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EDIBLE INSECTS AS AN ALTERNATIVE PROTEIN SOURCE IN HUMAN AND ANIMAL NUTRITION

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ABSTRACT
Entomophagy has received widespread attention in both developed and underdeveloped nations. However, the exponential increase in demand for the few available conventional food and feed ingredients that are limited in supply and production has spurred the interest of food scientists and researchers to scale up their efforts to attain a more sustainable food ecosystem. This review, however, focuses on the current state of knowledge and the prowess of entomophagy to provide global faunas (micro and macro) with more extensive food and feed options. Edible insects potentially satisfy human dietary protein demands compared with other protein sources such as beef, chicken and pork. Unlike other animal-based proteins, edible insects contain higher protein levels, reaching 30% to 85% on a dry matter basis, and can quickly transform low-quality organic waste into edible protein. More so, studies have shown that replacing fishmeal with insect meal is a suitable alternative protein source for farm animals. Insect farming refers to the practice of raising and breeding insects as mini-livestock for the purpose of producing food or feed products that can be consumed directly by humans or animals. Insect farming is environmentally friendly due to its low ecological impact and the minimal need for arable land and water resources compared to other livestock species using about 80% of available agricultural land worldwide. When globally accepted, entomophagy and commercial insect farming have the potential to ease the hunger threat for the predicted world population, expected to be between 9.4 to 10.1 billion people in 2050.

Key words: alternative protein, entomophagy, environmental sustainability, food security, insect farming

INTRODUCTION
The global demand for protein as food and feed is increasing globally due to the rapid increase in population. Providing sustenance for this populace poses a formidable obstacle in light of the progressively restricted resources, such as arable land, which implies the necessity for alternative and sustainable sources of food or protein. This is essential to guarantee the availability and accessibility of sufficient, high-quality, safe and nutritious sustenance for all individuals consistently (Tao and Li, 2018; DiGiacomo and Leury, 2019; Imathiu, 2020).

Edible insects have been consumed by humans as a diet and way of life from the dawn of time, especially during times of food scarcity and when they are available for collecting (Ramos-Elorduy, 2009; Rumpold and Schlüter, 2013a; Imathiu, 2020). The habit of insect ingestion as a delicacy, also known as entomophagy, has received widespread attention in developed and developing nations (Imathiu, 2020). Entomophagy is an ancestral behaviour of most people in Africa, Asia, and South America (Rumpold and Schlüter, 2015). Moreover, edible insects constitute components of the standard edibles of approximately 2 billion people globally (van Huis, 2013), with over 2100 species supposedly eaten as food globally and over 470 edible insect species existing in Africa alone (FAO, 2013; Kelemu *et al*., 2015; Jongema, 2017). Edible insects can be eaten raw, boiled, roasted, fried, or pulverized across the stages of their life cycle (Sogari *et al*., 2019). Edible insect species are obtained from the wild in tropical environments. Women and children play an essential part in collecting, processing, and sales; daily ingestion requirements dictate the amount gathered (Kelemu *et al*., 2015; Kinyuru *et al*., 2018).

Insects have numerous advantages. For example, insects emit lower greenhouse gases and ammonia than conventional livestock species because they feed on organic matter waste (FAO, 2013; van Huis, 2013; Khan *et al*., 2020). The feed-to-protein conversion ratio of insects is substantially lower than cattle or pigs (Oonincx *et al*., 2015). van Huis

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and Oonincx (2017) highlighted that yellow mealworm and Black Soldier Fly (BSF) convert about 45% and 55% of dietary protein, respectively, to edible body mass. Industrial-scale insect farming requires less water and rearing space/land (Oonincx and De Boer, 2012) and can produce many generations within a short interval.

