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# Benefits of using edibleinsects as alternative protein source: A Review

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ABSTRACT

There is an urgent need for alternative protein sources due to the rapid population growth, climate change, environmental degradation by pollution, food-fuel competition and the reduction in arable land for agricultural use. Conventional livestock production is also deleterious to the environment due to the production of greenhouse gasses and ammonia. This article provides insights into the potentials of edibleinsects as novel food ingredients. The manuscript provides concise explanations for the need of embracing additional protein sources, edibleinsects consumption and their nutritional benefits and environmental and economic advantages of using edibleinsects as food. Literature was gathered through an online search on the Science Direct database and Google Scholar, relevant papers published between January 2002 and November 2020 were cited. Edibleinsects are good source of essential nutrients. They are rich in proteins and essential amino acids, contain good quality lipids and significant amounts of important minerals. They are potential source of proteins for humans and animals. They can play an important role in global food security by providing essential nutrients to the increasing global population. This can only be achieved when more attention is given to their production and processing. Creating awareness among new consumers on their nutritional and environmental benefits and the development of food products with appealing sensory properties will surely improve their acceptance as food.

## Introduction

The practice of insect-eating, also known as entomophagy, is as old as the history of humans (Sun-Waterhouse et al., 2016; Cartay et al., 2020; Das et al., 2019). Insects were a vital source of food to early men and nowadays they play an imperative role in the nutrition of Latin America, Africa, and Asia (Srivastava et al., 2009; Fernandez-Cassi et al., 2019). Edible insects are among the most neglected and underutilized forest resources (Muimba-Kankolongo et al., 2015) with great potentials in providing nutritional security and income at local and international levels (Padulosi et al., 2018).

Edible insects are excellent source of essential nutrients and bioactive compounds (Sun-Waterhouse et al., 2016), they are rich in proteins with good amino acids composition, contain mono and polyunsaturated fatty acids, significant amounts of indispensable minerals (Zielińska et al., 2015) and petty amounts of cholesterol (Giordano et al., 2018). Protein, fat, mineral, and vitamin contents of edible insects are similar to those of meat (Baiano, 2020). Insect farming can protect the environment and provide proteins for pets, livestock, poultry, aquaculture, and humans (Tomberlin et al., 2015; Govorushko, 2019). In addition to the provision of nutrients, edible insects are also natural renewable resources that degraded organic waste (Das et al., 2019).

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There is a growing interest in the development and marketing of novel food due to the increasing demand for protein-rich foods and the obligatory need to diversify protein sources (Pippinato et al., 2020). Passion to reconsider ignored food sources and incoporate them into modern recipes has attracted the interest of researchers, chefs, and businessmen (Testa et al., 2016). There is also a rising demand for conventional protein substitutes that are green and cost-effective to meet up the diverse nutritional, sensory, and safety requirements (Fasolin et al., 2019).

**The need for additional sources of protein**

There is a rising demand for conventional protein substitutes that are green and cost-effective to meet up the diverse nutritional, sensory, and safety requirements (Fasolin et al., 2019). Livestock production is among the major anthropogenic activities that lead to eco-degradation and global warming (Abbasi et al., 2016). Rapid climate changes, environmental degradation by pollution, diminishing resources, and accelerated population growth also cause a serious setback to the global food supply (Dermody and Chatterjee, 2016). The production of conventional proteins is associated with many environmental problems. Intake reduction of about 90% of the current consumption is required to curtail the sustainability issues related to meat production (Videbæk and Grunert, 2020). Providing sufficient amounts of protein to the exponentially growing world population, projected to be 9.7 billion by 2050, will be a serious challenge (Tomberlin et al., 2015; Gallo and Federico, 2018). Moreover, income and population growth in some countries cause a significant increase in the consumption of animal protein (Gallo and Federico, 2018). An increase of 60-70% in animal product consumption is expected (Makkar et al., 2014).

