

## Regenerative edible insects for food, feed, and sustainable livelihoods in Nigeria: Consumption, potential and prospects

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### ABSTRACT

Edible insects are imperative as food, feed, and other products for industries, but commercial farming and utilization of insects as food, feed and industries is seldom in Nigeria. However, consumption of insects in Nigeria is longstanding and increasingly becoming popular and receiving more attention because of their potential as alternatives to animal protein and a means of livelihood to mitigate hunger and poverty. We harnessed academic and grey literature and personal communications to obtain a wholesome and concise review of the edible insects in Nigeria. This process revealed 13 edible insect species consumed amongst various tribes and indigenous people in the country. We found that the consumption of insects in Nigeria is ubiquitous but more popular and generally accepted in southern Nigeria than in the northern part of the country. However, farming insects for food and feed is seldom because edible insects are harvested from wild populations. Insights into the challenges of farming edible insects in Nigeria revealed that funding, seasonality, technical know-how or expertise are at the forefront, while poor extension services, inadequate processing technologies, and not having in place strategies for their upscaling are also implicated. We recommend mutualistic cooperation between key stakeholders along the agricultural value chain in Nigeria, such as the government, investors, and others that will foster partnerships with established industries in East Africa, especially Kenya and Uganda, where farming insects for food, feed, and livelihoods is thriving.

### Introduction

Lack of food remains one of the biggest threats to human survival, life expectancy, and quality in sub-Saharan Africa (SSA) (FAO 2021; 2022). Despite the global concerted actions to achieve the United Nations (UN) zero hunger and good-health and wellness as enshrined in the Sustainable Development Goals (SDGs) by 2030, food insecurity and poverty are worsening in SSA (FAO 2021; 2022). More worrying is that SSA, albeit the poorest region of the world, will substantially add to the expected 2.5 billion increase in human population in developing countries by 2050 (UN, 2017); yet almost half (48 %) of the populace is currently food insecure, malnourished, and extremely poor. Over 18

million new jobs or more are needed yearly to minimize exacerbation of the already existing extreme poverty, food, and health crises (Black et al., 2013), which result in permanently stunted growth in 38 % of children under five, and other life-threatening diseases and defects associated with severe acute malnutrition (FAO, 2021). Put simply, food is insufficient in SSA, both in quantity and quality – the so-called hidden hunger (FAO 2021; 2022). Conversely, enhancing agricultural productivity is one of the critical entry points in designing poverty reduction strategies and food security in SSA (FAO, 2022). Hence, developing innovative solutions that address the challenges affecting agricultural productivity is crucial to meeting the nutritional and economic needs of SSA toward the full realization of the UN SDGs (FAO, 2021).

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Nigeria, popularly called “the giant of Africa”, due to its large population size and huge market potential, is the most populous country in Africa (~ 230 million people) (Zulu, 2009). Agriculture is a fundamental source of food and sustainable livelihoods for millions of people in the country, especially women and youths in rural communities that rely solely on small-scale farming for their livelihoods (Miech et al., 2016). Most people in Nigeria live in rural households, and about 57.3% of the people are engaged in agricultural-related means of livelihood. However, more than 70 % are food insecure, yet by 2050 the population would nearly double, and half will be under 25 years (FAO, 2022). Hence, the desideratum for innovative strategies to alleviate the current

food insecurity in preparing for the future. In this context, substantial increases in the production of traditionally underutilized foods such as edible insects have become warranted and are gaining traction across Africa (Anankware et al., 2015; Dorte et al., 2021). For example, Tanga et al. (2021) documented that in the last ten years, farming edible insects has increasingly become an emerging and profitable enterprise in East African countries, including Kenya, Tanzania, and Uganda. The authors elucidated that edible insect farming is thriving in East Africa because of the good knowledge of entomophagy in the region, especially in Kenya and Uganda. In fact, a previous study found that over 75 % of farmers in Kenya, Tanzania, and Uganda are willing to use and pay for insect-based

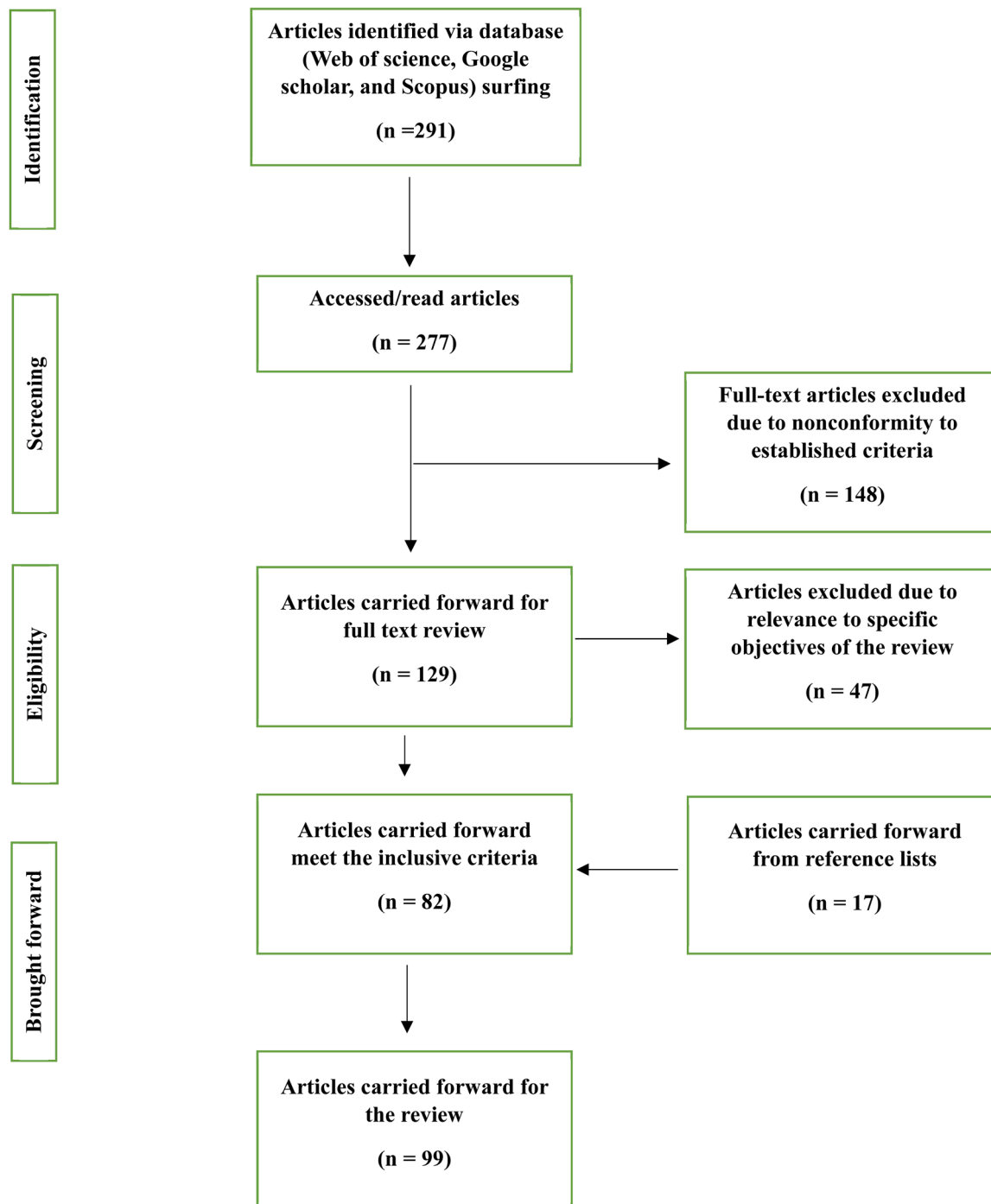


Fig. 1. Systematic flow chart of the selection process of relevant articles used to synthesize the literature on edibles insects in Nigeria, their consumption and nutritional composition.

feeds for their poultry, pig, and fish farms, compared to conventional fishmeal-based feeds (Chia et al., 2020).