Edible insects are an excellent source of dietary protein for both human consumption and livestock feed (Sogari *et al*., 2019; Olarewaju *et al.,* 2020). Animal protein is abundant in insects at all stages of development (Tang *et al*., 2019). Edible insects contain high levels of protein and fat (8-70% monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs) (Rumpold and Schlüter 2013b; Tang *et al*., 2019). They also contain vitamins and minerals such as magnesium (Köhler *et al*., 2019), zinc, iron, biotin (vitamin B7), pantothenic acid (vitamin B5), and riboflavin (vitamin B2) (Rumpold and Schlüter, 2013b), antioxidants, essential amino acids, and prebiotic fibre (Ramos-Elorduy *et al*., 1997; Khan *et al*., 2020). Edible insects usually contain more crude protein (CP) than conventional protein sources such as beef, fish, poultry, pork, etc. Due to the enormous variety of insect species, edible insects' nutritional value substantially varies. Even within the same species, the nutritional value of an insect may vary depending on its metamorphic stage, environmental influence, and diet (Finke and Oonincx, 2014); the food value of edible insects is entirely dependent on what they have eaten or ingested (FAO, 2013). According to research, grasshoppers in Nigeria fed diets high in essential fatty acids had twice the protein content of those fed energy diets (FAO, 2013). However, van Huis (2021) noted that the insect's diet has minimal effect on protein content, but the fatty acid composition can be tailored to the target insect species. Insects have a high concentration of micro-nutrients and minerals (Glover and Sexton, 2015). However, Dobermann *et al*. (2017) reported that "micronutrient levels vary substantially between insect species, with some species having consistently greater amounts of specific micronutrients." As the COVID-19 pandemic continues to have devastating impacts in many countries, many individuals in precisely developing countries are redirecting their attention away from the pandemic's lethal effects and its implications on their daily food supply (Mukiibi, 2020). On the other hand, because edible insects are a good source of protein, research focused on their potential to aid nutrition and food security since they have a short life cycle (Imathiu, 2020). Most papers have solely discussed edible insects as an alternative source of protein in human diets; however, this review aims to provide an overvie of edible insects' enormous potential as a sustainable protein source in human diets and the potential benefits of including insects as an alternative source of protein in diets of different livestock species.

Table 1: Global consumption of common edible insects

Insect order	Edible insect members	Number of species consumed
Coleoptera	Beetles	659
Lepidoptera	Caterpillars	362
Hymenoptera	Ants, bees, and wasps	321
Orthoptera	Crickets, locusts, and grasshoppers	278
Hemiptera	True bugs	237
Odonata	Dragonflies	61
Isoptera	Termites	59
Diptera	Flies	37

Jongema (2017)

Insect Farming

The activity of rearing and breeding insects as mini-livestock for direct human or animal consumption and producing insect-based food or feed products is known as insect farming. Most developing countries adopt the neoteric edible insect production method (Oonincx and De Boer, 2012; van Huis, 2015; van Huis and Oonincx, 2017). Natural harvesting, semi-domestication, and insect farming are the methods used to produce edible insects, which can be anything from a single small cage to a large industrial enterprise (Yen, 2015; Madau *et al*., 2020). However, edible insects are harvested from the wild in tropical countries, playing an important economic and social role (van Huis and Oonincx, 2017). The harvested insects are marketable to source income. However, insect prices, on the other hand, are higher than those of other meat products (Madau *et al*., 2020). Semi-domestication offers more control over the target species' predictability, greater availability, and ecological sustainability while putting much less exploitative stress on the overall ecosystem. The techniques range from transferring target insects onto food plants, promoting insect populations, and altering or cultivating appropriate food plants (Yen, 2015). When the world list of recorded edible insects compiled by Jongema (2017) was assessed, the result showed that harvested insects provide 92% of the global insect supply, with semi-domesticated insects accounting for 6%. Only 2% of supplied insects are currently farmed when only insects meant for direct human consumption are considered. There is a rising interest in insect farming globally. According to Govorushko (2019), insect farming for food and feed has become popular around the world, serving as a relevant source of income in tropical countries (Kim *et al*., 2019). Many businesses are devoted solely to this activity, and some European countries, such as Netherlands and France, are world leaders in this field (Govorushko, 2019). In Europe and a few other developed nations, the production of insects focuses on feeding livestock and companion animals, whereas, in the tropics, insects are raised for human consumption (Madau *et al*., 2020). The academic interest in using insects as food or feed is also exponentially increasing because insect-based food and feed are becoming a more popular source of protein for humans and animals, respectively.

