*Feature Article*

# New insights into the emerging edible insect industry in Africa

**Chrysantus M. Tanga[†] and Margaret O. Kababu[†,‡]**

[†]International Centre of Insect Physiology and Ecology (icipe), P.O. Box 30772 – 00100, Nairobi, Kenya

[‡]School of Agricultural and Food Sciences, Jaramogi Oginga Odinga University of Science and Technology (JOOUST), P.O. BOX 210, Bondo, Kenya

### Implications

- Insect farming for feed and food is rapidly expanding, with new registered farms emerging each day in Africa.
- Insects convert organic waste into multiple high-value market products (protein, oils, chitin/chitosan, frass fertilizer among others).
- Insect farming is highly profitable, and it benefits people of all ages and income levels.
- It contributes to improving food insecurity, creating jobs, and improving livelihoods, while reducing waste and protecting the environment.
- Promoting the development and harmonization of standards and conformity assessment along the edible insect-based value chain in Africa would ensure sustainability and safety of insect-derived products.

## Introduction

Consumption of insects is an ancient practice that is common among many cultures with more than 2 billion people in 113 countries across the world practising entomophagy (van Huis, 2013). More than 2,000 species of edible insects have been recorded worldwide out of which 470 species occur in Africa (van Huis, 2013; Kelemu et al., 2015). The rapid growth in human population and increased demand of animal proteins has drawn more interest on the use of insects as food and feed to mitigate food insecurity and malnutrition (Kewuyemi et al., 2020; Babarinde et al., 2021).

Edible insects have a rich profile of proteins, carbohydrates, fats, minerals, vitamins, and bioactive compounds that are essential for human health and nutrition (Zhou et al., 2022). Their high nutrient content, availability and low cost of production has increased their use as a substitute protein source in animal feed (van Huis et al., 2013; Tanga et al., 2021). The trade of edible insects is a big source of revenue with the global market for edible insects expected to reach $1.2 billion USD this year (Liceaga, 2021) Recent advances have led to the development of mass production units for insects as food and feed across the world; development of processed products and extraction of bioactive compounds for different uses (Liceaga, 2021; Meyer-Rochow et al., 2021; Tanga et al., 2021; Zhou et al., 2022). The industrialization of insect rearing yield large quantities of frass; as such the utilization of insect frass as fertilizer to enhance soil health and crop production is gaining momentum in the development of sustainable agriculture and circular economy (Poveda, 2021).

In spite of the growing interest in the use of edible insects as food and feed, their uptake remains suboptimal due to seasonal availability of insects, low consumer acceptability, safety concerns and lack of legislation to govern the edible insect industry (Liceaga, 2021; Meyer-Rochow et al., 2021). The industrialization of edible insect production, commercial processing and product development remains limited in parts of the world including Africa. This review sought to establish new insights on the emerging insect industry in Africa. The review focused on identification of companies producing edible insects and production quantities; processing technologies, application of insect production, safety and legislative framework governing the insect industry in Africa.

## Methodology

Figure 1 illustrates the use of mixed methods approach to generate evidence-based data on the emerging edible insect sector in Africa through in-depth literature review, mapping the status of insect farming companies, survey on production scale and collation of *icipe*'s experiences on edible insect research and their applications. Literature was sourced from internationally recommended online data bases such as Scopus, Web of Science, and Google scholar using the following search items: edible insect farming, production scale, edible insect processing


https://doi.org/10.1093/af/vfad039

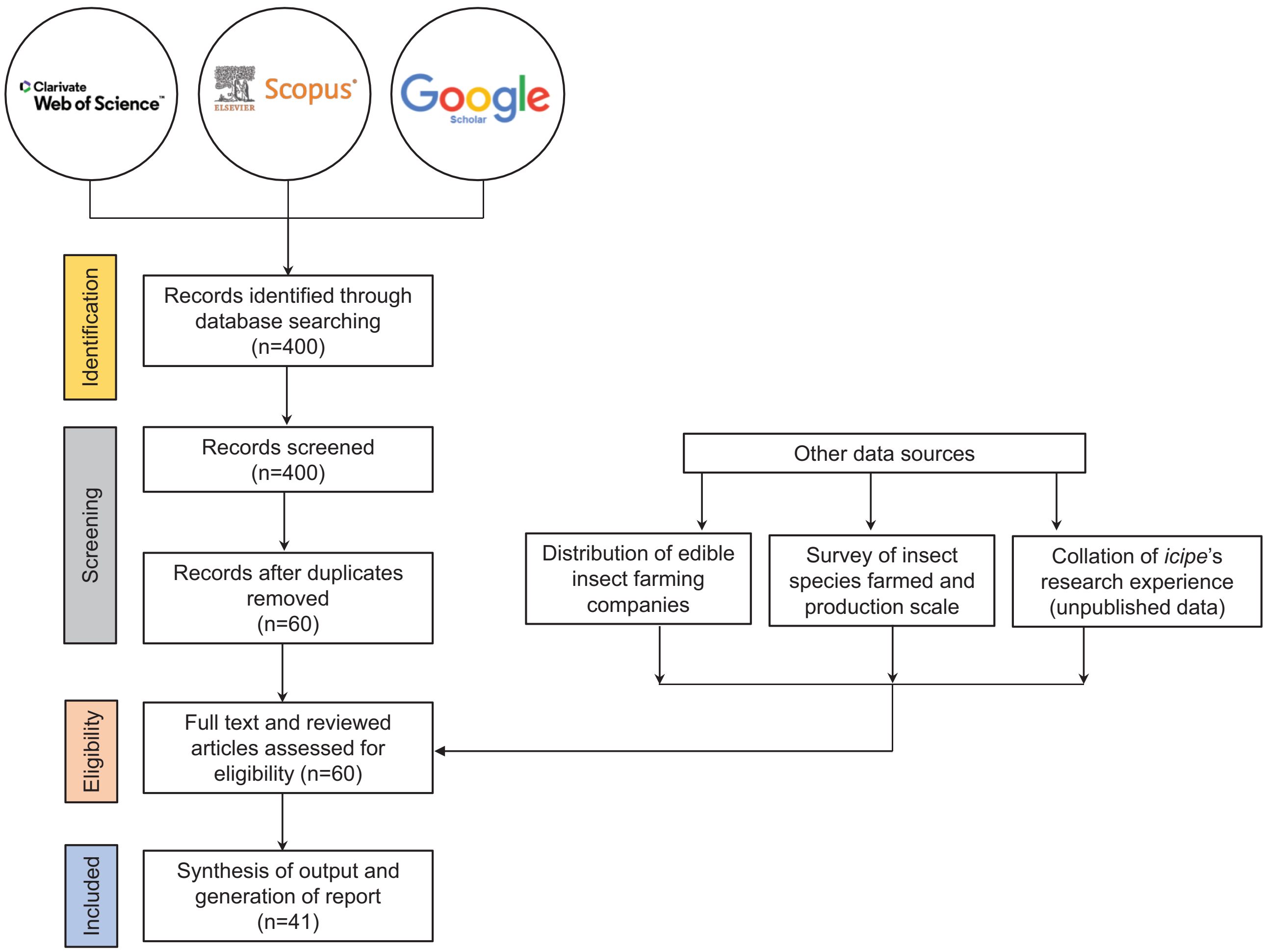



**Figure 1.** Schematic flow of the methodology for review of the status of the emerging insect-based enterprises in Africa.

techniques, nutritional composition, safety quality and application and legislation on edible insects in Africa. A total of 41 research articles most of which were review papers and two reports were included in the final analysis and synthesis of the report. A survey and mapping of companies were conducted through online interviews with different stakeholders involved in the production of edible insects across the continent. In addition, in-depth research and high-value products developed from research efforts also form part of this review.

## Companies and Production Quantities

The launching of sensitization and awareness creation campaign by the Food and Agriculture Organization of the United Nations (FAO), since 2013, to promote the domestication of insects as "Mini livestock" for food and feed (van Huis et al., 2013) have seen massive and continuous expansion of the enterprise in Africa. These insects are produced as alternative nutrient-rich biomass for direct human consumption, or as functional ingredients in feeds for livestock and fish (Babarinde et al., 2021). This new wave of emerging small-to-medium-to-large-scale insect farming represents an environmentally friendly way to reduce competition between human and animal nutrition by taking the pressure off soya bean, cotton seed cake, sunflower seed cake, fishmeal among other feed protein sources (Figure 2). The rapidly growing pressure to identify new alternative protein sources that are cheap, locally and readily available in the market, and of good quality has ignited remarkable interest in mass-producing farmed insects. This is clearly reflected in previous studies in Uganda, Kenya, Rwanda, Benin, and other where farmers (poultry, fish, and pig farmers), feed traders and processors have shown significant motivation with over 80% of them demonstrating willingness to pay and integrate insect-derived protein in animal feed (Chia et al., 2020). Though high levels of acceptability have been reported in a few countries, African farmers are willing to adopt and farm insects. This underpins why the insect farming venture is expanding rapidly with many public and private sector partners are actively participating in the insect value chain.