Like East Africa, the utilization of insects and insect-based feeds for human and livestock consumption is also longstanding in Nigeria but awareness, promotion, and research towards commercialization for sustainable livelihoods are lagging. This review provides snapshot insights into the history of insect farming for food and feed in Nigeria. It further elucidates the current status, role, and prospects of regenerative edible insects for food and feed in Nigeria, and the potential livelihood opportunities it may confer, especially in impoverished rural communities. Finally, summaries of the discussions on the future of edible insects for food and feed in Nigeria and its prospects for health and sustainable livelihoods during a German Academic Exchange Services (DAAD) Alumni event meeting, held with key stakeholders along the value chain, including the Edo State Government and several related agricultural and environmental ministries and agencies and DAAD Alumni, in Nigeria in July 2023 are presented.

## Methodology

A generic and specific search and review of relevant academic and grey literature was undertaken in three databases (Google Scholar, ISI Web of Science, and Scopus) (Fig. 1). Published papers, conferences, symposiums, workshop proceedings, and dissertations, some of which are not available online, were also accessed. Before systematically reviewing the reference lists in the acquired papers, we sorted all data sources and included only articles relevant to the history, benefits, uses, and challenges, of edible insects especially in Nigeria as well as other parts of Africa, and then globally (Fig. 1). This was supported by personal communications with some researchers, extension workers from the relevant government ministries in Nigeria, and farmers.

## Consumption and benefits of farming edible insects in Nigeria

### Consumption

Insects have played a notably significant role in the history revolving around human nutrition (Roos and van Huis, 2017), not just in Africa but in continents such as Latin America and Asia (Bodenheimer, 1951; Yi et al., 2010; Kelemu et al., 2015; Roos, 2018; Tarboton, 2017). The diversity in the numbers and groups of edible insects consumed or in traditional diets is found highest in Asia, followed by Africa and South America, respectively (Costa-Neto, 2015; Kelemu et al., 2015; Yen, 2015). Numerous species of insects have been consumed as food by humans, including various aquatic insects, cicadas, winged ants, larvae and pupae of ant brood, wasps, bees, winged termites, adults and grubs of beetles, caterpillars, and grasshoppers (Banjo et al., 2006; Srivastava et al., 2009; Roos, 2018; Thomas et al., 2019).

Several insect species or products have been used or consumed as food in various parts of Nigeria and eaten mostly as titbits, particularly by children (Ene, 1963; Banjo et al., 2006). Nigeria has a longstanding tradition of insect consumption, with the southern part of the country recording over 50 species of edible insects (Kelemu et al., 2015). In 2017, the very first food consumption table for the country was released and this included information on the nutrition of three edible insect species namely: winged termites *Macrotermes bellicosus*, African Rhinoceros beetle (*Oryctes* sp.) and African Palm weevil *Rhynchophorus phoenicis* (F.) (Coleoptera: Curculionidae) (Bride and Nwaoguikpe, 2011; NFDN, 2017).

Fasoranti and Ajiboye (1993) in their study reported the consumption of the variegated grasshopper, *Zonocerus variegatus* L., (Orthoptera: Pyrgomorphae) in an area in Ondo State named Akoko. The population of the grasshoppers was also found to be highest in the dry season in southwestern Nigeria. Other southwestern Nigerian states where *Z. variegatus* is consumed include Lagos, Ogun, Osun, Oyo, and Ekiti (Banjo et al., 2006). The larvae of the palm weevil *R. phoenicis* are eaten

either in its raw form or fried in Edo, Bayelsa, and Delta states and across various parts of western Nigeria (such as Lagos, Ogun, Ekiti, Osun, Ondo, Oyo) (Table 1) where these fried grubs/larvae of palm weevil are marketed or displayed in commercial boxes or trays for buyers (Banjo et al., 2006; Ekop et al., 2010; Elemo et al., 2011).

The winged termites *Macrotermes nigeriensis* and *M. bellicosus* (Fig. 2) are enjoyed and consumed as traditional delicacies across various parts of Nigeria (Fig. 3), especially during the onset of the rainy season characterized by reduced food quantity (e.g., reduced stored products, newly planted crops not yet mature for production and decline in livestock) (Banjo et al., 2006; Igwe et al., 2011). There have been documented reports from several parts of western Nigeria on the consumption of termites *M. bellicosus*. Here, the winged adults are typically caught or collected from the ground after wings shedding, or while on nuptial flight and then roasted or fried and consumed (Banjo et al., 2006; Alamu et al., 2013).

The grubs of *O. monoceros* have become a commonly consumed delicacy by some people in the Niger Delta region (Ifie and Emeruwa, 2011). The larvae of the African silkworm *Anaphe venata* are widely found and commonly consumed by the people of Kwara State in southwestern Nigeria (Adamolekun, 1993; Iwalewa et al., 2005). This species has also been reported to be consumed and enjoyed by people in Lagos, Ogun, Osun, Ondo, Oyo, and Ekiti States (Banjo et al., 2006). Okweche et al., 2022 reported the consumption of the African cricket *Brachytrupes membranaceus* in Cross River State in Nigeria. Braide et al. (2010b) reported that the Igbo-speaking ethnic group or tribe of the southern and eastern part of Nigeria consume the caterpillar of *Bunaea alcinoe*, locally called “Egu” as a traditional delicacy. *Zonocerus variegatus* and the yam tuber beetle *Heteroligus meles* are generally eaten by people in some parts of Benue State and in the southeastern part of Nigeria such as Abia State (Ekop et al., 2010; Elemo et al., 2011; Okore et al., 2014; Serra, 2023). Additionally, in Benue State, the most consumed, preferred, abundant, and marketed edible insects by the people are *Macrotermes natalensis*. This is followed by *B. membranaceus* and *Cirina forda*, respectively (Agbidye et al., 2009). *Zonocerus variegatus* is also widely consumed and perceived as a local delicacy amongst the Babur people in Borno State of Northern Nigeria, where the grasshoppers are marketed by display in baskets and sold to people as meat (Soloman et al., 2008; Alamu et al., 2013).

Also, in Kwara State, people widely consume “Kanni” which is a local name for *C. forda*, a Saturnid caterpillar (Adegbola et al., 2013). This caterpillar is also commonly consumed by the Nupe tribe of Niger State (Fasoranti and Ajiboye, 1993) as well as in the southwestern Nigerian states such as Lagos, Ogun, Osun, Ondo, Oyo and Ekiti (Banjo et al., 2006). Adegbola et al. (2013) posit that this caterpillar is used by people for vegetable soup preparation and remains the most extensively marketed edible insect consumed in Nigeria and sold for about twice the price of beef. In Niger State, the people of Gwari/Gbagyi ethnic group/tribe consume the larvae of *Aphodius rufipes*, a dung beetle, as a local delicacy and perceive it as an alternative source of protein (Paiko et al., 2012). The North Central region of Nigeria particularly the people of Plateau State locally consume the larvae/caterpillar of *Lepidoptara litoralia* (Fig. 2) which is commonly found in the landscapes (Solomon and Prisca, 2012). Okore et al. (2014) reported consumption of an African Rhinoceros beetle (*Oryctes* sp.) by people of Ondo, Akwa Ibom, Delta, Cross River, and Abia states.

