and infected wounds and burns [75]. Furthermore, insect products have also been used in engineering methods in the production of biomaterials [76].

11. Conclusion

Sustainably meeting global food demands is one of humanity's greatest challenges and has attracted considerable attention in the past few years [77]. There is general consensus on agriculture's positive contribution to food security through its role in increasing availability of affordable food and the incomes of the poor. Within the context of sustainable diet, the use of insects as food and feed has a significant role to play in assuring food security and improving livelihood of the African people. Edible insects are rich in protein and amino acids, especially essential amino acids which are necessary for the human body. They can also supply unsaturated fatty acids, minerals, vitamins, and carbohydrates, which have an excellent nutritive value. They are also of valuable importance medically, commercially, and ecologically. These edible insects should therefore be taken into consideration for a world in which human nutrition has been a huge problem.

12. The way forward

Recent studies have identified four important challenges that must be addressed in order to tap the huge potentials that edible insects offer for enhancing food and feed security.

To begin with, more work on the nutritional values of edible insects is needed in order to establish insects as food. Also, insect farming should be compared with livestock farming in order to determine which one of them is more environmentally damaging or environmentally friendly. Furthermore, there should be a further clarification on the socioeconomic importance of edible insects in enhancing food security. Lastly, clear comprehensive legal framework at (inter)national levels is needed to pave the way for more investment, leading to the full development of production and international trade in insect products as food and feed sources.

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