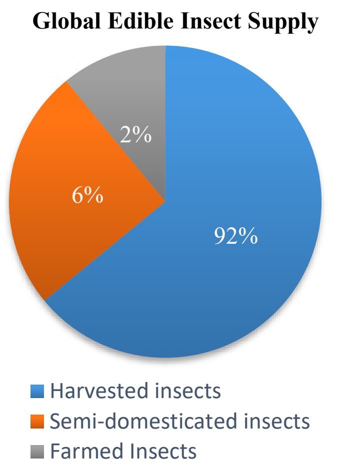

Figure 1: Pie chart showing global edible insect supply according to Jongema (2017)

Insect farming holds considerable potential for food security and long-term sustainability (Niyonsaba *et al*., 2021). When collecting the same amount of insects from the wild, there is no dispute raising insects can produce more insects with fewer negative environmental consequences (Yen, 2015). Hence, commercial insect rearing has received much attention, providing protein feed and food. However, there are regional differences in commercial insect production due to variations in species, production size, farm types and insect-eating preferences (Niyonsaba *et al*., 2021). Insect farming involves rearing insects in captivity, with the rearing stages monitored/controlled, including the living condition, the diet, and food quality (Madau *et al*., 2020). Since insects are reared in captivity, climatic factors need to be controlled. For example, high temperatures can result in the desiccation of soft-bodied larvae.

Thailand is an example of a country where edible insects are consumed as food. About two hundred (200) edible insect species are consumed in the country, forming part of their primary diet (Hanboonsong *et al*., 2013; Imathiu, 2020). In Thailand, over one hundred and thirty-seven thousand (137,000) households farm silkworms, accounting for 80% of the country's silkworm production. More importantly, about twenty thousand (20,000) farms produce an average of seven thousand five hundred (7,500) tonnes of silkworm per year (Hanboonsong *et al*., 2013). The house cricket (*Acheta domesticus*), the red palm weevil (*Rhynchophorus ferrugineus*), and the gigantic water bug (*Lethocerusindicus*) are recent examples of edible insects commercially produced for human consumption in Thailand (van Huis, 2013; Dobermann *et al*., 2017). More than 18 companies in the Netherlands produce insects (Govorushko, 2019). Kreca Ento-Feed BV has been producing insects for the animal feed industry since 1981, when it was established in the Netherlands. Protix, an insect-based company founded in the Netherlands in 2009, is a significant supplier of insect-based products. More recently, insect-producing companies have emerged in developing countries like Nigeria. Magprotein and Ento-Organics Nigeria, founded in 2017 and 2020, respectively, are commercial insect-producing companies using BSF larvae to produce insect meals for poultry and fish diet. In India, INSECTIFii and Freshrooms Life Sciences, founded in 2019 and 2016, respectively, are commercial-scale insect-based farms using BSF to convert urban organic waste into high-value insect protein.

Generally, the mass production or wild harvest of edible insects for human consumption primarily focuses on crickets and mealworms (Hawkey *et al*., 2020). These insects potentially satisfy human nutritional and protein demands compared with other protein sources such as beef, pork, fish, chicken, and so on. (de Carvalho *et al*., 2019).

Benefits of Edible Insect Farming

Health and nutritional benefits

Edible insect consumption provides numerous nutritional and physiological benefits for human health. They contain relatively large amounts of key nutrients in human diets, including protein, fat, energy, minerals, and vitamins, and about 77% to 98% of edible insects are digestible (Dobermann *et al*., 2017). Edible insects have a substantial amount of protein, reaching 30% to 85% on a dry matter basis (Rumpold and Schlüter, 2013a; Rumpold and Schlüter, 2015; Dobermann *et al*., 2017; Tang *et al*., 2019; Madau *et al*., 2020). According to Raheem *et al*. (2019), edible insects are high in protein and contain higher protein than most other protein sources from plants and animals.

Fat is the second most abundant nutrient in edible insects after protein. Oils obtained from edible insects are highly rich in PUFAs (linoleic and α-linolenic) and MUFAs (oleic acid and palmitoleic), which are essential for the growth and development of infants and children (FAO, 2013). The fat content (on a dry matter basis) of some commonly consumed insects in Africa includes the African palm weevil (*Rhynchophorus phoenicis,* 54%), termites (*Macroterms* sp., 49%), edible grasshopper (*Ruspolia differens,* 67%) (Womeni *et al*., 2009; FAO, 2013). Imathiu (2020), in their review, reported that insects are good sources of many minerals. According to Rumpold and Schlüter (2013b), many edible insects contain high phosphorus levels to meet an adult's dietary needs. However, Köhler *et al*. (2019) showed that locusts, scarab beetle, and crickets are good sources of iron, zinc, and magnesium with high concentrations. Insects also contain a wide range of vitamins, including pantothenic acid (vitamin B5), biotin (vitamin B7), and riboflavin (vitamin B2); grasshoppers, beetles, locusts, and crickets are particularly rich in folic acid (vitamin B9) (Imathiu, 2020).