A close observation of the practice of entomophagy or the consumption of various edible insects in Nigeria revealed higher frequencies in the middle belt and southern regions compared to the northern part of the country (Fig. 4). This can be attributed to the climate of the middle-belt and southern regions of the country, which supports the growth of trees that act as plant hosts to most of these insect species than in the far northern parts of Nigeria (Alamu et al., 2013). However, this does not suggest the unavailability of edible insects in northern Nigeria. Further, the cultural perception of the Hausa people may also be implicated in the lower frequencies of entomophagy in the region. Also, inadequate

**Table 1**  
Common edible insects consumed by various indigenous people across different States in Nigeria and life stage consumed as food.

Species	Common name	Local common name	Order	Family	State	Stage consumed	References
<i>Rhynchophorus phoenicis</i>	African palm weevil	Yoruba: Munimuni Igbo: Eruru, Erungwo Hausa: Kwaron dabino	Coleoptera	Curculionidae	Edo, Delta, Bayelsa, Lagos, Ogun, Ekiti, Osun, Ondo, Oyo.	Larva, Adult	Banjo et al., 2006; Ekop et al., 2010; Elemo et al., 2011; Okore et al., 2014.
<i>Zonocerus variegatus</i>	Variegated grasshopper	Yoruba: Tata Igbo: Ụkpana Hausa: Fara	Orthoptera	Pyrgomorphidae	Ondo, Benue, Abia, Borno.	Adult	Fasoranti and Ajiboye, 1993; Soloman et al., 2008; Ekop et al., 2010; Elemo et al., 2011; Alamu et al., 2013; Adegbola et al., 2013.
<i>Macrotermes nigeriensis</i>	Adult/gregarious winged termite	Yoruba: Esusun Igbo: Akụ Ibibio (Akwa Ibom): Mbube Hausa: Shinge	Isoptera	Termitidae	Various parts of Nigeria	Winged queen	Banjo et al., 2006; Igwe et al., 2011; Alamu et al., 2013.
<i>Macrotermes bellicosus</i>	Termite	Yoruba: Esusun Igbo: Akụ Ibibio (Akwa Ibom): Mbube Hausa: Shinge	Isoptera	Termitidae	Various parts of Nigeria	Winged queen	Banjo et al., 2006; Igwe et al., 2011.
<i>Oryctes monoceros</i>	African rhinoceros beetle	Yoruba: Ipe, Labombom Igbo: Akpa Hausa: Kwaron karkanda	Coleoptera	Scarabaeidae	Niger Delta region, Ondo, Akwa Ibom, Delta, Cross River, Abia	Larva, Adult	Ifie and Emeruwa, 2011; Okore et al., 2014.
<i>Anaphe venata</i>	Silk moth/African silkworm	Yoruba: Ekuku	Lepidoptera	Notodontidae	Kwara	Larva	Adamolekun, 1993; Iwalewa et al., 2005; Young, 2013.
<i>Bunaea alcinoe</i>	Cabbage tree emperor moth	Igbo: Egu	Lepidoptera	Saturniidae	Eastern and Southern Nigeria	Larva	Amada et al., 2005; Braide et al., 2010b; Hollander, 2023
<i>Heteroligus meles</i>	Yam tuber beetle	Igbo: Ebeke, Ebe Hausa: Kwaron doya	Coleoptera	Dynastidae	Benue, Abia	Larva, Adult	Ekop et al., 2010; Elemo et al., 2011; Okore et al., 2014. Georgen, 2016
<i>Macrotermes natalensis</i>	Fungus-growing termite	Yoruba: Esusun Igbo: Akụ Ibibio (Akwa Ibom): Mbube Hausa: Shinge	Blattodeae Infraorder: Isoptera	Termitidae	Benue	Winged queen	Agbidiye et al., 2009; Kim et al., 2014
<i>Brachytrupes membranaceus</i>	Tobacco cricket	Yoruba: Ire Igbo: Abụzụ/ Mbụzụ Hausa: Gyareh	Orthoptera	Gryllidae	Benue	Adult	Agbidiye et al., 2009.
<i>Cirina forda</i>	Pallid emperor moth/shear defoliator	Yoruba: Ekuku	Lepidoptera	Saturniidae	Benue, Kwara, Niger	Larva	Fasoranti and Ajiboye, 1993, Agbidiye et al., 2009; Adegbola et al., 2013.
<i>Aphodius rufipes</i>	Night-flying dung beetle	–	Coleoptera	Scarabaeidae	Niger	Larva	Paiko et al., 2012; Henriklh, 2023
<i>Lepidoptra litoralia</i>	Defoliator of <i>Isobertinia doka</i>	Hausa: Makambari	Lepidoptera	–	Jos	Larva	Solomon and Prisca, 2012.

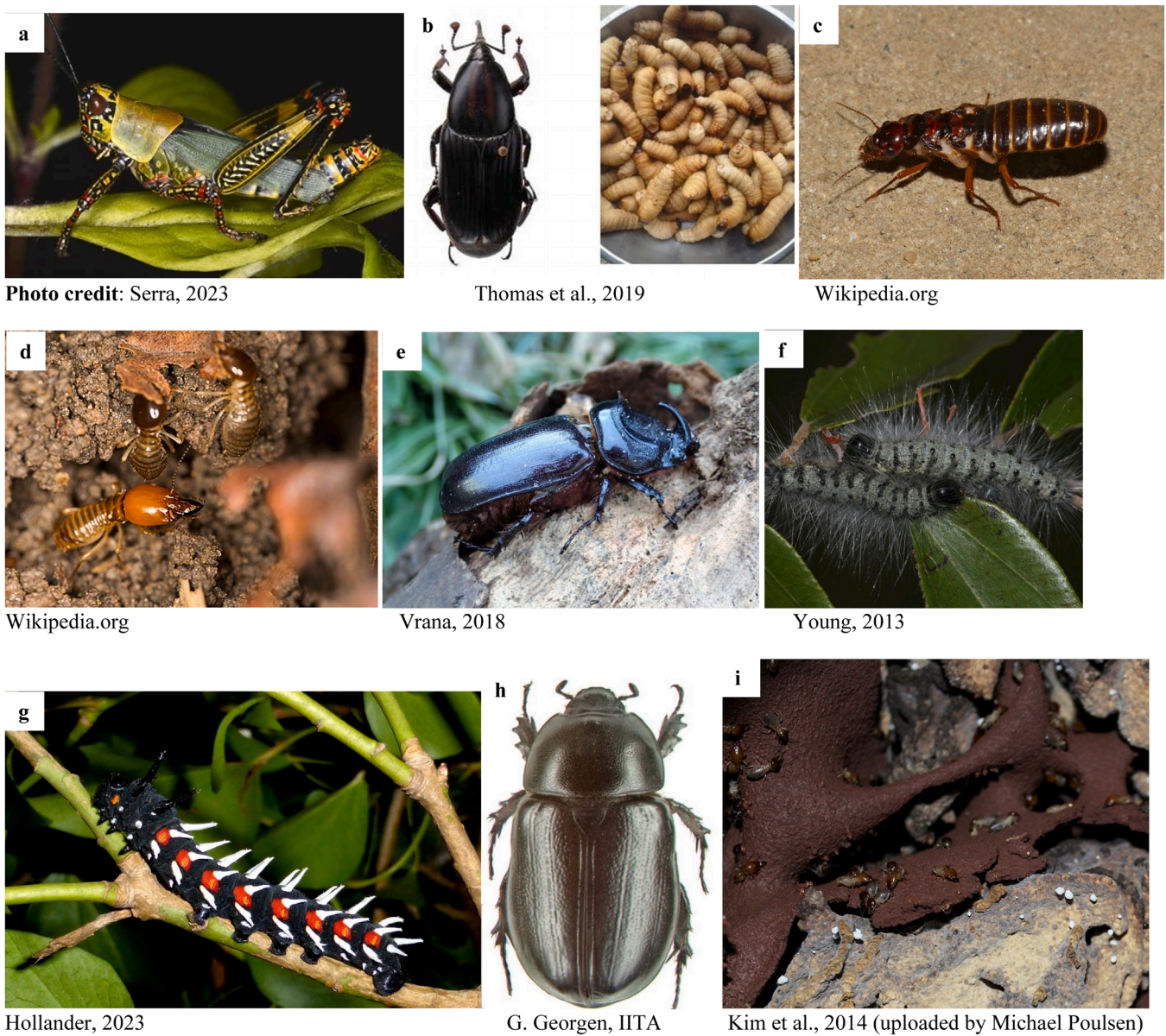
research, literature documentation, and reports on the practice of entomophagy in northern Nigeria are lacking (Alamu et al., 2013).