Across Africa, the number of registered new private companies are growing each day, due to the large numbers of insect farmer base of locally available experts to guide new market entrants through training and provision of start-kits (eggs or 5-days old larvae) as the market rapidly expands and demand increases. Currently, the insect-based enterprises comprise of smallholder farmers, entrepreneurs (small-and-medium enterprises—SMEs), and large-scale insect farming companies. This

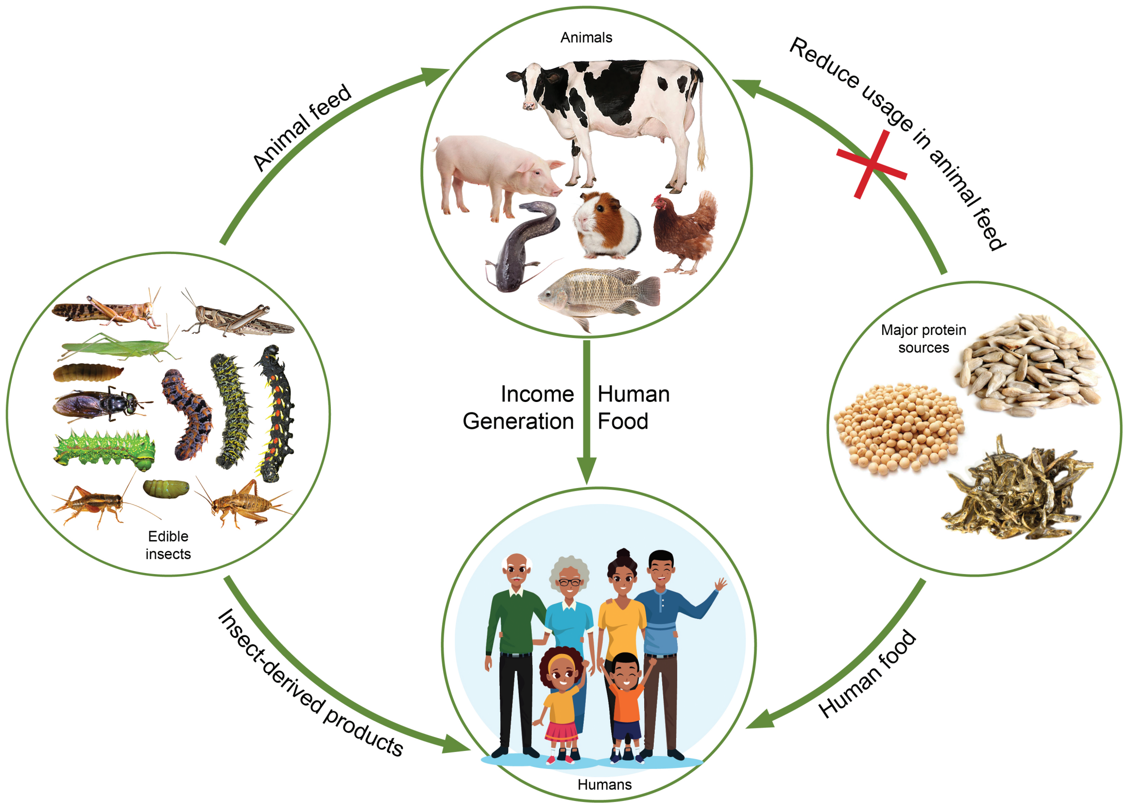



**Figure 2.** Illustration to demonstrate the replacement of major protein sources (fish, soya bean, and sunflower seeds) in animal feeds with insect protein to reduce competition between humans and animals on the limited food resources.

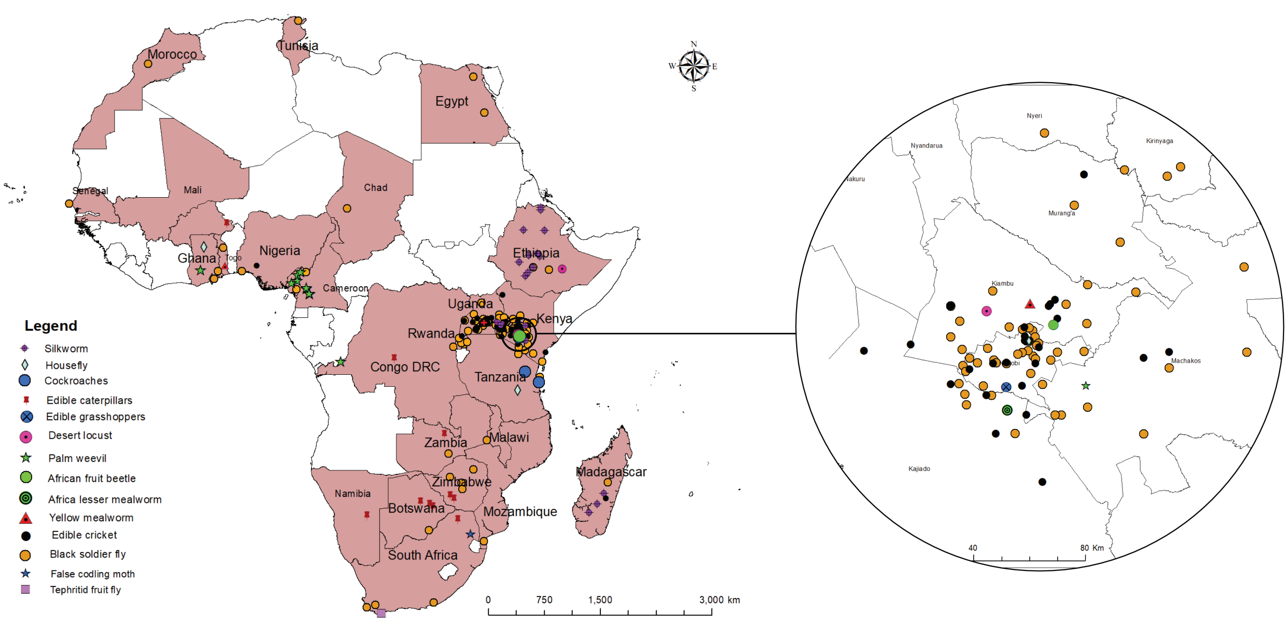



**Figure 3.** Distribution of semidomesticated and domesticated edible insect species in Africa. Countries with white background have no insect farming activities and those shaded with maroon color have operationalized insect farms for food and feed.

strongly suggests that the industry will continue to grow and become more profitable, particularly to the youths and women that make up majority of the vulnerable population. Through mapping, it is established that approximately 2,300 active insect farms exist in the continent (Figure 3), with <2% considered as large-scale insect farms.

This list is by no means exhaustive because the actual number of insect farms in the 54 countries remains largely unknown beyond these estimates. So far, 14 farmed, or semifarmed insect species have been identified in Africa, particularly in Kenya with over 10 species. After the awareness campaign launched by FAO, many insect farms started emerging in 2013, which indicates that it is a relatively new business opportunity in Africa. Among the insects farmed in Africa, silkworm (*Bombyx mori* L.) farming is the oldest form practiced in Kenya, Madagascar and Ethiopia dating back 25–50 years ago (Verner et al. 2021). However, black soldier fly (*Hermetia illucens* L.) is the fastest developing insect farming industry as shown in Figure 3. Our survey yielded fourteen insect species, which is consistent to that reported by Halloran et al. (2018), who demonstrated that approximately 18 insect species were suitable for intensive captive rearing (domestication) and upscaled production for animal feed or direct human consumption as food. (Verner et al. 2021) revealed that Kenya breeds approximately 17 edible insect species. Over 80% of the farmed insect species in Africa are produced for fish and livestock feed, while 15% for human consumption. On the other hand, only 5% of the farmed insects are used for both food and feed. The most popularly raised (>80%) edible insects include the black soldier fly, African palm weevil larvae, domestic silkworm (*Bombyx mori*), cricket species (*Gryllus bimaculatus*, *Acheta domesticus*, and *Scapsipedus icipe*) and mealworms (Africa lesser mealworm and the yellow mealworm). Contrarily to other Africa countries, other insects largely produced in Kenya include the garden fruit chafer, long-horned grasshopper, and the desert locust. However, the highest concentration of edible insect farms are located in East Africa, particularly, Kenya and Uganda.

However, advanced research has demonstrated that some more suitable insect species might likely be identified as the case of Kenya (*Scapsipedus icipe* Hugel and Tanga) (Tanga et al., 2018) and *Gryllus madagascariensis* Walker in Madagascar (Borgerson et al., 2021). Farmed insects are deliberately selected for large-scale commercial production due to the following optimal characteristics such as relatively short and simple life cycle, shortest generation time, better taste, disease resilience, higher growth rates, increased productivity, increased feed efficiency, increased insect tolerance to overcrowding, less aggressiveness, manageability, and high nutritional profile—thus a regular cash flow and increased profitability to various in the farming systems (Lecocq et al., 2019). More than 80% of the farm-level grown insects generally require fewer than two months to complete their life cycle to marketable size or harvestable size. For example, house flies and black soldier fly have the shortest growth period compared to crickets and edible caterpillars. The edible caterpillars and giant cricket (*Brachitrupes membranaceus*) have the longest life cycle, which explains why they are usually farmed under semimanaged and fluctuating environmental conditions.