Conventional sources will not be enough to sustain the fast-growing population (Rao, 2016). Alternative sources of proteins are required to complement the projected shortfall (Megido et al., 2014; Tang et al., 2019) and deal with the rising costs of animal proteins, environmental pressures (van Huis et al., 2013), the decline in the availability of arable land used for agricultural purposes (van Huis, 2015; Nadeau et al., 2015) and food-fuel competition (Makkar et al., 2014). An exponential increase in food production is needed (van Huis et al., 2013). A production increase of at least 60% is required to meet up with the demand (New, 2013). There is a need to investigate and explore other sources of protein in addition to traditional ones (Poelaert et al., 2018; Patel et al., 2019). This can be achieved through innovative changes in the food supply (Dicke, 2018). The high pressure on protein and other essential resources hasten the interest of using insects as food and feed (Gjerris et al., 2016). Insects are an important source of food to the diversity of animal species including humans (Srivastava et al., 2009). Edible insects are among the leading alternative protein sources that are receiving adequate attention (Mancini et al., 2019). Nutrients deficit can be solved by carefully studying local insects and chose the species with similar nutrients profiles (Nadeau et al., 2015).

Developing countries are battling food insecurity due to an increase in population and a decrease in food production (Gahukar, 2011). The majority of the people in these countries are suffering from hunger and undernutrition, and food-related diseases are affecting more than 50% of their population (Ramos-Elorduy, 2009). The risk of micronutrient deficiency is increasing in these countries because the most of the staple foods consumed are deficient in some essential nutrients including essential amino acids (Lategan, 2019). Most of these countries have abundant wild insects that can solve or minimize these problems, but taboos associated with edible-insects, their seasonal and localized nature prevent their consumption globally year-round (Nantanga and Amakali, 2020). Edibleinsects can be a part of the global food recipes when these hurdles are overcome (Akhtar and Isman, 2018; Patel, 2019; Caporizzi et al., 2019; Skrivervik, 2020).

**Insect consumption**

Entomophagy is an old tradition that is still active in many traditions (Yen, 2015a). The dietary pattern of any community depends on their surrounding ecosystem and resources available within their premises (Ramos-Elorduy, 2009). Insects are consumed comfortably and habitually in societies that accepted their consumption and are viewed as an important source of nutrition and medicine (Costa-Neto and Dunkel, 2016). Even children were encouraged to consume locally processed insects in some localities (Bose, 2020). The effects of lifestyle changes on entomophagy are quite insignificant in some parts of the world as the tradition remains the same over time (Dube et al., 2013). Eating insects as food is determined by culture, religious practice (van Huis et al., 2013; Niassy et al., 2016; Ruby and Rozin, 2019b), dietary needs (Yen, 2015b), location, and availability (Chakravorty, 2014). Insects are predominantly consumed more in tropical countries, because they occur naturally in mass (van Huis, 2015). Insects are favoured food in some parts of Latin America, West Africa and Southeast Asia (Ruby et al., 2015). They are also an important diet to Australian indigenes, Arabs in the Middle East, and South and Central Americans (Chung, 2008). Insects are consumed more in Thailand, China, Japan, Korea, and Indonesia than in any other nation (Chung, 2008). Thailand's insect industry is well developed with more than 20,000 registered insect farming enterprises (New, 2013).

Entomophagy is more common in rural areas (Chung et al., 2002) and the consumption of species can be restricted to a tribe or community (Niassy et al., 2016). In some parts of Africa, more than 90% of a community can participate in entomophagy (Dube et al., 2013). Central African region is the leading consumer of insects on the continent (Kelemu et al., 2015). Insects are consumed more by women and children than adult men in Africa (Akullo et al., 2017). A different inclination may likely emerge in the Western countries as men are more interested in entomophagy than women in Denmark (Videbæk and Grunert, 2020), America (Ruby and Rozin, 2019), and Italy (Tuccillo et al., 2020).

Insects that are consumed by humans are those that can easily gather in a huge quantity and do not have any unpleasant odour (Srivastava et al., 2009). Insects are consumed as a whole, as processed powder or paste, as extracts such as protein isolate (Williams et al., 2016), raw, cooked, or as ingredients in food preparation (Gahukar, 2011; Ayensu et al., 2019; Imathiu, 2020). They are consumed as either snacks or side meal (Akullo et al., 2017), while in some cultures insects, and other arthropods, are consumed as a staple (Srivastava et al., 2009). In Africa, insects are mostly consumed as complimentary food, and as the main dish in very few cases (Niassy et al., 2016). In India, raw insects are consumed (after trimming wings and legs) with processed fish (Shantibala et al., 2012), while bamboo worms and honey bees are processed and incorporated into condiments such as curry powder (Shantibala et al., 2012). Termites are boiled, blended with spices, mold into a ball, and cooked in banana leaves to serve as a main dish in Uganda (Akullo et al., 2017). In Northeast India, soft-bodied insects are consumed raw or processed into a condiment, while hard-bodied insects are consumed either roasted or fried (Shantibala et al., 2012).