### Benefits and uses of edible insects

People have been eating insects as part of their diets on a regular basis for thousands of years across the world (van Huis et al., 2013). Due to its numerous benefits, there has been an increased interest in edible insects in recent years (Fasoranti and Ajiboye 1993; Ebenebe and Okpoko 2015). As a developing country, Nigeria has many opportunities for benefiting from entomophagy due to the abundance of edible insects in the country (Ebenebe and Okpoko 2015; Tan et al., 2015). For example, rural women in Nigeria add edible termites, raw or ground, to soup to improve the taste (Fasoranti and Ajiboye 1993), and the nutritional quality of the food, particularly protein content (Ebenebe and Okpoko 2015). This could contribute to the realization of the first three UN SDGs (zero poverty, zero hunger, and good health and well-being) (Ayieko et al., 2016; Imathiu, 2020). The following are some uses and benefits derived from edible insects in Nigeria.

### High nutritional value

Edible insects possess a high nutritional value given that they have various nutritional compositions such as protein, carbohydrate, minerals, and vitamins (Amadi et al., 2005; Banjo et al., 2006; Vrana, 2018). Consequently, they are considered a good source of nutrients. Edible insects may help consuming populations meet their nutritional requirements, especially micronutrients like magnesium, calcium, copper, iron, selenium, and zinc (Gibson, 2015; Raubenheimer and Rothman, 2011; Schiavone et al., 2018). According to a recent study, termites and crickets are among the most consumed insects in southern Nigeria (Ibitoye et al., 2021). These insects (termites and crickets) have been reported to have protein contents ranging from 43.8 to 71.0 %, respectively (Oibiokpa et al., 2017). When compared to the value of protein contained in conventional meat, dairy products, fish, and plants, Defoliart (2002) and Jacob et al. (2013) highlighted that the protein content in crickets and termite were considerably higher (Oibiokpa et al., 2017). These are crucial to preventing health deficiencies linked to the lack of proteins in infants and children such as “kwashiorkor” (Ekpo,



**Fig. 2.** Edible insects consumed in Nigeria: (a) variegated grasshopper (*Zonocerus variegatus*), (b) adult and larvae of African palm weevil (*Rhynchophorus phoenicis* F.), (c) adult gregarious termite (*Macrotermes nigeriensis*), (d) termite (*Macrotermes bellicosus*), (e) African rhinoceros beetle (*Oryctes monoceros*), (f) caterpillars of African silk moth (*Anaphe venata*), (g) caterpillar of cabbage tree emperor moth (*Bunaea alcinoe*), (h) yam tuber beetle (*Heteroligus meles*), (i) fungus-growing termites (*Macrotermes natalensis*), (j) tobacco cricket (*Brachytrupes membranaceus*), (k) caterpillar of pallid emperor moth (*Cirina forda*), (l) larva of night-flying dung beetle (*Aphodius rufipes*), (m) caterpillars of defoliator of *Isoberlinia doka* (*Lepidoptera litoralia*), (n) larva of African rhinoceros beetle (*O. monoceros*).

2011). With their high protein, lipid, mineral, vitamin, and fiber contents, a wide variety of edible insect species substantially contribute to the fight against hunger and poverty. Consequently, eating edible insects serves as an alternative to 'hidden hunger', prevalent in developing countries like Nigeria (Gibson, 2015), as they contain a higher level of calcium, zinc, and iron than chicken, pork, and beef, and cost-effective (Sirimungkararat et al., 2010). For example, *R. phoenicis* is rich in protein (28.42 %), carbohydrates (48.6 %), vitamins (A, B<sub>2</sub>, C), and calcium (39.58 %) (Table 2). Okweche et al. (2022) denoted that crickets contain a significantly higher level of crude fiber compared to conventional Nigerian meat sources, such as fish, chicken, beef, and goat. In comparison to animal and plant-based protein sources (e.g., beef, chicken, fish, soybeans), edible insects have a higher protein content in percentage to body mass ratio (Stull et al., 2019). An excellent example is the mopane worm *Gonimbrasia belina* (Westwood) (Lepidoptera:

Saturniidae), which has three times the protein content of beef (Kwiri et al., 2020). In addition, due to the low salt content of edible insects, people with high sodium sensitivity can include them in their reduced sodium diets (Rumpold and Schluter, 2013).

#### Environmentally sustainable

In addition to providing nutritional benefits, edible insects play a vital role in environmental sustainability (Ooninx et al., 2010). This is because they can feed on organic waste, which reduces environmental pollution and greenhouse gas emissions (Van Huis, 2013). The yellow mealworm *Tenebrio molitor* L. (Coleoptera: Tenebrionidae) grows well on organic waste (Khusro et al., 2012), which would otherwise be discarded, resulting in environmental pollution. Many insect species have been found to be highly effective bio-converters of organic wastes. These