In Africa, over 28% of the 2,300 insect species are considered edible (Kelemu et al., 2015). The 18 species suitable for farming requires reduced space and water, unlike other animal production systems. Small and medium enterprises (SMEs) of insect can be housed in simple screen houses, home-based structures, or shelters. On the other hand, all the medium-and-large-scale insect farming facilities do require larger warehouse or large screen house facilities. These large-scale production facilities are generally located in urban or peri-urban areas, often close to industrial parks, or close to sources of plenty of organic municipal waste, which is primarily considered as feeding substrate. In Africa, private sector investment is increasing in an alarming rate targeting large-scale production and supply to the marketplace of insect protein, particularly abroad. Large-scale insect production companies and suppliers like Regen Organics (formerly called Sanergy Ltd (Kenya), InsectiPro Ltd (Kenya), Mana Biosystems Ltd (Kenya), Marula Proteen Ltd (Uganda), Black soldier fly Egypt (Egypt), Proticycle (South Africa), Inseco (South Africa), Maltento (South Africa), BioCycle (South Africa), Nambu (South Africa), and others—are increasingly investing in novel insect-based proteins as feed sources. Investment capital reported from 2013 has ranged between US$1.0 and US$105 million in insect commercial farming operations (AgriProtein, 2018; AgriTech Capital, 2019). These companies focus on black soldier with excellent biological capacity for efficient conversion of a broad range of organic substrates to nutrient-rich biomass. These substrates include vegetable waste, mixed household waste, animal waste such as manure or slaughter offal, industrial waste from breweries, wineries, or other industries as well as human waste (fecal waste). The companies use a combination 2–3 different waste streams which are transformed by the insect larvae into multiple high-value and marketable products: oils (feedstock for biodiesel, additive in cosmetic and soap, adjuvant in repellants, glycerin products, etc.), chitosan products, nitrogen-rich soil conditioners (fertilizer), protein press cakes, and briquettes. The production capacity of these companies ranges from 6 to 3,600 tons of dried BSF larvae per year (Tanga et al., 2021). Current estimate reveals that the volume of production of dried black soldier fly larvae (BSFL) in Africa is 19,732 tons per year with potential to produce 3.9 million tons of feed at 50% inclusion of BSFL meal. This will be capable of feeding 1.4 million broiler chicken (8 weeks), 2.8-million-layer chicks (2–8 weeks), 8.6-million-layer growers (9–18 weeks), and 9.7-million-layer chicken producing table eggs from 20 to 72 weeks. Unfortunately, information on the direct application of the dried black soldier fly larvae remains limited and needs comprehensive understanding.

## Role of Insect Farming Industries in the Circular Economy

Across the African continent, most of the insect farms are rapidly increasing their production volumes, facility sizes, overall investments, and number of employees. Over the past five years, these insect enterprises significantly have addressed societal challenges, such as gender inequality, unemployment of the youths and women, and poor sanitation. For example, these operations employs between 2 and 150 people in each farm, particularly from disadvantaged communities or most vulnerable segment of the populations including youth, women, and refugees or displaced. Thus, insect farming

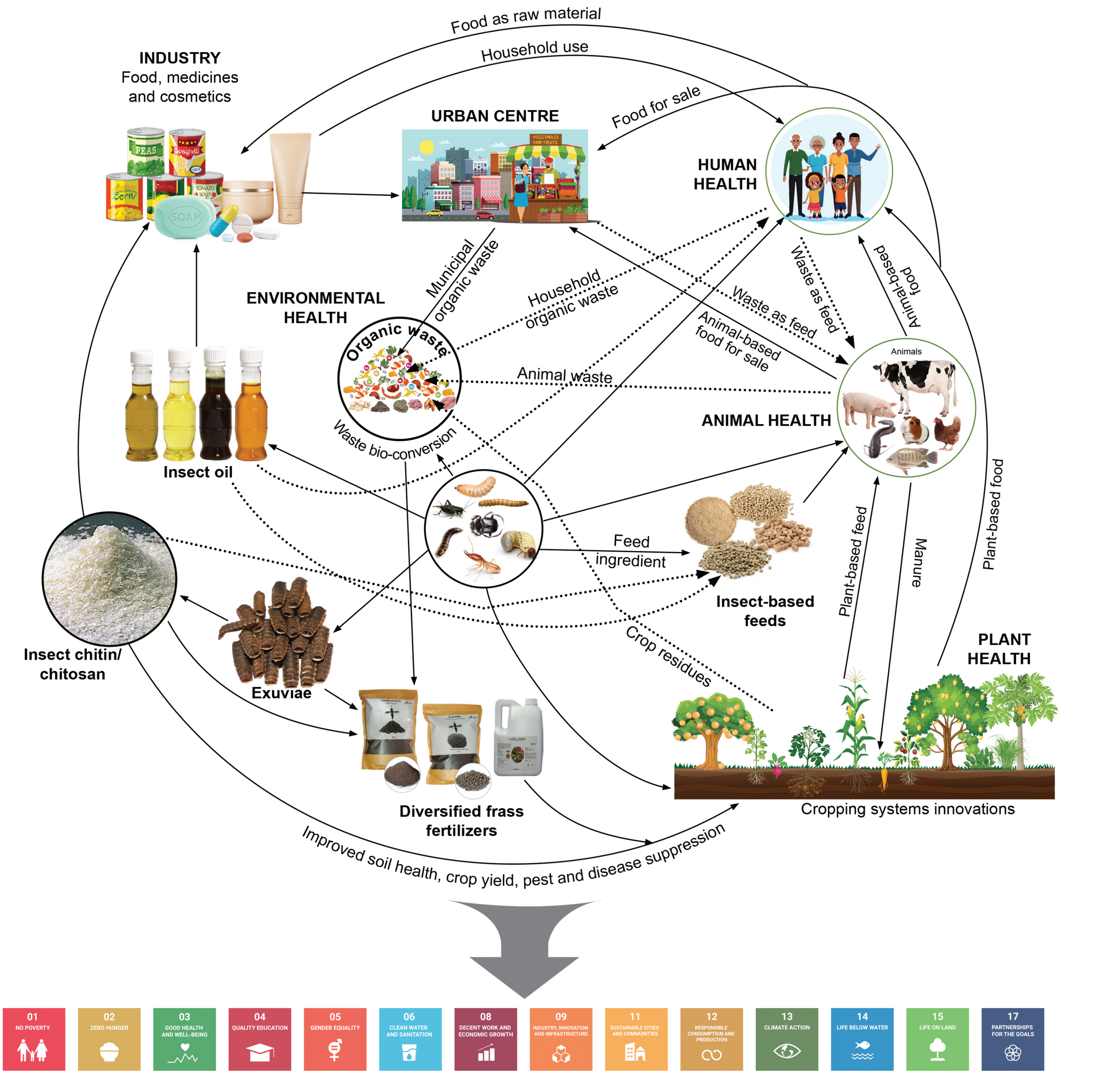



**Figure 4.** Schematic representation of edible insect farming in Africa through a circular economy and its contribution to Sustainable Development Goals (SDGs) and One-Health.

provides an opportunity to empower rural women and youths by increasing their access to livelihoods, helping them achieve greater financial independence for all ages and income levels. Although, insect farming institutions and regulatory frameworks are still in their infancy, understanding its many benefits within a circular economy and One Health perspective is crucial (Figure 4). According to Zewdu et al. (2020), replacing the conventional feeds by 5% to 50% insect-based meal in the commercial poultry sector in Kenya would increase the availability of fish, soya bean, and maize that can feed 0.47 to 4.8 million people. These could translate to reducing poverty by 0.32 to 3.19 million people, increasing employment by 25,000 to 252,000 people, and recycling of 2 to 18 million tonnes of biowaste. Similarly, the foreign currency savings would increase by 1 to 10 million USD by reducing feed and inorganic fertilizer importation. Also, in Uganda, it is projected that the substitution of existing protein sources with insect-based meal will generate net economic benefits of USD 0.73 billion in 20 years (0.037 billion per year) and lift about 4.53 million people above the poverty line in the country (Zewdu et al., 2022). These findings suggest that greater investment is required to promote insect-based agribusiness for improved profitability, thus boosting economic, environmental, and social sustainability (Figure 5).


**Figure 5.** Socioeconomic and environmental benefits of adopting insect-based feeds in Kenya.

Our observation is further supported by Verner et al. (2021), who reported that each year, insect farming in Africa has the potential to generate crude protein worth up to US$2.6 billion and biofertilizers worth up to US$19.4 billion from 125 million tons of organic waste that is generated annually in sub-Saharan Africa. That is enough protein meal to meet up to 14% of the crude protein needed to produce pigs, fish, and chickens. The studies also estimated that through black soldier fly farming, the continent could replace 60 million tons of traditional feed production with black soldier fly larvae protein annually, leading to 200 million tons of recycled organic waste, 60 million tons of organic fertilizer production, and 15 million jobs, while saving 86 million tons of carbon dioxide equivalent emissions, which is the equivalent of removing 18 million vehicles from the roads. However, only 4% of this waste is recycled and the rest degrades in the open, threatening human health and contributes to greenhouse gas emissions. Therefore, countries are encouraged to enforce policies and strategies like adhering to the use of appropriate, safe, and cost-effective techniques to segregate, contain, transport, treat and distribute organic waste for effective recycling through different advanced technologies like insect farming.