Beyond the nutritional benefits, edible insects can improve human gut microbiota. Several components of edible insects can benefit human health, including chitin (Belluco *et al*., 2013; Nowakowski *et al*., 2021). According to Belluco *et al*. (2013), edible insects are a rich source of complex carbohydrates in human diets because of their high chitin content (at least 10% of thoroughly dried insects). Chitin is a non-toxic fibre-like carbohydrate polymer, particularly polysaccharide, which forms the exoskeleton of most arthropods. Although chitin is insoluble in water, it can be degraded to some extent by digestive enzymes in the gastrointestinal tract (GIT) of humans (Paoletti *et al*., 2007; Selenius *et al*., 2018). Chitin has been proven to enhance human gastrointestinal microbiota due to its probiotic and prebiotic potential (Selenius *et al*., 2018). This is accomplished by encouraging the growth of naturally occurring bacteria in the gut; chitin helps in intestinal disease states and digestion disorders (Selenius *et al*., 2018). Stull *et al*. (2018) found that supplementing 25 grams of dried, roasted cricket powder daily for 14 days boosted the proliferation of probiotic bacterium (*Bifidobacterium animalis*) in healthy people. Selenius *et al*. (2018) also reported that chitin enhanced *Lactobacillus rhamnosus* GG's growth and inhibited *Escherichia coli* TG's growth. Most research has shown that when chitin is consumed through insect-derived food, functional fibres like chitosan derived from chitin can help lower low-density lipoprotein (LDL) and total cholesterol levels in the blood (Ylitalo *et al*., 2002; Liao *et al*., 2007; Choi *et al*., 2012).

Environmental sustainability

According to the United Nations (UN), the global population is projected to stand between 9.4 to 10.1 billion people in 2050 (FAO, 2019). This would necessitate a greater demand for food, particularly of animal origin, with consequences for the environment, freshwater resources, and sustainability (Miglietta *et al*., 2015). Rearing edible insects is environmentally friendly compared to other livestock species like cattle. Insects serve as food sources with low ecological impact due to their minimal need for arable land and water resources than other livestock species that currently use about 80% of available agricultural land worldwide (Herrero *et al*., 2015; Ritchie, 2017).

The question of land availability regularly comes up in discussions about sustainable agriculture. As the demand for meat rises, producers are under increased pressure to raise more livestock, requiring more acreage. Higher livestock demand necessitates more feed, prompting farmers to increase the area of land planted, resulting in deforestation or increased fertilizer use (Dobermann *et al*., 2017). Compared to mealworms, beef requires about 8 to 14 times the quantity of land and almost five times the amount of water to produce a gram of useable protein (van Huis and Oonincx, 2017). In chicken production, 1 g of edible protein requires about 2 to 3 times more land and about 50% more water compared to mealworm (Oonincx and De Boer, 2012; Miglietta *et al*., 2015).

Besides less land and water for rearing edible insects, they contribute minimally or no amount to greenhouse gas and carbon dioxide emissions than large livestock species, accounting for 18% of greenhouse gas emissions (Oonincx and De Boer, 2012; van Huis, 2015). Regarding greenhouse gas emissions, mealworms have been demonstrated to have a lower impact on the environment than conventional livestock species. Compared to mealworms on an edible protein basis, broiler chickens emit 32 to 167% more carbon dioxide, while beef cattle emit 6 to 13 times more carbon dioxide equivalents (Oonincx and De Boer, 2012). An assessment of the life cycle of an industrial cricket farm study in Thailand by Halloran *et al*. (2017) reported that broiler production had a more significant environmental impact than cricket production. Edible insect larvae such as the BSF larvae can degrade organic waste, including manure; they can quickly convert low-quality human and animal organic waste into high-quality organic fertilizers for crop production (van Huis, 2013). They utilize these wastes and kill or reduce pathogenic bacteria such as *Salmonella enterica* or *Escherichia coli* (*E. coli*) found in cattle or poultry manure (Erickson *et al*., 2004; Liu *et al*., 2008). According to Lundy and Parrella (2015), feeding biodegradable waste to insects could make them more eco-friendly.