House cricket (*Acheta domesticus*) is the most reported edibleinsect in the literature. Other commonly consumed insects in the world are grasshoppers, locusts beetles, termites, and caterpillars (Cartay et al., 2020; van Huis, 2020a). Different parts of insects at various stages of development are consumed as food. It could be eggs, larvae or nymphs, pupae, or adults (Chung, 2008). Insects are consumed by many as just traditionally inherited diets without knowing their nutritional potentials (Akullo et al., 2017). Non-native insect consumers prefer to eat insect products such as flour than eating whole insects (Ruby et al., 2015). People interested in tasting novel foods will accept new food, such as insects, quite easily unlike people with the opposite opinion (Hartmann and Bearth, 2019).

## Benefits of using insects as food

More attention was given to entomophagy in recent years due to identified nutritional and environmental benefits (Castro-López et al., 2020). Eating insects is encouraging due to the number of benefits including better nutrient composition, feed conversion efficiency, organic waste conversion, fewer requirements for water, and low greenhouse gas emission (Niassy and Ekesi, 2016). Insects are used in human medicine, as an aphrodisiac, animal feed, and bait during fishing, also as an agent for biodegradation (Niassy et al., 2016). Insects have a shorter production duration and their feed conversion rate is higher than that of higher animals (Megido et al., 2014; Fernandez-Cassi et al., 2019). They are poikilothermic, they do not use the energy generated through metabolism for body temperature control (Alexander et al., 2019). They have higher fecundity and require small space when compared with conventional livestock (Ayensu et al., 2019). The edible insect has a higher protein value and production efficiency when compared with conventional livestock (Dermody and Chatterjee, 2016). Insects eat inedible biomass of plants and produce high-quality proteins with all essential amino acids (Tong et al., 2011). Insects such as termites, grasshoppers, caterpillars, weevils, and houseflies are by weight richer in protein than beef, chicken, pork, or lamb (Srivastava et al., 2009). Entomophagy is expected to be among the key solutions to global food shortage through the provision of a high amounts of good quality proteins, fats, vitamins and minerals (Tang et al., 2019).

## Nutritional and health benefits

The use of insects as food by various communities contributed to food security in many ways (Müller et al., 2016). The nutritional value of edible insects will promote their consumption and they may appear on the menu of many eateries in the future (Bednárová et al., 2013). Edible insects can play an important role in ensuring food and feed security through the development of safe and adequate rearing and processing methods that will preserve their nutritive value (Rumpold and Schlüter, 2015). In doing so, a balance must be maintained between safety and nutritional qualities (Grabowski and Klein, 2017).

Growing location, feed composition, killing and processing methods significantly affect the nutritional compositions of edibleinsects (Table 1). Any of these factors can cause noticeable variations in nutritional composition, even within species. Sex is another factor that affects the nutritional composition of edibleinsects. Kulma et al. (2019) reported variation in proximate composition and chitin contents between male and female house cricket, such that the male cricket contains more proteins and chitin, while female contains more lipids. The protein value of insects is affected by the rearing condition and harvesting age (Morales-Ramos et al., 2018). The design of an insect rearing facility can also have effects on protein quality (Berggren et al., 2018). Compositions of insect nutrients depend on the rearing method, feed composition (Chinarak et al., 2020) and their ability to convert feed into body mass (Straub et al., 2019). Growing season significantly affects protein, fat, and mineral contents, location and season affect vitamin $B_{12}$ content, location affects mineral contents within the same season (Ssepuuya et al., 2019). Gut microbiota composition and eating patterns also determine vitamin $B_{12}$ content (Schmidt et al., 2019). Zou et al. (2017) reported significant variations in the lipid contents of different strains of silkworm pupae.