The International Centre of Insect Physiology and Ecology jointly with the local governments of the various countries have strongly supported industrialization by establishing local pilot insect farms made up of simple locally fabricated processing machines, waste grinding mills, and implementing youth and women incubation programs with mentoring and personalized one-on-one hands-on training on various topics related to the edible insect value chain. These programs allow for exchange visits between insect farmers within or from other countries to visit these pilot facilities and learn insect rearing and processing, pest and disease management, facility and equipment operations. These efforts are done in collaboration with universities and other research institutes. The pilots or demonstration or learning sites help to promote insect-based value-added products through exhibitions and media coverage events to raise the much-needed public awareness campaigns on the insect sector's value and benefits to the continent as a whole.

## Processing of Edible Insects

In Africa, edible insects are consumed in raw or processed forms (Hlongwane et al., 2021). Processing is crucial for satisfying quality standards; meeting consumers expectations; enhancing safety and preservation (Ojha et al., 2021). Processing methods can increase or decrease the nutrient content and digestibility of edible insects; and reduce microbial load and allergenicity of edible insects (Manditsera et al., 2019; Kewuyemi et al., 2020).

Traditionally, once insects are collected from the wild they are sorted to remove substrate residue, inactivated, starved overnight and degutted, the wings, legs, and ovipositors are removed, then washed (Hlongwane et al., 2021; Meyer-Rochow et al., 2021). The insects can then be sun dried, roasted, toasted, boiled, fried, smoked, blanched, ground into powder, crushed, pickled or fermented (Melgar-Lalanne et al., 2019; Kewuyemi et al., 2020). Insects powder and paste are incorporated into various food products or used directly in preparation of preferred dishes (Meyer-Rochow et al., 2021; Ojha et al., 2021).

More conventional processing methods such as freeze and oven drying, freezing, microwave processing, dry heat treatment, dry fractionation, marination, ultrasound-assisted extraction, cold atmospheric pressure plasma, supercritical $CO_2$ extraction, deep eutectic solvent extraction, enzymatic hydrolysis for fat, protein and chitin extraction, three-dimensional food printing technologies and modified atmosphere packaging methods have been tested on edible insects (Lee et al., 2021; Ojha et al., 2021). However, most of these methods are not utilized in Africa; their efficacy should therefore be tested and explored for implementation in Africa to enhance the extraction of useful products from edible insects.

## Nutritional Composition of Edible Insects in Africa

Edible insects are rich source of protein, carbohydrates, fats, energy, minerals, and vitamins. Figure 6 contains information on the proximate composition of edible insects commonly consumed in Africa from different orders. The highest crude protein content of edible insects ranged from 63% to 80% in Diptera and Orthoptera, respectively; crude fats varied between 33% and 77% in Homoptera and Lepidoptera, respectively; carbohydrate ranged from 8% in Hemiptera to 52% in Coleoptera while the highest energy content oscillated 460 to 777 kcal/100 g in Diptera and Lepidoptera, respectively (Rumpold and Schlüter, 2013; Hlongwane et al., 2020; Zhou

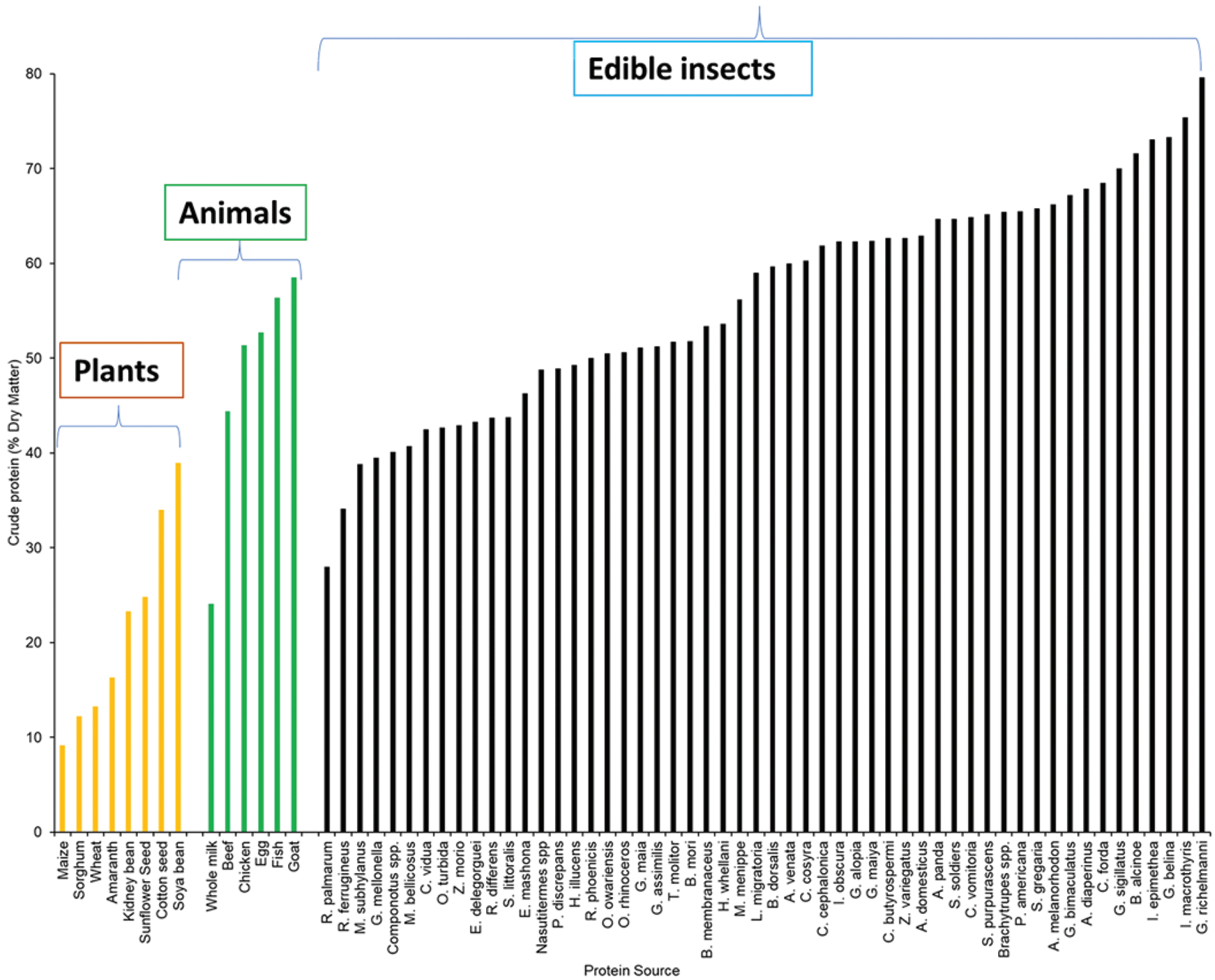



**Figure 6.** Comparative analyses of edible insect, plant and animal protein sources in Africa

et al., 2022). Protein content of edible insects exceed the quantity obtained from commonly consumed animal and plant protein sources. They also contain all the essential amino acids which makes them a suitable alternative to supplement the existing protein sources (Hlongwane et al., 2020; Zhou et al., 2022). Insects fats contain high level of monounsaturated and polyunsaturated fatty acids that are critical in improving health outcomes such as prophylaxis of cardiovascular diseases and cancer (Govorushko, 2019; Zhou et al., 2022).

Insects are abundant in minerals and vitamins which are essential in metabolic process of humans and animals (Table 1). Insects are rich in macro- and microminerals with high quantities of calcium (2,010 mg/100 g), potassium (3,259 mg/100 g) and phosphorus (21,800 mg/100 g) recorded in dipterans, lepidopterans, and orthopterans, respectively (Rumpold and Schlüter, 2013; Hlongwane et al., 2020; Zhou et al., 2022). The highest quantities of zinc (232 mg/100 g) and iron (1,562 mg/100 g) have been reported in orthopterans (Hlongwane et al., 2020). Inclusion of insects in diets can therefore be employed to curb the rampant cases of iron and zinc deficiency that is widespread in children and women of childbearing age in Africa.

Insects contain vitamins such as retinol, riboflavin, niacin, pantothenic acid, folic acid, ascorbic acid, and tocopherol. Orthopteran contain high levels of retinol (67 mg/100 g) and tocopherol (30 mg/100 g) while higher level of niacin (15 mg/100 g), ascorbic (46 mg/100 g), and pantothenic acid (13 mg/100 g) occur in lepidopterans (Hlongwane et al., 2020; Zhou et al., 2022). Deficiency of vitamins and minerals lead to adverse health outcomes such as inflammatory bowel disease, anemia, and growth retardation; it also accounts for approximately one million premature deaths annually (Zhou et al., 2022). Inclusion of insects in diets can therefore improve health outcomes and lower the rate of premature deaths that arise from micronutrient deficiencies.