Socio-economic benefits

Additionally, insect farming benefits the economy in diverse ways. Throughout Southeast Asia, importing and exporting insects for food play a significant economic role (Dobermann *et al*., 2017). However, edible insect farming can provide a constant income for established farmers because the market value of edible insects often exceeds that of other protein sources (Dobermann *et al*., 2017). In developing countries, particularly in rural areas, edible insects serve as a source of livelihood, especially during food shortages, to facilitate food access and consumption. However, in these rural areas, edible insect improves the local diets and provides employment and earning income for women and children who are primarily involved in the farming, gathering, processing, and selling of edible insects (Kelemu *et al*., 2015; Gahukar, 2016; Kinyuru *et al*., 2018). The growth prediction that increased acceptance of entomophagy on a global level plays a significant role in food security and presents an excellent opportunity for new businesses, particularly in developing countries (Dobermann *et al*., 2017). In Thailand, insect farming, particularly cricket farming, is a very thriving route out of poverty that has been shown to significantly improve the living conditions of the country's rural farmers while also serving as an alternative income source and increasing social and human capital (Halloran *et al*., 2017).

Edible Insects as Human Food

Food is one of the basic requirements of a living organism, including humans. Human beings need food that can provide the complete essential nutrients the body needs to keep functioning and sustain a healthy life system (Devi *et al*., 2022). However, edible insects have long been part of human diets, especially in tropical and Asian countries (Rumpold and Schlüter, 2015). Although edible insects provide environmental and economic benefits, the nutritional value of edible insects is highly beneficial. It serves as food to humans, providing essential nutrients such as protein, fat, vitamins, and minerals the body needs. Edible insects can be consumed in different forms, including fried, boiled, roasted, and, most times, in raw form (Sogari *et al*., 2019). Furthermore, farmed edible insects could be dried and milled to produce insect flour, which can be added to food products such as bread, biscuit, cake, and other bakery products to increase further their nutritional value and functionality (Williams *et al*., 2016). Insects can be used as food additives and are usually consumed for medicinal purposes (de Carvalho *et al*., 2019). Incorporating edible insects in food and forming insect-based products has been carried out in several studies (da Rosa Machado and Thys, 2019; Duda *et al*., 2019; González *et al*., 2019). Osimani *et al*. (2018) found that mixing cricket powder (*Acheta domesticus*) and wheat flour at various levels in bread increased the nutritional profile, especially the protein content of the bread, although the hardness was affected. González *et al*. (2019) also reported that flour made from edible insects could be used in baked products such as bread to improve their nutritional composition, especially protein content. However, the authors (González *et al*., 2019) further noted that a 5% inclusion of insect flour (*Acheta domesticus*) in bread dough is suitable for bread formation and would result in better functional properties and flavour. In addition, cricket flour is also high in vitamin B12, which aids in the healthy functioning of the heart and central nervous system (CNS) and the health of the skin, hair, and nails (Ordoñez-Araque and Egas-Montenegro, 2021). It is noteworthy that cricket flour does not contain gluten, making it suitable for people with gluten intolerance and celiac disease (Kowalczewski *et al*., 2019). Regarding mineral content, cricket powder is highly rich in zinc, copper, manganese, and magnesium (Montowska *et al*., 2019).

As a valuable source of protein, edible insects are highly digestible by humans (Belluco *et al*., 2013). They contain essential amino acids (methionine, tryptophan, lysine, tyrosine, and phenylalanine) recommended by World Health Organisation (WHO) in human nutrition (Chakravorty *et al*., 2016; Lange and Nakamura, 2021; Devi *et al*., 2022). According to Kewuyemi *et al*. (2020), the essential amino acid content of African palm weevil (*Rhynchophorus phoenicis*) includes leucine (47.00 mg g^{-1}), threonine (29.00 mg g^{-1}), histidine (11.00 mg g^{-1}) phenylalanine (65.00 mg g^{-1}), methionine (21.00 mg g^{-1}), lysine (42.00 mg g^{-1}), valine (41.00 mg g^{-1}) and isoleucine (24.00 mg g^{-1}). Unlike other nutritional content of edible insects, protein value does not significantly change irrespective of the stage of development (Ordoñez-Araque and Egas-Montenegro, 2021). For instance, Kim *et al*. (2019) noted that the protein content of the leaf-footed bug (*Thasus gigas*) in the adult stage is 65%, while the nymph stage is 63%.