Nutrients in edible insects can promote good health (Ayensu et al., 2019). Some species provide health-promoting constituents (Dicke, 2018). Edible insects are seen as an alternative to conventional animal proteins in terms of their nutritional qualities (Roos and van Huis, 2017). The nutritional content of many insects is similar to that of conventional livestock (Kelemu et al., 2015; Lillford and Hermansson, 2020) and in some cases is superior to conventional livestock, milk, and eggs (Nadeau et al., 2015). Insect proteins are cheap protein substitute that can be used to fight malnutrition among the vulnerable groups in developing and underdeveloped nations (Ayensu et al., 2019). The likelihoods of using insects as conventional protein alternative depend greatly on understanding their nutritional profile (Payne et al., 2016) and confirming the claimed health benefits using acceptable health researches including human trial (Roos and van Huis, 2017).

Most edibleinsects contain more proteins and ash (minerals) than conventional protein sources, but possess lower levels of essential amino acids (Table 1). Edible insects can provide carbohydrates, proteins, fats, minerals, and vitamins (Gahukar, 2011; Ayensu et al., 2019). The proximate profile of most insects is better than that of other meats (Gere et al., 2019). The chitin in the edible insect with exoskeleton can be a good source of fiber (Koko and Mariod, 2020). The most common fiber in edible insects is N-acetylglucosamine (chitin), located at the exoskeleton and also the main component of the insect body (Caporizzi et al., 2019).

Certain insects and insect products such as honey and pollen are used as both food and medicine (Chung, 2008). Various species of insects contain bioactive compounds with potential health benefits that can contribute to combating global health challenges (Roos and van Huis, 2017). The essential *Lachnospiraceae* bacteria, responsible for fiber digestion, is among the natural biota found in house crickets (Frigerio et al., 2020). Chemicals produced by insects for self-defense can be used in the production of antimicrobial and anticancer drugs (Srivastava et al., 2009). Insects have enormous potentials in providing essential nutrients and active substances not only to humans but also to livestock (Tang et al., 2019). Livestock fed with insects tends to have better growth and amazing sensory qualities as reported in chicken by Waithanji et al. (2019).

Most edible insects have favourable nutrient contents, some can possess a low amount of iodine, vitamin A and some essential amino acids (Lategan, 2019). Insects, such as silk moth, can contain a large amount of proteins with all essential amino acids, numerous essential minerals, vitamins, and fatty acids (Tong et al., 2011). *Gryllus assimilis* and *Zophobas morio* are rich in palmitic, oleic, linoleic, and essential minerals (calcium, magnesium, iron, and zinc), they have protein contents of 65.52% and 46.80% and lipid contents of 21.80% and 43.64%, respectively (Araújo et al., 2019).

Edibleinsects can provide well-balanced proteins by converting organic waste (Payne et al., 2016). Edibleinsects are loaded with essential nutrients, they are rich in protein and can provide a well-balanced diet rich in essential amino acids since the protein value is very similar to that of meat and fish (Das et al., 2019). They are an excellent source of essential amino acids with easy digestibility and can be used to tackle chronic malnutrition when large production is promoted (Cartay et al., 2020). Insect protein has good digestibility in its raw form and after processing, and its amino acid profile meets the human dietary requirements (Poelaert et al., 2018). Edible insects contain more proteins than plant protein sources, including soybean (Rumpold and Schlüter, 2015) and they meet the WHO recommendation for amino acids (Tang et al., 2019). Termites have more than 35% of proteins, while crickets, grasshoppers, and locusts can contain more than 60% of proteins (Rumpold and Schlüter, 2015). Silkworm powder is more nutritious than snail, fish, chicken, beef, and pork (Tong et al., 2011). Crickets, honeybees, and palm weevil larvae were reported to be nutritionally superior to meat (Payne et al., 2016). González-Escobar et al. (2018) associated the higher protein value of insects with the abundant indigenous nitrogen-fixing bacteria.

The concentration of essential amino acids in many edibleinsects meets FAO/WHO standards (Oibiokpa et al., 2018). The most common limiting amino acids in insects are methionine (Zeece, 2020), cysteine, tryptophan (Tang et al., 2019), and lysine (Testa et al., 2016), but can contain up to 46 to 96% of essential amino acids (Testa et al., 2016). Tryptophan is limited in long-horned grasshopper (Ssepuuya et al., 2019), locust, and cricket; lysine in the scarab beetle; leucine in the silkworm (Köhler et al., 2019); lysine, methionine, and cysteine in yellow mealworms (Severini et al., 2018); methionine and cysteine in house cricket (Kulma et al., 2019); methionine in beetle and cricket (Manditsera et al., 2019); phenylalanine in cockroaches (Kulma et al., 2020), and methionine and lysine in black soldier fly (Surendra et al., 2020). Termite, moth caterpillar, and grasshopper possess low levels of sulfur-containing amino acids (methionine and cysteine) and isoleucine (Oibiokpa et al., 2018).