## Safety of Edible Insects in Africa

### *Allergens*

Insects like other arthropods contain allergens such as hemocyanin, hyaluronidase, microtubulin, phospholipase A, protomysin, and arginine kinase that produce allergic reactions in humans which may arise from handling or consumption of

**Table 1. Mineral and vitamin content of different insect orders (Hlongwane et al., 2020; Rumpold and Schlüter, 2013; Zhou et al., 2022)**

| Parameter | Blattodea | Coleoptera | Diptera | Hemiptera | Homoptera | Hymenoptera | Lepidoptera | Orthoptera |
|---|---|---|---|---|---|---|---|---|
| *Proximate composition (%) dry matter* | | | | | | | | |
| Crude protein | 19.0–65.6 | 8.9–71.1 | 31.1–63 | 27.0–72.0 | 29–72 | 4.9–70.0 | 13.17–79.6 | 6.3–80.3 |
| Crude fat | 6.7–50.9 | 0.7–69.8 | 1.8–49 | 4.33–54.2 | 4–33 | 5.8–62.0 | 1.4–77.2 | 2.2–53.05 |
| Crude fiber | 2.2–13.1 | 1.5–28.1 | 0.0–12.4 | 2.0–23.0 | 19.2 | 0.9–29.1 | 1.68–29.0 | 1.0–22.8 |
| Moisture | 2.8–69.1 | 1.0–67.9 | 5.8–78.4 | 4.9 | 29.3 | 3.8–59.5 | 2.5–85.7 | 2.6–69.2 |
| Ash | 1.9–11.3 | 1.0–10.9 | 3.9–30.9 | 1.0–21.0 | 4.5–9 | 1.6–9.6 | 0.6–11.5 | 0.34–14.0 |
| Carbohydrates | 6.1–23.2 | 13.1–51.6 | 22.9–31.6 | 5.0–7.6 | 16.0 | – | 8.2–40.2 | 15.1–47.2 |
| NFE | 0.8–43.3 | 0.0–43.6 | 10.6 | 0.01–18.07 | – | 0.0–77.7 | 1.0–66.6 | 0.00–85.3 |
| Energy (kcal/100 g) | 617.4 | 282.3–652.3 | 326.9–460.3 | 329.0–622.0 | 329.0–629.0 | 400.1–655.0 | 293.3–776.9 | 90.1–566.0 |
| *Minerals (mg/100 g)* | | | | | | | | |
| Calcium | 0.1–132.0 | 0.0–208.0 | 140.0–2010.0 | 69.8–1021.2 | – | 15.4–108.0 | 7.0–391.0 | 2.0–1290.0 |
| Potassium | 336.0–507.3 | 0.2–2209.0 | 792.2 | 108.0–412.5 | – | 24.0–1159.5 | 47.6–3259.0 | 41.0–2030.0 |
| Magnesium | 0.2–47.7 | 6.1–280.0 | 130–673.4 | 63.1–1910.0 | – | 5.2–982.0 | 1.0–402.2 | 0.1–902.0 |
| Phosphorus | 1.5–136.0 | 1.5–1420.0 | 1100.0–1320 | 57.0–1234.3 | – | 106.0–936.0 | 45.9–1200.0 | 0.8–21800.0 |
| Sodium | 92.7–112.0 | 26.3–174.1 | 270.0–660.0 | 58.6–401.1 | – | 20.0–270.0 | 30.0–3340.0 | 1.0–1350.0 |
| Iron | 1.0–332.0 | 2.3–30.9 | 28.6–60.4 | 20.2–57.0 | – | 5.0–118.0 | 1.3–64.0 | 0.4–1562.0 |
| Zinc | 0.1–17.6 | 2.3–26.5 | 14.7–29.8 | 7.9–59.0 | – | 5.7–32.0 | 4.3–25.3 | 0.4–232.0 |
| Manganese | 0.1–1.7 | 0.2–1.36 | 1.6–21.5 | 3.2 | – | 0.3–32.3 | 0.3–10163.1 | 0.0–10.4 |
| Copper | 0.1–1.7 | 0.9–2.1 | 0.9–3.4 | 4.6 | – | 0.9–2.4 | 0.2–2.6 | 0.5–4.6 |
| *Vitamins (mg/100 g)* | | | | | | | | |
| Vit A/Retinol | 2.6–2.9 | 0.0–12.5 | 0 | 0.2 | – | 0.0–12.4 | 0.0–3.4 | 0.0–67.0 |
| Vit B1 | 0.7 | 0.2–3.4 | 1.5 | 0.3–1.0 | – | 0.1–0.6 | 0.2–4.0 | 0.1–3.4 |
| Vit B2/Riboflavin | 1.5–2.0 | 0.1–2.6 | 2.3 | 0.3–0.9 | – | 0.2–20.3 | 0.1–5.5 | 0.0–11.1 |
| Vit B3/niacin | 2.7 | 0.4–14.8 | 11.1 | 0.7–2.6 | – | 0.3–6.3 | 1.0–15.2 | 1.2–12.6 |
| Vit 5/Pantothenic acid | – | 3.7–6.9 | – | – | – | – | 4.9–12.5 | 7.5–11.5 |
| Vit B9/folic acid | – | 0.2–0.4 | – | – | – | 0.5 | 0.0–0.4 | 0.2–0.9 |
| Vit C/ascorbic acid | 3.0–23.8 | 3.1–45.7 | – | – | – | 0.0–36.1 | 2.0–46.3 | 0.0–25.5 |
| Vit E/tocopherol | – | – | – | – | – | – | – | 1.3–30.0 |

insects (Meyer-Rochow et al., 2021). These reactions may be mild or severe and include dermatitis, conjunctivitis, edema, rhinitis, urticaria, asthma, facial swelling, itchy skin rash, difficulty in breathing, gastrointestinal issues, tachycardia, hives, fainting, mild hypotension, and anaphylactic shock (Ribeiro et al., 2021).

Allergenicity of edible insects can be mitigated through different processing methods such as fermentation, enzymatic hydrolysis, thermal processing, fermentation, high pressure processing, irradiation, use of preservatives, and PH alterations (Kewuyemi et al., 2020; Zhou et al., 2022). However, some of these processing methods are not practised in Africa. There is need for screening for allergenicity of the edible insects' species consumed across Africa in order to mitigate such allergic reactions (Babarinde et al., 2021). Assessment of the efficacy of different processing methods in eliminating the allergenicity of edible insects is also paramount to ensure their safety as food and feed.

## Biological hazards

Edible insects contain a wide array of microorganism some of which may be pathological to human and animals (Murefu et al., 2019). Contamination arise from poor hygienic practices, inadequate packaging and storage conditions that can occur during rearing, harvesting, and processing (Mutungi et al., 2019).

More than 20 and 10 genera of bacteria and fungi, respectively, have been isolated from wild harvested and mass reared edible insects (Murefu et al., 2019). Some of the bacterial species are pathogenic to both human and animals; they may cause life-threatening infections and produce toxic effects that may be fatal (Meyer-Rochow et al., 2021; Niassy et al., 2022). There is lacuna of data on parasitic hazards associated with edible insects in Africa; however, such evidence has been demonstrated outside the continent. A couple of helmiths (tapeworms, round worms, and whipworms) and protozoans (*Toxoplasma*, *Giardia*, and *Entomoeba* species) have been isolated from edible insects (Mutungi et al., 2019). In spite of this evidence, screening of edible insects for biological hazards in Africa remain limited raising safety concerns following their consumption.

## Chemical hazards

Chemical hazards such as pesticides, heavy metals, antinutrients, and toxic bioactive substances have been reported in edible insects in Africa (Murefu et al., 2019; Mutungi et al., 2019). Chemical contamination of edible insects arises from consumption of pesticide and metal contaminated vegetation and wastes from refineries in mining communities (van Huis et al., 2013; Meyer-Rochow et al., 2021). Organophosphorus pesticides and heavy metals such as lead, chromium, cadmium, mercury, and nickel among others have been reported in Africa (Mutungi et al., 2019). When consumed in large quantities, these contaminants have prolonged residual activity which leads to bioaccumulation along the food chain which result into adverse health challenges such as headache, cancer and failure in endocrine and reproductive system (Murefu et al., 2019). This calls for the need for assessments of potential contamination of edible insects with pesticides in areas where chemical control of pests is employed to eliminate such risks.

Edible insects such as beetles, grasshoppers, stinkbugs, and caterpillars retain antinutrients such as phytates, tannins, oxalate, saponins, alkaloids, and thiaminases derived from plants in their tissues (Murefu et al., 2019; Mutungi et al., 2019). These substances may confer a bitter taste in food, interfere with feed intake, uptake of micronutrients, digestibility, and growth of animals while some of them may be toxic when consumed in large quantities (Kekeunou and Tamesse, 2016; Mutungi et al., 2019; Meyer-Rochow et al., 2021). The toxicity of high levels of antinutrients in edible phytophagous insects calls for their screening to eliminate the risk of their negative effects. There is also need for more research on the elimination or reduction of quantities of antinutirents in edible insects. Evidence suggest that this can be achieved through dephytinization of feed, manipulation of diets in mass rearing units and processing through deactivation and extraction of antinutrients (Mutungi et al., 2019).