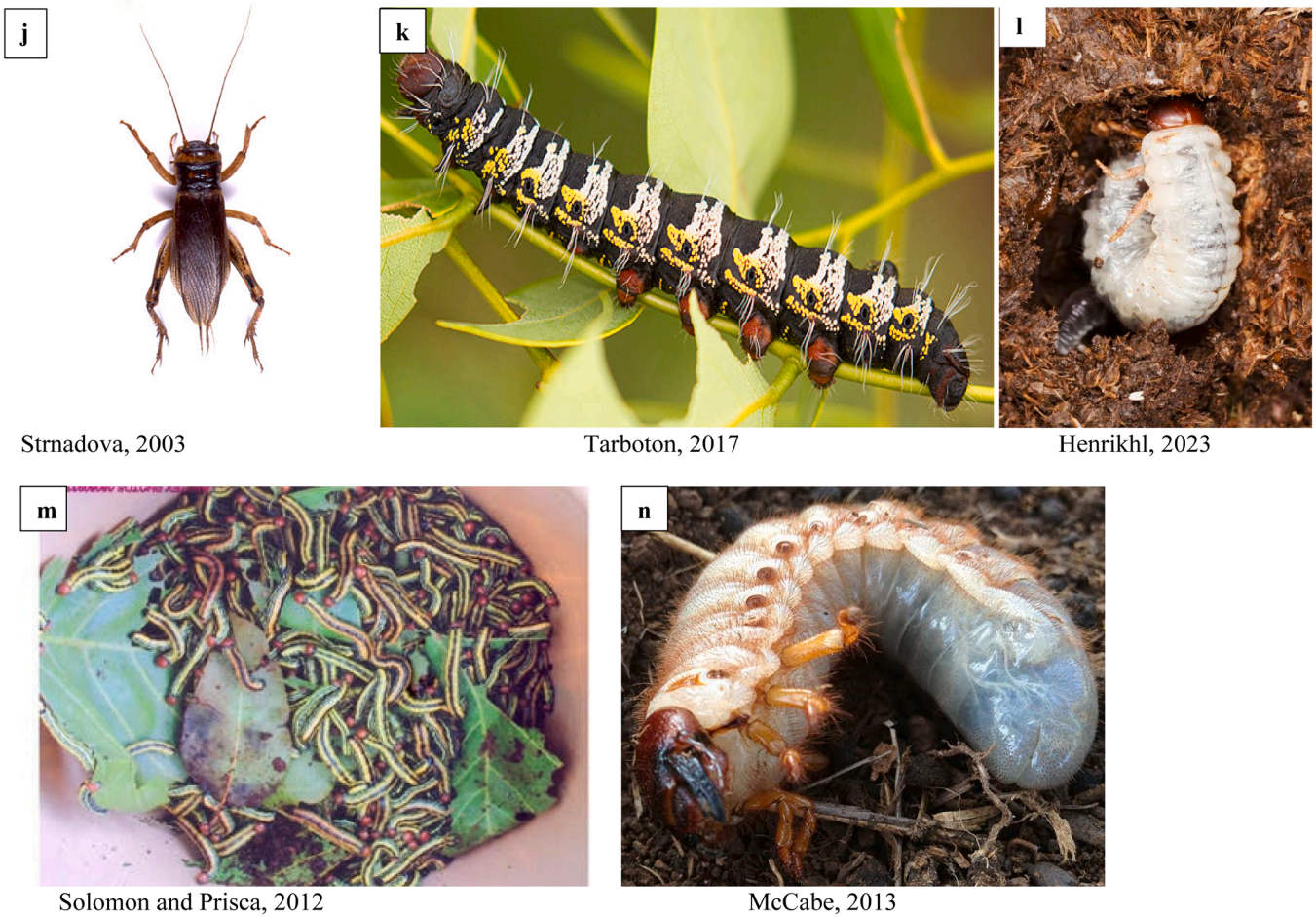


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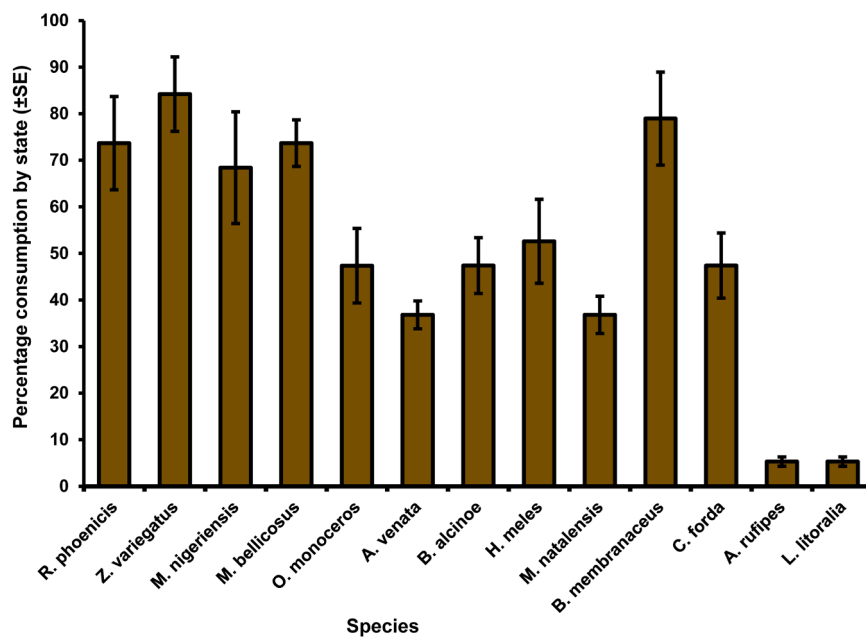


Fig. 3. Percentage consumption of various edible insects across the nineteen (19) states in Nigeria where consumption was recorded.

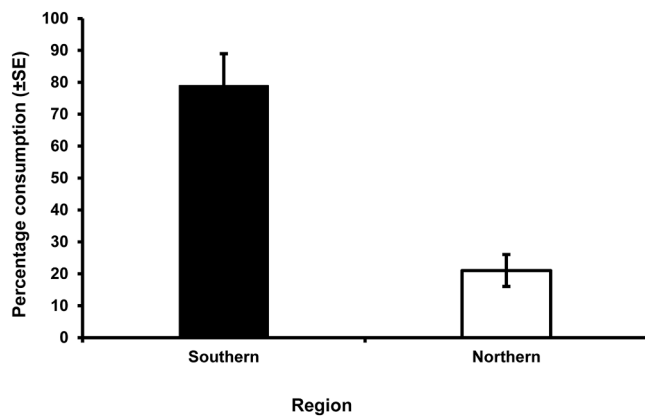


Fig. 4. Percentage consumption of various edible insects in the two major regions in Nigeria.

include *T. molitor*, maggots of the common housefly *Musca domestica* L., (Diptera: Muscidae), and the black soldier fly *Hermetica illucens* L., (Diptera: Stratiomyidae) (Alagappan et al., 2022). As a result of their potential to transform ~1.3 billion tonnes of biowaste annually, these species are gaining traction (Veldkamp et al., 2012). Other environmental benefits of insect farming include significantly less amount of land and water use than livestock farming (Oonincx and De Boer, 2012; Mlček et al., 2014; Nadeau et al., 2015; Halloran et al., 2017; Govorushko, 2019). Oonincx and De Boer (2012) found that *T. molitor* production facility accounted for only 0.2 % of the total land use, while the facility to produce conventional animal feed accounted for 99 % of land use. Additionally, comparing broiler chickens, cattle, and mealworms, broilers and cattle emit greenhouse gases between 32 and 167 %, which is 6–13 times more emissions compared to mealworms (Oonincx and De Boer, 2012). Miglietta et al. (2015) found that the facility to produce mealworms requires less water compared to livestock production. A gram of edible protein from livestock (e.g., beef) would require 8–14 times more land and about 50 % more water compared to mealworms (Oonincx and De Boer, 2012; Miglietta et al., 2015). Also, when compared to crickets, producing 1 kg of beef requires 3000 times more water, 12.5 times more feed, and significantly more acreage for husbandry (Van Huis, 2013; Halloran et al., 2016; Guiné et al., 2021).

#### Efficiency in feed conversion

Edible insects have additional benefits over livestock, including high rate of reproduction and feed conversion efficiency (Klunder et al., 2012). According to Van Huis and Oonincx (2017), edible insects have a higher feed conversion efficiency; larvae of *H. illucens* may convert up to 55 % of dietary protein into edible body mass and *T. molitor* up to 45 %. Van Huis and Oonincx (2017) underscored that this feed conversion efficiency is significantly higher than chicken. Also, up to 80 % of the content of crickets is edible and digestible, compared to 40 % for cattle and 55 % for chickens and pigs (Nakagaki and DeFoliart, 1991). This has been corroborated by Heckmann et al. (2018) and Van Huis et al. (2013), suggesting a potential for large reductions of food loss. Van Huis et al. (2013) also showed that crickets are four, two, and twelve times more efficient in converting feed into meat than pigs, chickens, and cattle, respectively. The latter authors articulated that this efficiency may be because insects are cold-blooded and do not require energy to regulate their body temperature. Furthermore, in livestock production, for 1 kilogram of live animal weight, 2.5 kg of feed is needed for chicken, while 5 kg is required for pork, and 10 kg for beef (Smil, 2002). In contrast, insects eat significantly smaller food quantities. In summary, the benefits of consuming insects increase when mass production is considered (Collavo et al., 2005; van Huis, 2013).

#### Entomophagy facilitates pest control

About 92 % of edible insects are from wild harvest, and harvesting insect pests for use as food reduces anthropogenic consumption of toxic pesticides (McCabe, 2013; Strnadova, 2003). Insects, especially edibles, would not be considered pests but rather a source of essential protein when most people eat them. Furthermore, some locust species that are dreaded and regarded as harmful to crops in tropical Africa are considered delicacies by people from other areas and cultures (Adegbola et al., 2013). Dobermann et al. (2017) highlighted that entomophagy is a viable technique for managing crop insect pests such as locust, exemplified in Thailand in 1978 because of the government's promotion of insect consumption. Therefore, a critical entry point to boost food production and ameliorate pest pressure in agroecosystems could be harvesting insects for food (van Huis, 2018). It has also been demonstrated that rearing and eating insects considerably reduces the frequency of pesticide applications (Cerritos and Cano-Santana, 2008). Hence, lowering the lethal and sublethal effects of pesticides to beneficial species and pesticide residues in crops.