Insect larvae usually contain more fat than conventional meat and insect, in general, contains healthier lipids, because their polyunsaturated fatty acids content is much more superior when compared with that of conventional meat (Table 1). The higher fat content in the larvae of some insects provides attractive flavour and facilitates edibility (Tang et al., 2019). Insects contain a significant amount of unsaturated fatty acid and can be used as a source of polyunsaturated fatty acids in the landlocked countries with limited access to fish (Koko and Mariod, 2020). The lipid of silkworm pupae contains more than 70 % polyunsaturated fatty acid which is rich in α-linolenic acid (Zou et al., 2017). Omega-3 and omega-6 fatty acid contents of mealworms are comparable to that of fish (van Huis et al., 2013). Feeding insects with fish waste increases their polyunsaturated fatty acid content. An increase in polyunsaturated fatty acid content was observed in black soldier fly larvae fed with fish waste (Barroso et al., 2019). The omega-3 and omega-6 fatty acid ratio in *Eulepida mashona* and *Henicus whellani* is well-balanced (Manditsera et al., 2019). *Imbrasia* caterpillars have appreciable levels of omega-3 and omega- 6 fatty acids that can prevent several diseases, *Imbrasia truncata* and *I. epimethea* contains healthy lipids and all essential amino acids at the levels higher than that recommended by FAO (Mba et al., 2019). Oil extracted from *Tenebrio molitor* and *Pachymerus nucleorum* larvae noticeably reduced cholesterol and glucose levels in the experimental rat (Alves et al., 2019).

Edible insects are rich in minerals such as copper, iron, magnesium, manganese, phosphorous, selenium, and zinc (Rao, 2016). Entomophagy can be a cheap means for combating iron and zinc deficiencies in developing countries (Christensen et al., 2006). Incorporation of the edible insect into cereal-based food increases iron consumption and facilitates growth in infants (Ayensu et al., 2019). The calcium, sodium, manganese, and zinc contents of black soldier fly larvae meal are higher than that of soybean meal and other plant protein sources (Fisher et al., 2020). The consumption of 50 g of wild *Eulepida mashona* and *Henicus whellani* can supply 30% of daily recommended levels of zinc and 50% of daily iron requirement (Manditsera et al., 2019). Earthworm, house cricket, and mealworm larvae have excellent vitamin content (Gere et al., 2019). Cockroach, mealworm, cricket, and grasshopper contain a significant amount of vitamin $B_{12}$ (Schmidt et al., 2019).

## Environmental benefits

Protein production using insects is more friendly to the environment when compared to the resource intense conventional livestock farming (Stull et al., 2018). Insect-based foods were perceived to have lower environmental impact than beef products (Kusch and Fiebelkorn, 2019a). Entomophagy is expected to reduce agricultural land footprint and significantly curtail food waste when universally accepted (Alexander et al., 2017). One of the reasons for promoting insect-eating is the concern about the sustainability of the global ecosystem (Waltner-Toews and Houle, 2017). The integration of insect protein into the human diet is a sustainable alternative to conventional animal proteins (Megido et al., 2014), because conventional animal production puts too much pressure on the environment (Kusch and Fiebelkorn, 2019b; Weindl et al., 2020a) to the level that threatens the integrity of the ecosystem (Weindl et al., 2020b). Promoting insect consumption as an alternative source of proteins will reduce the environmental impact associated with conventional livestock production (Yen, 2015a).

Major environmental challenges such as deforestation and global warming can be minimized when insects are incorporated into diets (Jensen and Lieberoth, 2019). When compared with conventional livestock, insects require less space (Rumpold and Schlüter, 2015) and insect farming generates lower greenhouse gas and ammonia than livestock farming (Oonincx et al., 2010; Testa et al., 2016).