Some insects such as termites, beetles, and caterpillars possess toxic bioactive compounds which makes them fatal upon consumption (Pener, 2014). Cryptotoxic insects produce noxious substances such as dihydrotestosterone, toluene, benzoquinones, cantharidine, and cyanogenic glycosides. Consumption of such insects may result into adverse health outcomes in humans. For instance, cyanogenic glycoside are degraded to produce hydrogen cyanide that is associated with acute toxicity in human (Murefu et al., 2019; Mutungi et al., 2019).

### Physical hazards

Consumption of edible insects such as grasshoppers without removal of their legs can result into fatal consequences due to abdominal blockage and constipation. This results from the presence of large spines and tibia that may necessitate surgical removal (van Huis, 2013; Kekeunou and Tamesse, 2016). Such hazards can be mitigated by processing to eliminate the unwanted parts and grinding of insects into powder.

## Application

### Insects as human food

The most abundant species of edible insects in Africa belong to the orders Lepidoptera (caterpillars), Orthoptera (locusts, crickets, and grasshoppers), and Coleoptera (beetles) (Kelemu et al., 2015; Babarinde et al., 2021). The insects are consumed at various stages of their lifecycles and form part of a main dish or snack depending on their seasonal availability (van Huis, 2013). Edible insects are also used as additives or substitutes for grain based foods with species such as termites, crickets, and grasshoppers incorporated in the production processed food products such as buns, biscuits and cookies as a way of increasing consumer acceptability (Ayieko et al., 2016; Melgar-Lalanne et al., 2019).

Edible insects' proteins have been applied as additives to a couple of meat products such as sausages and meat batter in the west (Lee et al., 2021). In spite of this, limited work exists on the use of insects as additives in production of such products in Africa. This presents an opportunity that can be explored to provide alternative sources of animal proteins to curb food insecurity.

### Insects as animal feed

The increasing demand and high cost of animal feed and feed ingredients calls for alternative cheaper sources of animal feed (van Huis, 2013; Govorushko, 2019). Insects have adequate nutrient to meet the nutritional demands of domesticated animals and can therefore be utilized to substitute protein sources in animal feed (van Huis et al., 2013; Oyegoke et al., 2014; Mutungi et al., 2019). For instance, production of black soldier fly in Eastern Africa is estimated at 9,780 metric tons of protein annually which is adequate to substitute soy bean meal and fish meal in animal feed (Tanga et al., 2021). Other insects species commonly used in the production of animal feed include common housefly, silkworm, yellow mealworms, cockroaches, grasshoppers, and termites (van Huis, 2015, 2020). The use of insects as animal feed has been reported in several countries in Africa including South Africa, Nigeria, Togo, Democratic Republic of Congo, Angola, Benin, and Burkina Faso (Mutungi et al., 2019).

### Insects as a source of frass fertilizer

Mass rearing of edible insects on organic waste streams has been reported to yield large quantities of frass (excreta) that forms a source of effective organic fertilizer that can be utilized in the development of sustainable agriculture and circular economy (Poveda, 2021). This recycling process into high-quality marketable organic fertilizer is an emerging area of research and business opportunities with high profit margins in Africa. The emerging products and their application are multipurpose, cost-effective, and environmentally friendly interventions that can significantly improve soil health, crop productivity and suppresses pests and diseases. Though this has received limited research attention, *icipe* has develop diversified frass fertilizer products to suit different crops production requirements, accelerate wider product uptake by private sector partners for commercialization, and provide fertilizer and food self-sufficiency in the continent. The benefits of frass fertilizer include: addition of nutrients to the soil, addition of microorganisms and biomolecules that enhance plant growth and increased tolerance to abiotic stress and resistance to pests and pathogens (Poveda, 2021; Beesigamukama et al., 2022). Frass fertilizer from nine different insect species have been reported to contained adequate quantities and concentration of nutrients sufficient for improved soil fertility and crop productivity, therefore making them an alternative to existing organic and inorganic fertilizers (Beesigamukama et al., 2022). The team at the International Centre of Insect Physiology and Ecology (icipe) has developed over 10 different frass fertilizer products currently available in powdered, liquid and granulated forms using low-cost insect-based bioconversion technologies (Figure 7). For example, the concentrations of nitrogen, phosphorous, and potassium (NPK) in powdered frass fertilizer products has been shown to be 1.5- to 2-folds higher than existing commercial organic fertilizer (Figure 8). However, additional studies to generate evidence-based data on their potential benefits (i.e.,


**Figure 7.** Diversification of insect frass fertilizer production to suit production requirements and economic conditions.

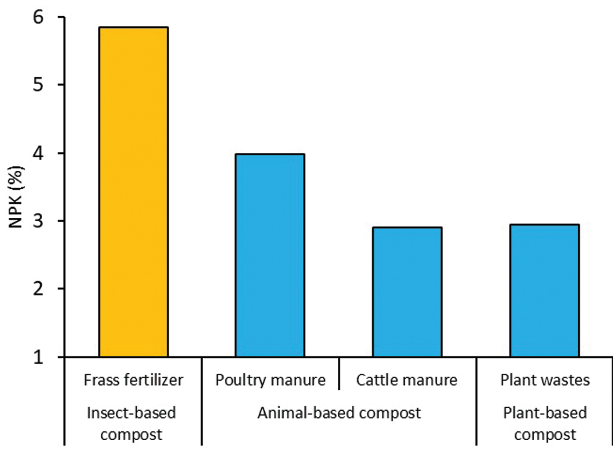



**Figure 8.** Superiority of insect powdered frass fertilizer quality over commercial organic fertilizers.

richness in beneficial microbes, growth hormones, chitin and free from contaminants) on various crop performance, yield, nutritional quality, pest and disease suppression or control as well as soil health are needed.

Many studies undertaken under field conditions have revealed significant increase in crop vigour, growth performance, and yields per hectare (Figure 9) when compared to those grown on soils amended or unamended with commercial organic and synthetic fertilizers. Smallholder farmers using insect frass fertilizer have been reported to observed significant increase of profitability up to 44% with high protein (2- to 3-folds) and minerals (2.8-folds) for harvested maize crop. Additional information on profitability and nutrient profiles of various crops grown using different insect frass fertilizers are urgently warranted. Additionally, in Africa the lack of affordable and quality pesticides have caused a continuous decrease in crop yields, pushing a large fraction of farmers into abject poverty, hunger, and food insecurity. Ongoing studies, have already demonstrated the potential of chitin-fortified frass fertilizers to control of onion and cabbage root fly (*Delia radicum*), root knot nematodes (*Meloidogyne incognita*), potatoes cyst nematodes and tomato bacterial wilt disease (*Ralstonia solanacearum*). Preliminary results on chitin-fortified liquid frass fertilizer have shown promise to induce 100%, 96%, 27%, and 35% suppression of root knot nematodes, potato cyst nematodes, onion and cabbage root flies, and tomato bacterial wilt disease, respectively (Figure 10). There are indications that root knot nematode suppression capacity ranges from 89% to 95% when the soil was amended with chitin-fortified liquid frass fertilizer, which demonstrates an efficacy like that of synthetic nematicide (96%) (Kisaakye et al., 2023, unpublished). The high potential of frass fertilizer to reduce the incidence and severity of key crop pests such as aphids, fall armyworm, diamondback moth, whiteflies and leaf miners under climate-smart vertical farming systems has been documented (Abiya et al., 2022). This implies that insect-composted organic fertilizer has the capabilities to suppress soil-borne pathogens and pests while enhancing the activities of soil enzymes and beneficial soil microbes that are key in nutrient cycling and plant protection. Thus, these findings provide evidence-based data to guide the introduction of frass fertilizer into the integrated pest management toolbox to manage multipurpose disease and pest situations frequently observed under field conditions hampering crop productivity to a larger extend.

## *Insects as a source of bioactive compounds*

Insects are recognized as viable source of bioactive compounds such as polyphenols, peptides, polysaccharides, carotenoids, flavonoids, alkaloids, chitin, chitosan, and fatty acids which can be exploited due to their biological properties (Jantzen da Silva et al., 2020). The huge diversity of over 500 edible insect species (Kelemu et al., 2015) reported in Africa such as crickets, grasshoppers, beetles, black soldier fly, lesser mealworm, yellow mealworm, silk worm, saturniid caterpillars, termites, desert locust, palm weevils, among others are known to possess bioactive substances with significant antimicrobial, antioxidant, antidiabetic, antihypertensive, anticancer, antitumor, blood lipid and glucose regulation, lowering of blood pressure and decreased risk of cardiovascular diseases, immunomodulating, anti-inflammatory, and antithrombotic properties (Zhou et al., 2022). These substances can be exploited for medicinal use due to their pharmacological properties. Presently, much attention has not been paid to the role of bioactive compounds from edible insects on human and animal health (Babarinde et al., 2021).