In addition, the Orthoptera order (grasshoppers, crickets, and locusts) of edible insects is proven to contain higher protein levels than other insect orders (Ordoñez-Araque and Egas-Montenegro, 2021). Based on the nutritional components and benefits of edible insects, entomophagy may be a viable solution and appealing food source in low-income countries to solve the problem of food and nutrition insecurity.

Table 2: Protein and fat contents of some commonly consumed edible insects

Scientific name	Common name	Protein (% of dry weight)	Fat (% of dry weight)	Reference
Rhynchophorus phoenicis	African palm weevil	11.47	54.00	FAO (2013); Rumpold and Schlüter, (2013b)
Macrotermes sp.	Termites	42.63	49.00	FAO (2013); Rumpold and Schlüter, (2013b)
Ruspolia differens (green)	Edible grasshopper	43.10	48.20	Kinyuru *et al*. (2011)
Ruspolia differens (brown)	Edible grasshopper	44.30	46.20	Kinyuru *et al*. (2011)
Tenebrio molitor	Mealworm	53.22	34.54	Ghosh *et al*. (2017)
Schistocerca gregaria	Desert locust	76.00	12.97	Zielińska *et al*. (2015)
Gryllodes sigillatus	Tropical house cricket	70.00	18.23	Zielińska *et al*. (2015)
Acheta domesticus	House cricket	64.10	24.00	Rumpold and Schlüter (2013b)
Bombyx mori	Silkworm	58.00	35.00	Rumpold and Schlüter (2013b)
Gryllusbi maculatus	Two-spotted cricket	56.54	15.82	Ahmed *et al*. (2021)
Zonocerus variegatus	Variegated grasshopper	30.73	20.00	Anaduaka *et al*. (2021)
Allomyrina dichotoma	Japanese rhinoceros beetle	54.18	20.24	Ghosh *et al*. (2017)
Brachytrupes portentosus	Wild field cricket	53.32	22.29	Ahmed *et al*. (2021)

Insects in Animal Feed

The demand for alternative protein sources in animal feed is of great concern due to the cost of other protein sources like soybean and fishmeal. These feed ingredients compete in human and animal nutrition, dramatically affecting the availability of conventional feed ingredients intended for human consumption. Feed costs and feed production, on the other hand, account for 50-85% of overall commercial animal production (Spring, 2013; Alqaisi *et al*., 2017; Govorushko, 2019; Mallick *et al*., 2020; Elahi *et al*., 2022). For instance, in Nigeria, conventional feed cost accounts for 81% (Osinowo and Tolorunju, 2019), while in India, feed cost accounts for 60% (van Huis, 2013) of the total cost of production in raising poultry. Still, the steady lack of maize and soybeans hinders feed production. Insects have excellent nutritional characteristics and can successfully substitute components used in feed manufacturing, such as fish, soybeans, and so on (Govorushko, 2019). Insects are already part of the natural diets of livestock animals, making insects an alternative protein source or feed for them (Rumpold and Schlüter, 2013a). Silkworms (*Bombyx mori*), Yellow mealworms (*Tenebrio molitor*), Common housefly (*Musca domestica*) larvae, and BSF (*Hermetia illucens*) larvae have been recognized as significant insect species for commercial feed production (Veldkamp *et al*., 2012; Oonincx *et al*., 2015; van Huis, 2015; Veldkamp and Bosch, 2015).

Insect meal in poultry diet

Several types of research have been carried out to ascertain the effects of insect meal on the growth performance, blood parameters, carcass traits, laying performance, meat quality, and gut health of poultry birds (Zuidhof *et al*., 2003; Schiavone *et al*., 2017; Biasato *et al*., 2018; Bovera *et al*., 2018; Schiavone *et al*., 2018; Kim *et al*., 2020; Gariglio *et al*., 2021). In a study conducted by Schiavone *et al*. (2017), the authors reported that partial (50%) or total (100%) replacement of soybean oil with BSF larvae fat in broiler diets did not adversely affect growth performance, carcass traits, and meat quality. Including BSF pre-pupae meal up to 15% in broiler diets doesn't influence meat quality, sensory quality (flavour, juiciness, aroma and tenderness), and broiler chicken carcass characteristics (Pieterse *et al*., 2019). Maurer *et al*. (2016) also reported that replacing soybean cake with BSF meal is a valuable replacement for soybean cake in layers diet without affecting feed efficiency, metabolic, and health status of the hen.