**Table 1.** Proximate values, Minerals, total essential amino acids (EAA) and total polyunsaturated fatty acids (PUFAs) in commonly consumed edibleinsect species

| Insect | Location/ Habitant | Feed | Killing method | Protein | Lipids | Ash | Fiber | Fe | Ca | P | Cu | Zn | EAA | PUFAs | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | % Dry matter | | | | | | Mg/100g | | g/100g | g/100g |
| **Farmed species** | | | | | | | | | | | | | | | |
| **Crickets** | | | | | | | | | | | | | | | |
| *Acheta domesticus* | Thailand | | Obtained as ready-to-eat, deep-fried | 53.90 | | | | 5.81 | 176.90 | 762 | 3.00 | 21.80 | 37.0 | | (Köhler et al., 2019) |
| | Thailand | Fed with grains and vegetable mix | Obtained as whole insect powder | 48.48 | 28.75 | 3.50 | 7.64 | | | | | | 50.60 | 36.17 | (Osimani et al., 2018) |
| | Netherlands | | Obtained as whole insect powder | 64.4 | 23.7 | 4.9 | 6.9 | 7.7 | 103.6 | 1008 | 3.4 | 24.4 | | | (Ribeiro et al., 2019) |
| *Gryllodes sigillatus* | Netherlands | | Obtained as whole insect powder | 65.3 | 23.5 | 4.2 | 7.1 | 4.7 | 117.3 | 782 | 4.9 | 16.8 | | | (Ribeiro et al., 2019) |
| **Cockroaches** | | | | | | | | | | | | | | | |
| *Blaberus craniifer* | Czech Republic | Dog pellets, staled bread apple, carrot, and lettuce leaves | 24 hrs Fasting and freezing | 66.60 | 24.30 | 1.40 | 7.40 | | | | | | | | (Kulma et al., 2020) |
| *Zophobas morio* larvae | Czech Republic | Dog pellets, staled bread apple, carrot, and lettuce leaves | 24 hrs Fasting and freezing | 48.10 | 34.00 | 0.7 | 5.3 | | | | | | | | (Kulma et al., 2020) |
| *Nauphoeta cinerea* | Brazil | fruit and vegetable remains | Boiled water | 59.78 | 21.27 | 5.11 | 6.85 | | | | | | | | (de Oliveira et al., 2017) |
| *Tenebrio molitor* larvae | France | wheat bran, cereal, premix and NaCl | freezing (-18 °C) | 65.50 | 24.50 | | | | | | | | | | (Azagoh et al., 2016) |
| Bombay locust (*Patanga succincta L.*) | Thailand | | Obtained as ready-to-eat, deep-fried | 36.31 | | | | 3.45 | 65.60 | 267 | 1.69 | 8.22 | 33.2 | | (Köhler et al., 2019) |
| Scarab beetle (*Holotrichia sp.*) | Thailand | | Obtained as ready-to-eat, deep-fried | 28.92 | | | | 9.10 | 75.10 | 260 | 1.08 | 8.80 | 36.7 | | (Köhler et al., 2019) |
| Mulberry silkworm (*Bombyx mori L.*) | Thailand | | Obtained as ready-to-eat, steamed | 50.20 | | | | 3.18 | 107.60 | 526 | 0.94 | 15.50 | 43.9 | | (Köhler et al., 2019) |
| Sago palm weevil (*Rhynchophorus ferrugineus*) larvae | Thailand | Fed with sago palm trunk | Blanching for 5 minutes | 18.0-28.5 | 52.4-60.1 | 2.4-2.9 | 3.8-4.5 | 2.63 | 43.3 | 494 | 1.03 | 8.33 | | | (Chinarak et al., 2020) |