## *Legislation*

The establishment of regulations and policies on edible insects' value chain in Africa is paramount to ensure sustainability and safety for consumers and the environment (Niassy et al., 2022). However, regulatory frameworks on the utilization of insects as food and feed in many countries are still lacking (Grabowski et al., 2020; Niassy et al., 2022). Realization of food safety regulations on edible insects has been hampered by a wide array of factors such as limited compliance with international agreements on food safety and quality standards; inadequate enforcement of local, regional and international standards and global best practices; lack of large-scale industrial production of insects to supply and meet the growing demand by the food and feed sector; low quantities of insects consumed; limited data on insects' safety and inadequate resources to facilitate scientific risk assessment and upgrading of food safety regulatory systems (van Huis, 2013; Niassy et al., 2022). It is noteworthy that the laws governing edible insects across the continent are contrasting, with each country withholding its own legislation, with high concerns on the safety. Given the inconsistency in the regulations it is challenging to market edible insects effectively due to the diversity of restrictions in the different countries (Azmir et al., 2013; Lähteenmäki-Uutela et al., 2021). Azmir et al. (2013) reported that the lack of clear legislation on edible insect farming, consumption, and commercialization in majority of the countries has severely hampered the development of insect-based enterprises and their potential to benefit the nutrition and health of humans and animals. Basically, many countries around the African continent are making


**Figure 9.** Benefits of insect frass fertilizer on improved crop yield per hectare when compared to commercial organic and synthetic fertilizers as well as un-amended soils.

intentional efforts toward regulating and developing standards on insect-derived products, particularly in European Union (Belgium, the United Kingdom, the Netherlands, the Kingdom of Denmark, Finland), Africa (Kenya, Uganda, Rwanda, Tanzania, and now in Ethiopia), United States, Central and South America, Asia, Canada, and Australia (Halloran et al., 2015; Mariod et al., 2020; Lähteenmäki-Uutela et al., 2021). Currently, the International Centre of Insect Physiology and Ecology (*icipe*) and the African Organization for Standardisation (ARSO) have established a strategic partnership to promote the development and harmonization of standards and conformity assessment for edible insect-derived products in Africa as the availability and


**Figure 10.** Potential of insect-composted fertilizer in suppressing common pests and diseases affecting economically important crops in Africa.

accessibility of insect farming, consumption, and development of high-value added products continues to grow.

## Conclusion

The adoption of insect farming is growing at an alarming rate, but the volume required to supply the animal feed and human food market is still low. Safety of edible insects for food and feed remains a major concern. Advanced research on the role of bioactive compounds from edible insects on human health is largely lacking. Therefore, pharmacological, and therapeutic properties of edible insects need to be exploited for improve human and animal health. Insect frass fertilizer, another value-added product from insect farming is quickly picking up and ready for up scaling for improved soil health and increased crop yield. Africa's regulatory frameworks are still in their infancy and require urgent attention. Countries like Kenya and Uganda that have developed new or modified existing regulations to accommodate new industries, insect farming is now operating almost throughout the entire country.

The emerging sector has created thousands of jobs in the private sector and incomes for insect farmers and processors, who are increasingly investing in the novel insect-based protein.

## Conflict of Interest

The authors have declared no conflict of interest.


## Funding

The authors gratefully acknowledge the financial support for this research by the following organizations and agencies: Australian Centre for International Agricultural Research (ACIAR) (ProteinAfrica grant no: LS/2020/154), the Rockefeller Foundation (WAVE-IN—Grant No: 2021 FOD 030); Bill & Melinda Gates Foundation (INV-032416); the Curt Bergfors Foundation Food Planet Prize Award; Norwegian Agency for Development Cooperation, the Section for research, innovation, and higher education grant number RAF–3058 KEN–18/0005 (CAP–Africa); Horizon Europe (NESTLER—Project: 101060762—HORIZON-CL6-2021-FARM2FORK-01), IKEA Foundation (G-2204-02144), the Norwegian Agency for Development Cooperation, (NORAD) (Grant No SAF-21/0004.), Novo Nordisk Foundation (RefIPro: NNF22SA0078466), the Swedish International Development Cooperation Agency (Sida); the Swiss Agency for Development and Cooperation (SDC); the Australian Centre for International Agricultural Research (ACIAR); the Federal Democratic Republic of Ethiopia and the Government of the Republic of Kenya. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The views expressed herein do not necessarily reflect the official opinion of the donors.


## Data Availability

All datasets presented in this study are included in the article and can be availed by the authors upon reasonable request.


## Acknowledgments

We would like to thank all the technical staff of ICIPE for their commitment and technical support, which was instrumental in contributing consistently to the realization of this study.


## References


Abiya, A.A., D.M. Kupesa, D. Beesigamukama, M. Kassie, D. Mureithi, D. Thairu, J. Wesonga, C.M. Tanga, and S. Niassy. 2022. Agronomic performance of Kale (Brassica oleracea) and Swiss Chard (Beta vulgaris) grown on soil amended with Black Soldier Fly Frass Fertilizer under Wonder Multistorey Gardening System. Agronomy. 12:2211. doi:10.3390/agronomy12092211.

AgriProtein. 2018. USD 105 million raised for sustainable feed firm: AgriProtein secures largest investment to date in insect protein sector. Press Release, AgriProtein Online, June 4, 2018. https://www.agriprotein.com/press-articles/usd-105-million-raise-for -sustainable-feed-firm/.

AgriTech Capital. 2019. The buzz about insect protein. AgriTech Capital, June 22, 2019. https://www.agritechcapital.com/ideas-you-can-use-food-beverage/2019/6/22/the-buzz-about-insect-protein.

Azmir, J., I.S.M. Zaidul, M.M. Rahman, K.M. Sharif, A. Mohamed, F. Sahena, M.H.A. Jahurul, K. Ghafoor, N.A.N. Norulaini, and A.K.M. Omar. 2013. Techniques for extraction of bioactive compounds from plant materials: a review. J. Food Eng. 117:426–436. doi:10.1016/j.jfoodeng.2013.01.014.

Ayieko, M.A., H.J. Ogola, and I.A. Ayieko. 2016. Introducing rearing crickets (Gryllids) at household levels: adoption, processing and nutritional values. J. Insects Food Feed. (9):1739–1750. doi:10.3920/JIFF2015.0080.

Babarinde, S.A., B.M. Mvumi, G.O. Babarinde, F.A. Manditsera, T.O. Akande, and A.A. Adepoju. 2021. Insects in food and feed systems in sub-Saharan Africa: the untapped potentials. Int. J. Trop. Insect Sci. 41(3):1923–1951. doi:10.1007/s42690-020-00305-6.

Beesigamukama, D., S. Subramanian, and C.M. Tanga. 2022. Nutrient quality and maturity status of Frass fertilizer from nine edible insects. Sci. Rep. 12:1–13. doi:10.1038/s41598-022-11336-z

Borgerson, C., S.E. Johnson, E. Hall, K.A. Brown, P.R. Narváez-Torres, B.J.R. Rasolofoniana, and C.D. Golden. 2021. A national-level assessment of lemur hunting pressure in Madagascar. Int. J. Primatol 43:92–113. doi:10.1007/s10764-021-00215-5.

Chia, S.Y., J. Macharia, G.M. Diiro, M. Kassie, S. Ekesi, J.J.A. van Loon, M. Dicke, and C.M. Tanga. 2020. Smallholder farmers' knowledge and willingness to pay for insect-based feeds in Kenya. PLoS One. 15:e02305521. doi:10.1371/journal.pone.0230552.

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

Grabowski, N.T., S. Tchibozo, A. Abdulmawjood, F. Acheuk, M.M. Guerfali, W.A.A. Sayed, and M. Plötz. 2020. Edible insects in Africa in terms of food, wildlife resource, and pest management legislation. Foods. 9(4):502. doi:10.3390/foods9040502.

Halloran, A., R. Flore, P. Vantomme, and N. Roos. 2018. Introduction. In Halloran, A., R. Flore, P. Vantomme, and N. Roos, editors. Edible insects in sustainable food systems. Springer International Publishing. doi:10.1007/978-3-319-74011-9.

Halloran, A., P. Vantomme, Y. Hanboonsong, and S. Ekesi. 2015. Regulating edible insects: the challenge of addressing food security, nature conservation, and the erosion of traditional food culture. Food Security. 7:739–746. doi:10.1007/s12571-015-0463-8.

Hlongwane, Z.T., R. Slotow, and T.C. Munyai. 2020. Nutritional composition of edible insects consumed in Africa: a systematic review. Nutrients. 12(9):27861–27828. doi:10.3390/nu12092786.

Hlongwane, Z.T., R. Slotow, and T.C. Munyai. 2021. Indigenous knowledge about consumption of edible insects in South Africa. Insects. 12(22):1–19. doi:10.3390/insects12010022.

Jantzen da Silva, L.A., L. Menegon de Oliveira, M. da Rocha, and C. Prentice. 2020. Edible insects: an alternative of nutritional, functional and bioactive compounds. Food Chem. 311:126022. doi:10.1016/j.foodchem.2019.126022.

Kekeunou, S., and J.L. Tamesse. 2016. Consumption of the variegated grasshopper in Africa: importance and threats. J. Insects Food Feed. 2(3):213–222. doi:10.3920/JIFF2015.0087.

Kelemu, S., S. Niassy, B. Torto, K. Fiaboe, H. Affognon, H. Tonnang, N.K. Maniania, and S. Ekesi. 2015. African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J. Insects Food Feed. 1(2):103–119. doi:10.3920/JIFF2014.0016.