#### Entomophagy promotes food diversity

Due to the increase in human population and its associated pressure on the ecosystems and natural resources to generate animal protein, the demand for animal feed is rising (Verbeke et al., 2015). For example, in Nigeria, the costs of beef, chevon, and poultry have been rising due to increasing demand by the teeming population. Therefore, focusing on eating insects may help or serve as an alternative to these essential protein-based foods, while also preserving biodiversity. Consequently, decreasing the demand for some over-farmed livestock and encouraging environmentally friendly practices (Yen, 2015). Insects can also be used to make protein bars, snacks, and other culinary items when ground into flour for baking (Yen, 2015).

#### Disease risk reduction

Unlike other meat products, reports of zoonotic or food poisoning are from edible insects. However, research or information on safety is important to satisfy or dissipate potential concerns by consumers in Nigeria (Adeoye et al., 2014). Edible insects may be a safer food source because they are less likely to spread zoonotic diseases to people when compared to conventional livestock and game meat. More importantly, most edible insects are herbivores (Gullan and Cranston, 2014), and have clean eating habits, which makes them safer and healthier than chicken, pigs, and many other conventional protein sources such as crabs or lobsters, which eat carrion and are sometimes collected from contaminated aquatic systems (Mitsubishi, 2016). *Zonocerus variegatus* which is popularly consumed in Nigeria is one of the safest food sources in the country (Abbasi and Abassi, 2011), and others such as termites, palm weevil, and crickets are generally herbivores and considered safe. However, carelessness in processing and handling methods may pose potential food safety risks (Ebenebe and Okpoko, 2015).

#### Insects as feed

The increasing cost of livestock feed in Nigeria in the past ten years has increased the cost of animal protein, especially poultry and fish. Insects such as black soldier flies, maggots, and cricket have proven useful for the replacement of protein sources of animal feed (Tanga et al., 2021). Ten years ago, van Huis (2013) articulated that insect-based protein diets fed to poultry did not adversely affect the quality and texture of the meat. Additionally, Al-Qazzaz et al. (2019) found that the growth, appearance, and texture of the Nile Tilapia *Oreochromis niloticus* L., (Cichliformes: Cichlidae) were not adversely affected by replacing fish meal with insect-based meals. Due to the prebiotic action of chitin, broiler hens given a diet consisting of

**Table 2**  
Nutritional composition of the 13 edible insects recorded in Nigeria.

Species	Protein (%)	Fat (%)	Carbohydrate (%)	Fibre (%)	Vitamins (mg/100 g)											Minerals (mg/100 g)					References
					A	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	B <sub>6</sub>	B <sub>9</sub>	B <sub>12</sub>	C	D	E	K	Ca	Fe	Zn	P	Mg	
<i>Rhynchophorus phoenicis</i>	28.42	–	48.6	2.82	11.25	–	2.21	–	–	–	–	4.25	–	–	–	39.58	12.24	–	126.4	7.54	Banjo et al., 2006
<i>Zonocerus variegatus</i>	41.13 <sup>a</sup> ±0.31	32.1 <sup>c</sup> ±0.39	6.80 <sup>b</sup> ±0.46	–	11.69 <sup>c</sup> ±0.67	0.47 <sup>a</sup> ±0.00	0.26 <sup>a</sup> ±0.02	1.35 <sup>c</sup> ±0.04	25.3 <sup>b</sup> ±0.08	0.42 <sup>a</sup> ±0.08	0.26 <sup>a</sup> ±0.01	6.46 <sup>b</sup> ±0.10	–	10.5 <sup>a</sup> ±0.23	–	30.78 <sup>c</sup> ± 0.09	38.10 <sup>b</sup> ± 0.72	18.11 <sup>c</sup> ± 1.33	412.90 <sup>c</sup> ± 2.20	31.33 <sup>b</sup> ± 1.11	Atowa et al., 2021.
<i>Macrotermes nigeriensis</i>	35.9	–	–	5.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Mbah and Elekima, 2010
<i>Macrotermes bellicosus</i>	68.23 <sup>c</sup> ±1.01	8.29 <sup>a</sup> ±0.68	4.95 <sup>a</sup> ±0.32	–	2.65 <sup>a</sup> ±0.28	0.53 <sup>b</sup> ±0.06	3.34 <sup>b</sup> ±0.11	1.10 <sup>ab</sup> ±0.00	30.6 <sup>c</sup> ±0.71	0.56 <sup>bc</sup> ±0.06	0.34 <sup>b</sup> ±0.02	4.58 <sup>a</sup> ±0.22	–	18.8 <sup>b</sup> ±1.01	–	14.74 <sup>b</sup> ± 1.04	65.96 <sup>c</sup> ± 1.98	8.84 <sup>a</sup> ± 0.84	358.44 <sup>a</sup> ± 2.11	11.68 <sup>a</sup> ± 0.13	Atowa et al., 2021.
<i>Oryctes monoceros</i>	34.76 ± 0.442 <sup>a</sup>	10.00 ± 0.013 <sup>a</sup>	10.37±1.732 <sup>a</sup>	8.70 ± 0.701 <sup>a</sup>	0.17 ± ±0.01 <sup>a</sup>	5.90 ± ±0.24 <sup>a</sup>	27.1 ± 0.76 <sup>a</sup>	–	0.80 ± ±0.05 <sup>a</sup>	–	70.4 ± 4.12 <sup>a</sup>	4.13 ± ±0.01 <sup>a</sup>	0.51 ± ±0.01 <sup>a</sup>	24.0 ± 1.49 <sup>a</sup>	7.43 ± 0.57 <sup>a</sup>	360.00 ± ± 16.00 <sup>a</sup>	1.20 ± 0.16 <sup>a</sup>	0.65 ± 0.08 <sup>a</sup>	38.85 ± 1.50 <sup>a</sup>	145.20 ± ± 8.00 <sup>a</sup>	Anaduaka et al., 2021
<i>Anaphe venata</i>	25.7	–	55.6	2.30	3.12	–	1.25	–	–	–	–	2.22	–	–	–	8.57	2.01	–	100.5	1.56	Banjo et al., 2006
<i>Bunaea alcinoe</i>	44.23 ± 0.62	10.85 ± ±0.65	22.16 ± 1.09	11.80 ± ± 0.27	–	–	–	–	–	–	–	–	–	–	–	27.00 ± 0.12	38.67 ± 1.02	24.73 ± 0.90	128.50 ± 0.32	19.53 ± 2.10	Dauda et al., 2014
<i>Heteroligus meles</i>	38.1	32.0	20.1	3.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Jonathan, 2012
<i>Macrotermes natalensis</i>	22.1	21.4	42.8	2.20	2.56	–	1.54	–	–	–	–	3.01	–	–	–	18	29	–	114	0.26	Banjo et al., 2006
<i>Brachytrupes membranaceus</i>	53.4	53.0	15.10	15.0	0.0	–	0.0	–	–	–	–	0.0	–	–	–	9.2	0.7	–	126.9	0.1	Musundire et al., 2016
<i>Cirina forda</i>	53.28 <sup>b</sup> ±0.68	23.6 <sup>b</sup> ±0.59	4.60 <sub>a</sub> ±0.28 <sup>a</sup>	–	6.89 <sup>b</sup> ±0.45	0.64 <sup>c</sup> ±0.02	5.31 <sup>c</sup> ±0.36	1.08 ± 0.11	19.0 <sup>a</sup> ±0.47	0.48 <sup>ac</sup> ±0.05	0.31 <sup>b</sup> ±0.04	9.13 <sup>c</sup> ±0.61	–	18.7 <sup>b</sup> ±0.89	–	7.88 <sup>a</sup> ± 0.92	27.85 <sup>a</sup> ± 3.10	13.80 <sup>b</sup> ± 1.65	397.03 <sup>b</sup> ± 4.35	11.80 <sup>a</sup> ± 0.02	Atowa et al., 2021.
<i>Aphodius rufipes</i>	22.42 ± 0.10	30.50 ± ± 1.20	13.07 ± 0.00	28.12 ± ± 0.20	–	–	–	–	–	–	–	–	–	–	–	42.16 ± 0.10	30.85 ± 0.31	0.70 ± 0.00	131.2 ± 0.01	3.70 ± 0.10	Paiko et al., 2012
<i>Lepidoptara litoralia</i>	59.8 ± 2.2	17.0 ± 3.2	20.2 ± 1.3	3.1 ± 0.3	–	–	–	–	–	–	–	–	–	–	–	12.1 ± 0.1	19.5 ± 1.4	15.1 ± 0.3	9.0 ± 2.0	0.5 ± 0.5	Solomon and Prisca, 2012