| Insect | Location/ Habitant | Feed | Killing method | Protein | Lipids | Ash | Fiber | Fe | Ca | P | Cu | Zn | EAA | PUFAs | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | % Dry matter | Mg/100g | g/100g | g/100g | | | | | | | | |
| **Laboratory grown** | | | | | | | | | | | | | | | |
| Mealworms (*Tenebrio molitor*) | Belgium | wheat flour, brewer's yeast, and wheat bran | 24 hrs Fasting and freezing (-18 °C) | 43.00 | 40.90 | 3.40 | | | | | | | | 22.9 | (Megidoa et al., 2018) |
| | Germany | wheat bran | Freezing (-21 °C) | 52.00 | 26.75 | | 6.10 | | | | | | 40.8 | | (Kröncke et al., 2018) |
| **Wild species** | | | | | | | | | | | | | | | |
| Beetle (*Eulepida mashona*) | Zimbabwe | | Degutting and freezing | 54.47 | 7.98 | 4.69 | | 25–54 | | | | 16-21 | 28.8 | 24-35 | (Manditsera et al., 2019) |
| Cricket (*Henicus whellani*) | Zimbabwe | | Degutting and freezing | 65.75 | 7.68 | 4.99 | | 30–55 | | | | 16-21 | 27.4 | 42-47 | (Manditsera et al., 2019) |
| long-horned grasshopper (*Tettigonia viridissima*) | Kampala, Uganda | | No information | 34.2–45.8 | 42.2–54.3 | 1.79–2.72 | 3.93–5.34 | 48.6 | 70 | 517 | 1.91 | 11.24 | 49.4 | 63.5–64.7 | (Ssepuuya et al., 2019) |
| Short-horned grasshopper (*Chondacris rosea*) | Arunachal Pradesh, India | | Freezing | 68.88 | 7.88 | 4.16 | 12.38 | 7.81 | 300 | | 3.62 | 10.83 | 24.9 | | (Chakravorty et al., 2014) |
| Mole cricket, (*Brachytrupes orientalis*) | Arunachal Pradesh, India | | Freezing | 65.74 | 6.33 | 4.33 | 8.75 | 18.66 | 76.28 | | 1.53 | 8.50 | 21.3 | | (Chakravorty et al., 2014) |
| Meadow grasshopper (*Chorthippus parallelus Zetterstedt*) | Local grassland Belgium | | Fasting for 6 hours and freezing (-20 °C) | 69.00 | 7.88 | 4.00 | | | | | | | | | (Paul et al., 2016) |
| African palm weevil (*Rhynchophorus phoenicis*) larvae | Yaoundé, Cameroon | | Freezing (-20 °C) | 27.50 | 71.62 | 2.18 | | | | | | | | 4.0 | (Mba et al., 2017) |
| Arboreal ant (*Oecophylla smaragdina*) | Papumpare district, India) | | Freezing | 55.28 | 14.99 | 2.59 | 19.84 | | 74.67 | | 0.85 | 18.97 | | 8.19 | (Chakravorty et al., 2016) |
| **Conventional proteins** | | | | | | | | | | | | | | | |
| Whole cow milk | | | | 24.4 | 33.5 | 5.1 | | 0.15 | 118 | 96.56 | 0.03 | 0.33 | 49.08 | 0.138 | (Longvah et al., 2017) |
| Egg (poultry, whole raw) | | | | 56.5 | 39.0 | 3.4 | | 1.82 | 49.44 | 185 | 0.07 | 1.23 | 59.41 | 1.152 | |
| Chicken | | | | 58.5 | 38.0 | 3.4 | | 1.27 | 20.52 | 199 | 0.25 | 1.77 | 56.53 | 0.661 | |
| Beef | | | | 56.9 | 40.3 | 2.6 | | 2.22 | 6.50 | 201 | 0.07 | 4.64 | 57.9 | 1.008 | |
| Pork | | | | 47.0 | 50.8 | 2.0 | | 0.91 | 9.95 | 157 | 0.23 | 2.08 | 53.7 | 2.129 | |
| Catfish | | | | 69.7 | 27.4 | 4.1 | | 0.82 | 21.99 | 157 | 0.03 | 0.71 | 60.13 | 0.978 | |
| Soybean | | | | 37.7 | 21.0 | 5.0 | 22.8 | 8.29 | 239 | 483 | 1.29 | 4.01 | 40.76 | 11.279 | |

Insects have a higher feed conversion efficiency and require less water and land (Rao, 2016).

Putrefied wastes from food processing can be valorized by insects. Barroso et al. (2019) demonstrate how fish waste can be converted into polyunsaturated fatty acids when used as insect feed, though, Skrivervik (Skrivervik, 2020) reported that most of the commercial insect farmers are not using food waste as insect feed. Black soldier fly can efficiently convert waste into a high-value protein with qualities similar to that of soy meal and fishmeal (Surendra et al., 2020). Despite the little negative environmental impacts associated with insect farming, the utilization of their by-products can have additional benefits to the environment. Ulmer et al. (2020) reported that using honeybee drone brood as a novel source of protein can minimize the environmental impacts of beekeeping by 8%.