Kewuyemi, Y.O., H. Kesa, C.E. Chinma, and O.A. Adebo. 2020. Fermented edible insects for promoting food security in Africa. Insects. 11(5):2831–2816. doi:10.3390/insects11050283.

Lähteenmäki-Uutela, A., S.B. Marimuthu, N. Meijer. 2021. Regulations on insects as food and feed: a global comparison. J. Insects Food Feed. 7(5):849–856. doi:10.3920/JIFF2020.0066.

Lecocq, A., L. Joosten, E. Schmitt, J. Eilenberg, A.B. Jensen. 2019. *Hermetia illucens* adults are susceptible to infection by the fungus *Beauveria bassiana* in laboratory experiments. J. Insects Food Feed. 7(2021):63–68. doi:10.3920/JIFF2020.0042.

Lee, J.H., T. Kim, C.H. Jeong, I.H. Yong, J.Y. Cha, B. Kim, and Y. Choi. 2021. Biological activity and processing technologies of edible insects: a review. Food Sci. Biotechnol. 30(8):1003–1023. doi:10.1007/s10068-021-00942-8.

Liceaga, A.M. 2021. Processing insects for use in the food and feed industry. Curr. Opin. Insect Sci. 48:32–36. doi:10.1016/j.cois.2021.08.002.

Manditsera, F.A., P.A. Luning, V. Fogliano, and C.M.M. Lakemond. 2019. Effect of domestic cooking methods on protein digestibility and mineral bioaccessibility of wild harvested adult edible insects. Food Res. Int. 121:404–411. doi:10.1016/j.foodres.2019.03.052.

Mariod, A.A. 2020. The legislative status of edible insects in the World. In Adam Mariod, A., editor. African edible insects as alternative source of food, oil, protein and bioactive components. Cham, Switzerland: Springer International Publishing; p. 141–148.

Melgar-Lalanne, G., A.J. Hernández-Álvarez, and A. Salinas-Castro. 2019. Edible insects processing: traditional and innovative technologies. Compr. Rev. Food Sci. Food Saf. 18(4):1166–1191. doi:10.1111/1541-4337.12463.

Meyer-Rochow, V.B., R.T. Gahukar, S. Ghosh, and C. Jung. 2021. Chemical composition, nutrient quality and acceptability of edible insects are affected by species, developmental stage, gender, diet, and processing method. Foods. 10(1036):1036. doi:10.3390/foods10051036.

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

Mutungi, C., F.G. Irungu, J. Nduko, F. Mutua, H. Affognon, D. Nakimbugwe, S. Ekesi, and K.K.M. Fiaboe. 2019. Postharvest processes of edible insects in Africa: a review of processing methods, and the implications for nutrition, safety and new products development. Crit. Rev. Food Sci. Nutr. 59(2):276–298. doi:10.1080/10408398.2017.1365330.

Niassy, S., E. Omuse, N. Roos, A. Halloran, J. Eilenberg, J.P. Egonyu, C.M. Tanga, F. Meutchieye, R. Mwangi, S. Subramanian, et al. 2022. Safety, regulatory and environmental issues related to breeding and international trade of edible insects in Africa. Sci. Tech. Rev. 41(1). doi: 10.20506/rst.41.1.3309.

Ojha, S., S. Bußler, M. Psarianos, G. Rossi, and O.K. Schlüter. 2021. Edible insect processing pathways and implementation of emerging technologies. J. Insects Food Feed. 7(5):877–900. doi:10.3920/JIFF2020.0121.

Oyegoke, O.O., A.J. Akintola, S.A. Babarinde, O.I. Bello, and T.A. Ayandiran. 2014. Performance and organ characteristics of Cirina Forda (Westwood) (Lepidoptera: Saturniidae) larva meal in broiler birds. IOSR J. Pharm. Biol. Sci. 9(4):118–122. doi:10.9790/3008-0942118122.

Pener, M.P. 2014. Allergy to locusts and Acridid grasshoppers: a review. J. Orthoptera Res. 23(1):595967–595967. doi:10.1665/034.023.0105.

Poveda, J. 2021. Insect Frass in the development of sustainable agriculture: a review. Agron. Sustain. Dev. 41(5):1–10. doi:10.1007/s13593-020-00656-x.

Ribeiro, J.C., B. Sousa-Pinto, J. Fonseca, S.C. Fonseca, and L.M. Cunha. 2021. Edible insects and food safety: allergy. J. Insects Food Feed. 7:833–847. doi:10.3920/jiff2020.0065.

Rumpold, B.A., and O.K. Schlüter. 2013. Nutritional composition and safety aspects of edible insects. Mol. Nutr. Food Res. 57(5):802–823. doi:10.1002/mnfr.201200735.

Tanga, C.M., J.P. Egonyu, D. Beesigamukama, S. Niassy, K. Emily, H.J.O. Magara, E.R. Omuse, S. Subramanian, and S. Ekesi. 2021. Edible insect farming as an emerging and profitable enterprise in East Africa. Curr. Opin. Insect Sci. 48:64–71. doi:10.1016/j.cois.2021.09.007.

Tanga, C., H.J. Magara, A.M. Ayieko, R.S. Copeland, F.M. Khamis, S.A. Mohamed, F.L. Ombura, S. Niassy, S. Subramanian, K.K. Fiaboe, et al. 2018. A new edible cricket species from Africa of the genus *Scapsipedus*. Zootaxa. 4486(3):383–392. doi:10.11646/zootaxa.4486.3.9.

van Huis, A. 2013. Potential of insects as food and feed in assuring food security. Annu. Rev. Entomol. 58:56356383–56356583. doi:10.1146/annurev-ento-120811-153704.

van Huis, A. 2015. Edible insects contributing to food security? Agric. Food Secur. 4(1):1–9. doi:10.1186/s40066-015-0041-5.

van Huis, A. 2020. Insects as food and feed, a new emerging agricultural sector: a review. J. Insects Food Feed. 6:27–44. doi:10.3920/JIFF2019.0017.

van Huis, A., J. van Itterbeeck, H. Klunder, E. Mertens, A. Halloran, G. Muir, and P. Vantomme. 2013. Edible insects: future prospects for food and feed security.

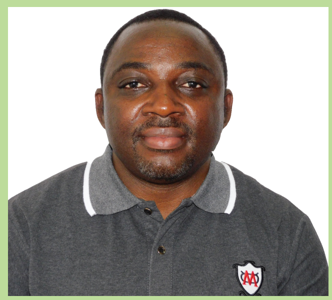
Verner, D., R. Nanna, H. Afton, S. Glenn, T. Edinaldo, A. Maximillian, V. Saleema and K. Yasuo. 2021. Insect and hydroponic farming in Africa: the new circular food economy. Agriculture and Food Series; Washington, DC: World Bank. © World Bank. http://hdl.handle.net/10986/36401.

Zewdu, A., M. Kassie, C.M. Tanga, D. Beesigamukama, and G. Diiro. 2020. Socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya. J. Clean Prod. 265(265):121871. doi:10.1016/j.jclepro.2020.121871.

Zewdu, A., I. Macharia, K. Mulungu, S. Subramanian, C.M. Tanga and M. Kassie. 2022. The potential economic benefits of insect-based feed in Uganda. Front. Insect Sci., Sec. Insect Economics. 2. doi: 10.3389/finsc.2022.968042

Zhou, Y., D. Wang, S. Zhou, H. Duan, J. Guo, and W. Yan. 2022. Nutritional composition, health benefits, and application value of edible insects: a review. Foods. 11:3961. doi:10.3390/foods11243961.

## About the Authors



**Chrysantus Mbi Tanga** is a senior scientist and Head of the Insects for Food, Feed and Others Uses Programme (INSEFF) at ICIPE. Tanga holds a PhD in Agricultural Entomology from the University of Pretoria, South Africa. He has over 10 years of wide-ranging experience in up-scaling, and dissemination of innovative technologies on insects for food, feed, therapeutics, and frass fertilizer in Africa and beyond. He is extensively involved in strengthening global partnerships on edible insects across ~40 organizations in 65 countries from 6 continents. His research interests include edible insect circular economy, One-health research, medicinal properties of edible insects, diversification of frass fertilizers, value-addition, youth and women empowerment, development and harmonization of standards and policy on edible insects. He has over 130 multidisciplinary cross-cutting edge research publications and has won internationally recognizable awards on edible insects. **Corresponding author:** ctanga@icipe.org

**Margaret Kababu** is researcher with experience in multi-disciplinary research. She is currently pursuing a PhD in Food Security and Sustainable Agriculture with focus on production and utilization of edible insects. She holds an MSc (Agricultural Entomology) and BSc (Zoological sciences) both from Kenyatta University. She was previously involved in implementation of research interventions on HIV and Gender Based Violence at LVCT Health. She is passionate about upscaling and adoption of mass production of edible insects to enhance food security and improve the livelihoods of small holder farmers. She is also keen on the mainstreaming of gender and HIV into food security to improve nutrition and health outcomes among women and children. Margaret is also a part-time lecturer at Rongo University where she teaches courses in Zoological sciences.