- Indicates no available data or information on the nutrition value

mealworm meal (MWM) had significantly higher disease resistance and immunological responses when compared to soybean meal (Bovera et al., 2015). Adding insect-based meals to pet feed can also be a good substitute for conventional protein sources (Areerat et al., 2021). Areerat et al. (2021) assessed the impact of substituting house crickets and mulberry silkworm pupae for poultry meals in adult mixed-breed dogs. Results from this study showed that this replacement or substitution of poultry meals had no adverse effects on the nutrient digestibility and overall health of the adult mixed-breed dogs. The latter authors concluded that crickets and mulberry silkworms are potential diet formulations for canines.

### Challenges of edible insect farming in Nigeria

Despite the role of edible insect farming in the attainment of the SDGs elucidated above, there are many challenges at the forefront of edible insect farming in Nigeria.

#### Limited access to funding

Awareness of edible insect farming is low in Nigeria. Consequently, access to funding is an uphill task because most agricultural credit-providing institutions would supply credit to mainstream agriculture/growers of staple foods such as livestock, cassava, and vegetables (Ayegba, 2016). Therefore, most insect farmers would have to rely on their own funds, which would apparently limit their ability to grow and compete in the market value chain (Ibitoye et al., 2019).

#### Insufficient information and skills

Currently, there is limited information on the benefits, technical know-how, costs, and profitability of edible insects and insect farming in Nigeria. Apart from *B. membranaceus*, where extensive research on domestication has been conducted (Okweche et al., 2022), there is a paucity of information, data, and protocols relating to rearing other edible insects such as *Z. variegatus*, *M. bellicosus*, *A. venata*, *C. forda*, *R. phoenicis* which are all reportedly known to serve as food in some parts of the country (Fasoranti and Ajiboye, 1993; Banjo et al., 2006). This paucity exacerbates the inability of farmers to access key information that can confer them the requisite skills and access to training materials. These are longstanding problems that are inimical to promoting insects for food and feed.

#### Lack of advanced processing technology

Storage and processing are important for sustainable insect production (Ebenebe et al., 2020). However, the majority of insects consumed in Nigeria, to date, are either eaten raw or prepared traditionally. Different traditional processing techniques exist, and include steaming, boiling, baking, deep-frying, sun-drying, roasting, smoking and processing into chutney or paste (Adeoye et al., 2014). Consequently, substantial research is needed on production and processing methods on industry or commercial scale levels and microbial safety (i.e., decontamination of edible insects). Several factors are crucial to produce these edible insects on industry scale. One such factor is the development of national regulations and guidelines (van Huis et al., 2013). Unfortunately, Nigeria has no clear legislation guiding the rearing, harvesting, consumption, and commercialization of edible insects. As a result, the processing methods are still at the traditional level, causing significant losses to farmers when roasted insects are not sold within the stipulated time frame (Ebenebe et al., 2017a). Fortunately, there is growing interest in using insects as alternative ingredients in the preparation of certain foods such as bread, pasta, cereal bars, soup, biscuits, and sausages in West Africa, including Nigeria (Bessa et al., 2019; Ayensu et al., 2019; Adeboye et al., 2021), indicating that the development of modern or state-of-the-art technology in the country is paramount, as potentials

embedded along these insects' value chain are enormous.

#### Poor extension service

The role of extension services in the growth of edible insect farming cannot be over-emphasized. However, its shortage in the country has resulted in a gap between research outcomes and edible insect farming (Ibitoye et al., 2021). Many researchers are opinionated that two critical steps may bridge the gap: (1) training and employing more competent and effective extension officers and (2) training to farmers on the adoption of best practices to enhance the growth of the sector (Ibitoye et al., 2019).

#### Seasonality

Edible insects are mostly harvested from the wild in Nigeria. Hence, changes in seasonality affect the phenology of these insects. Thus, results in low quantities during unfavorable climatic conditions (Ebenebe et al., 2020). Often, this causes frequent breakage or disruptions in the market supply chain all year round, resulting in high purchasing costs (Ibitoye et al., 2019).

#### Scaling production

Edible insect farming, especially at the start-up level, is confronted with difficulties such as finding reliable and consistent ways to up-scale production. Currently, the industry of feed production for livestock and the demand for feed outnumber production capacity and farmers that produce insects as feed (Nolet, 2017). Meeting up with this surging demand remains challenging for farmers. Other significant challenges for upscaling production capacity include insect feeding materials, production processes, expertise and knowledge, new product development, and regulatory uncertainties (Yang and Cooke, 2021).

#### Future outlook (Prospects)

The population of Nigeria is projected to exceed 330 million by 2050 (UN, 2022), making it one of the eight countries that will contribute more than half of the anticipated increase in global population by 2050 (UNDESA, 2022). The increase in population coincides with an increase in food prices. Conversely, the increase in food prices has been further aggravated by the increasing competition between humans and livestock for animal and plant protein sources. The increase in the cost of fish and other feed protein sources is one of the key factors that prompted the renewed interest in insects as alternative food and feed sources. Historically, many tribes in Nigeria have been consuming insects (Fasoranti and Ajiboye, 1993; Ebenebe et al., 2017b) and the country has influenced the consumption of insects in Benin, a neighbouring country (Ghosh et al., 2021). However, over the years, the consumption of insects has been reduced.

The prospects of insects as cheap alternatives to human and animal protein sources (Kim et al., 2019; Liceaga et al., 2022), coupled with the ecological, social, and economic benefits it offers, suggest that insect farming should be promoted in developing countries like Nigeria (Box 1). However, the huddles limiting entomophagy must be overcome. Govorushko (2019) identified five major tasks that are crucial to enhancing entomophagy for food security, viz: (1) knowledge dissemination, (2) increase in insect farming and semi-domestication, (3) development of the edible insect food industry, (4) edible insect species composition expansion, and (5) research into risk to human health.

In the last decade, global resurgence into the potential of insects as human food and animal feed research has led to an increase in published articles on insects as alternative protein sources. This research has not practically translated into a substantial increase in commercial insect farming in Nigeria (Box 1). In East Africa, many insect farming companies have emerged in the last 10 years, and they operate as an

enterprise that can be easily transformed into a more automated system with a growing market (Tanga et al., 2021). Creating awareness, especially among small-scale farmers, is fundamental to achieving this goal in Nigeria. Smallholder farmers contribute substantially to food consumption and the GDP of the Nigerian economy (Mgbenka et al., 2016). Unfortunately, today, most of them are very poor because they practice a crude and subsistent form of agriculture. Therefore, introducing insect farming to them could increase their sources of income, whilst serving as a strategy to alleviate poverty and improve food security.