Berggren et al. (2019) opposed the sustainability claims associated with edible-insects production. According to them, many ecological factors were not given appropriate considerations. These factors include the choice of right species, integrating insects into the agricultural system, their wastes disposal, and risk of mass harvesting to the local ecosystem.

**Economic benefits**

Edible insects have higher market potentials despite inadequate regulation and little value addition in their business (Odongo et al., 2018). The global market of edible insects was worth 55 million United States Dollars (USD) in 2017 and a gross addition of 43.5% is expected by 2024 (Koko and Mariod, 2020). The predicted increase in the demand for animal protein for both food and feed makes insect farming a lucrative and sustainable business that can promote income generation and provide employment (Niassy and Ekesi, 2016). The profitability of insect farming depends on their ability to eat from cheap, readily available, and unutilized organic wastes (van Huis, 2020b).

The low production cost, which is virtually zero in some developing countries, promotes edibleinsects consumption (Tang et al., 2019). Commercializing insect farming is important when looking at their nutritional and economical value (Srivastava et al., 2009). The production of insect protein is cheaper and more sustainable than the production of conventional proteins (Hartmann and Bearth, 2019), as conventional livestock production depends to a great extent on resources that are also suitable for human consumption (Dicke, 2018). Conventional animal protein is becoming more expensive due to obstacles impeding the development of the livestock industry in developing countries. Continuous increase in the price of animal feed, fishmeal, soybeans, and grains intensifies the difficulties in accessing animal protein by many individuals (Niassy and Ekesi, 2016). Insect farming will provide a suitable alternative as many edible species can grow mainly on organic waste (Dicke, 2018), although, associating edible insects with waste utilization, upsurges their rejection (Rumpold and Langen, 2020). Insect farming also requires less technical and capital expenditure for rearing and harvesting equipment when compared with conventional livestock farming (Testa et al., 2016).

Insects provide rich proteins that are relatively affordable unlike meat proteins (Srivastava et al., 2009). Edible insects are becoming a fashionable solution to poverty by the role they play in many food systems (Tang et al., 2019). Insect gathering can offer jobs and incomes at both households and industrial scales of processing (van Huis et al., 2013) as insects are easily collected, processed, and sold with minimal technical and capital expenditure (Rao, 2016). The insect industry is expected to be prosperous through the development of products extracted from insects. Additives such as food colours can be extracted from insects (Tang et al., 2019).

Devastating insect pests can be exploited to reduce damage caused by these insects to food crops and to minimize the use of insecticides in the agricultural field (Flores et al., 2015). Edible insects such as locusts can cause devastating damage to crops (van Huis, 2020a). Eating insect pests such as grasshopper will reduce their population and can contribute to economic development (Chung et al., 2002).

## Recommendation and conclusion

## Recommendation

1. Alternative sources of protein are necessary since traditional rearing of beef, poultry and pork is not sustainable as the price of grains and, subsequently, that of meat are expected to raise in the decades to come.
2. As many people are willing to accept insects as food, research needs to be intensified in their production to develop the value chain.
3. A worldwide campaign on consumption of edible insects should be launched and emphasis should be given to countries with acute food shortages. Women should be engaged in the entomophagy campaign as they decide the types of food to be consumed by the family.
4. Since the allergy status of many edible insects is not fully understood, insect-based foods should be

consumed with caution. A clear understanding of edible insect allergic status will improve their acceptability. Individuals allergic to crustacean and other seafood must be cautious with insect-based foods. The possibility of blocking allergic reactions through the modification of processing conditions should be studied.

## Conclusions

Edible insects can contribute to global food security when more attention is given to their production and processing. Accepting insects as novel food ingredient will improve their consumption and open more research areas on their safety, nutritional and health benefits and functionality. Insects gathering can provide jobs and incomes, save food crops, improve their safety, and reduce the cost of their production. Insects can also provide important industrial raw materials such as food supplements and other additives. Edibleinsects are excellent source of important nutrients. Most edibleinsects contain more proteins and ash (minerals) than conventional protein sources, they are good source of essential amino acids, fatty acids, and indispensable minerals. Insects larvae usually contain more fat than conventional meat and insects, in general, contain healthier lipids due to their good polyunsaturated fatty acids content. Accepting insects as food will improve the nutritional status of many, especially in developing countries, that are suffering from malnutrition and hunger.

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