Exploring the prospects and adoption of insects for human food and animal feed in Nigeria may require information dissemination to higher levels of education such as universities, colleges, and secondary schools. This strategy may increase the involvement of young people in insect farming (Box 1). Although there is no research information on the willingness of farmers and feed millers to adopt insects as feed in Nigeria, such investigation have been carried out in Kenya and results showed that over 80 % of poultry, fish, and pig farmers are willing to pay for insect for insect-based feed in Kenya (Chia et al., 2020). Considering the antecedents of some tribes in Nigeria as 'lovers' of insects as food, we anticipate that the dissemination of such information would be warmly received. Information dissemination and training efforts in Africa are usually conducted by researchers and non-governmental organizations (Verner et al., 2021). However, the government also has an important role in providing an enabling environment and policy framework.

Generally, insect farming in Africa is in the elementary phase but with the potentials to create jobs for several farmers, including women and youth. The potential market for farmed insects for human food and animal feed could be worth US\$ 8 billion by 2030 (Verner et al., 2021). Dried protein produced by the top nine insect farms is estimated at 9780 t annually and sufficient to feed 4.7 million chickens (Tanga et al., 2021). The black soldier fly – one of the most farmed insects in Africa, is probably one of the most documented, and it offers ecological benefits by converting waste to fertilizer and can be potentially used as biofuel (Li et al., 2011). Their ability to convert agricultural and industrial waste to protein makes them appropriate for breeding in disrupted countries (Verner et al., 2021). Therefore, internally displaced persons that are presently in various camps across Nigeria and neighbouring countries could be trained, engaged, and giving livelihood means in producing insects such as the black soldier fly.

Unlike some developed nations, many developing countries do not have standards regarding insects in the food supply chain (Verner et al., 2021). Although there are still regional variations in legislation (Renna et al., 2023), countries or regions like the EU, Australia, Canada and the USA have allowed the trade and use of the black soldier fly for feed production under certain conditions. Conversely, most countries with historic traditions of eating insects either do not have any regulation or are currently attempting to develop one (Alagappan et al., 2021). Lack of legislation guiding rearing, consumption, and commercialization has limited its exploitation for social, economic, and ecological benefits in Nigeria (Usman and Yusuf, 2021). Although there are bodies such as the National Agency for Food and Drug Administration and Control (NAFDAC) established in 1993 saddled with the responsibility of regulating and controlling the manufacture, importation, exportation, distribution, advertisement, sales, and use of food, drug, and other regulated products (<https://www.nafdac.gov.ng/>) may have an oversight function for the control of insect for food and feed, the specifics on entomophagy is not available (Usman and Yusuf, 2021). There will be a need for legislation and regulations guiding the production, processing, and consumption of insects for food and feed.

Generally, across the world, 92 % of insects are wild-harvested, while others are either semi-domesticated or reared (Yen, 2015). We documented above that most insects consumed in Nigeria are from wild sources. They are collected from various landscapes such as forests, abandoned plots, and agroecosystems (Alamu et al., 2013), and only a few farmers are engaged in commercial rearing and production of insects. We also elucidated multiple problems associated with absolute

dependence on wild harvesting such as seasonal availability and high costs of collection which limits the consumption of insects in Nigeria (Ebenebe et al., 2017b). For the sustainable production of insects, there is a need for more specific research on the optimization of rearing methods that can be recommended for farmers. Such methods can then be popularised, and farmers trained and encouraged to engage in commercial insect farming and processing. Insect farming is cheaper to maintain and requires limited land space making them easier to establish when compared to other forms of livestock production. The introduction of cheaper rearing and processing methods would enhance all year-round availability and productivity (Tanga et al., 2021). Small-scale insect farming can be installed in homes or small shelters, while production facilities can be in peri-urban areas around industrial parks close to sources of organic waste which is an important food for the larval stage of some edible insects (Verner et al., 2021). In China where insects have been largely bred for food, feed, and medicinal purposes, breeding is done either through complete domestication in captivity or partially raised in captivity by manipulating the environment to encourage rapid multiplication of these insects and increased production (Feng et al., 2018). Semi-domestication can be applied to insects that are difficult to rear either because they go into diapause or are not adequately researched.

We underscored that the processing of insects in Nigeria is traditionally by boiling, sun-drying, deep frying, roasting, frying with spices, and cooking inside the stew (Adeoye et al., 2014). Processing methods are fundamental to proper storage and the elimination of potential pathogens. Therefore, more research is needed on standardizing the rearing and processing procedures for common edible insects in Nigeria. This will take into consideration the need to maintain health and safety concerns without compromising the nutrient status of the insect. When insects as food becomes popular, concerns about safety may arise (Baiano, 2020). Unfortunately, studies on contamination from microbes are still limited (Imathiu, 2020). Therefore, popularising them would invariably demand more research into the microbiological, chemical, and allergenic agents that may affect their safety (Van der Fels-Klerx et al., 2018). Good hygienic practices during rearing and processing are important to establish the Hazard Analysis Critical Control Point (HACCP) (Babarinde et al., 2021).

## Conclusion

Despite the myriad benefits of farming edible insects for human consumption and use as feed and livelihood means to the teeming populace, they are still underutilized in Nigeria. Although many species, such as *G. lucens*, *Gymnogryllus lucens*, *O. rhinoceros*, and *R. phoenicis* are ubiquitous with a longstanding appreciation as food sources by the indigenous people and tribes in Nigeria, production is lagging due to several challenges plaguing the industry, encompassing funding, expertise, and seasonality. Nevertheless, a concerted countrywide alliance of the Government, non-governmental organizations, and agricultural stakeholders concomitant with regional and international partnerships may ameliorate these challenges. The key stakeholders in Nigeria and potential investors may consider fostering a proactive and inclusive relationship and cooperation between local edible insect farmers in Nigeria and elsewhere, such as East Africa, where farming edible insects for food and feed is thriving.

## Ethical statement

This study did not involve humans and animals.

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**Box 1**

Summaries of the discussions on the future of edible insects for food, feed, and livelihoods in Nigeria during a German Academic Exchange Service (DAAD) Alumni event with key stakeholders along the agricultural value chain, including the Edo State Government (ESG), Ministry of Agriculture (MoA), DAAD Alumni, and the Nigeria Institute of Oil Palm Research (NIFOR) in Benin City, Nigeria from 5th to 8th, July 2023.

- Edible insects are frequently eaten in Nigeria (MoA)
- Farming insects for food and feed is a relatively new concept in Nigeria (MoA, ESG)
- Utilization of insects as raw materials for industries in Nigeria is rare (ESG).
- Edible insect rearing can be a source of income (NIFOR)
- Rearing edible insects as food and feed is an employment opportunity, especially for marginalized and vulnerable groups, such as youth and women (MoA, ESG).
- Start-up of insect farming operation requires less infrastructural funding than traditional livestock farming (NIFOR).
- A research centre mandated for edible insects should be established in Nigeria (MoA, ESG)
- Farmers should be given incentives such as small loans and grants to encourage edible insect farming (MoA, ESG).
- Government should encourage training opportunities on edible insect farming (NIFOR).
- There should be a deliberate attempt to 'catch-them-young' by including the study of edible insect farming into the curriculum of basic education (MoA)

author Dr. Pascal Osa Aigbedion-Atalor titled: "Regenerative Edible Insects For Food, Feed, and Sustainable livelihoods - An Opportunity for One Health Framework in Rural Nigeria". We gratefully acknowledge the support and contributions of the Edo State Government, Nigeria during the DAAD Alumni meeting in July 2023. All opinions expressed herein are those of the authors and do not necessarily reflect the opinions of the DAAD and the Edo State Government.

**Declaration of competing interest**

None.

**Data availability**

Data will be made available on request.

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