Insect meal in swine diet

In Kenya, the dietary replacement of fishmeal up to 100% with BSF (*Hermetia illucens*) larvae meal (BSFLM) in growing pigs had no negative impact on blood traits and growth performance. In addition, the study's cost-benefit analysis demonstrated that using BSFLM in pig feed is a beneficial investment for farmers in pig production and that the complete replacement of fishmeal with full-fat BSFLM in pig feed is feasible (Chia *et al*., 2019). Another study by Chia *et al*. (2021) on finishing pigs demonstrated that replacing fishmeal with BSFLM (50 to 100%) is a suitable alternative protein source in pig diet, as it enhanced higher feed efficiency, body weight gain, and carcass traits. Dried mealworm (*Ptecticustene brifer*) larvae have also been reported as a suitable animal protein source to substitute fishmeal in weaning piglets, according to Ao and Kim (2019). Furthermore, when Ringseis *et al*. (2021) carried out a study to assess the effect of *Tenebrio molitor* larvae meal on antioxidant status and stress response pathway in tissues of growing pigs, the result showed that *Tenebrio molitor* larvae meal in the diet of growing pigs neither causes oxidative stress nor activates stress in essential metabolic tissues.

Insect meal in fish diet

In the aquaculture industry, the development of fish production is adversely affected by the high cost of fish feed (Saleh, 2020). A less expensive but nutritionally adequate alternative protein source to fishmeal is required to cut fish production costs and maximize profitability (Ajani *et al*., 2004). Using non-conventional feedstuffs for producing fish feed would reduce the total cost of fish production. Saleh (2020) noted that housefly larvae meal (HLM) is a feasible alternative to fishmeal in fish diets based on availability, affordability, feed conversion ratio, and biological value. Several authors reported replacing or partially substituting insect larvae meals such as BSFLM and HLM in fish diets (*Clarias gariepinus, Oreochromis niloticus, Oncorhynchus mykiss, Salmo salar*) did not affect growth performance and feed utilization. Therefore, BSFLM and HLM can serve as alternative protein sources in the fish diet (Ogunji *et al*., 2008; Belghit *et al*., 2019; Tippayadara *et al*., 2021; Melenchón *et al*., 2022).

Insect meal in ruminant diet

Using insects as feed or in the diets of ruminant animals has not been fully explored. However, insects such as BSF larvae have been shown to harbour different types of microorganisms, including *Lactococcus lactis*, which have great potential as probiotics to replace antibiotic growth promoters in young ruminants (Wynants *et al*., 2019; Astuti and Wiryawan, 2022). Ruminants such as cattle, sheep, and goats could survive by feeding on hay and silage. Still, in most situations, they require functional feed, including a flushing diet to boost growth rate and induce hormones during reproduction, a milk replacer for neonates, and a special diet for recovering from stress. BSF with a high essential amino acids profile, lauric acid as an antibacterial, and lactic acid bacteria as probiotics can potentially be used as functional feed for ruminants (Astuti and Wiryawan, 2022). The report from a study to assess the utilization and evaluation of cricket meal as a protein source in lamb ration showed that the inclusion of cricket meal at 15% to replace soybean meal could be a protein source in lamb ration without any adverse effect on palatability, performance, feed efficiency, and blood metabolites (glucose, triglyceride, total protein) (Astuti *et al*., 2016). Ahmed *et al*. (2021) found that substituting *Acheta domesticus* (house cricket), *Brachytrupes portentosus* (wild field cricket) *Bombyx mori* (silkworm), and *Gryllusbi maculatus* (two-spotted cricket) meal for soybean meal in ruminant diets had no negative impact on nutrient digestibility and fermentation profile. In addition, the inclusion of *Bombyx mori* (silkworm) and *Gryllusbi maculatus* (two-spotted cricket) meal in the diet of ruminants demonstrated significant potential to reduce methane (CH_4) production by up to 16.30 and 18.40%, respectively. Astuti *et al*. (2016) reported similar findings that utilizing 7.5% cricket meal in a lamb diet would significantly reduce methane production. Jayanegara *et al*. (2017) noted that replacing soybean meal with BSF meal in ruminant diet results in a lower nutritional value *in vitro*. This could be a result of high chitin content in BSF. However, BSF is better than soybean meal in a ruminant diet in reducing methane emissions.

CONCLUSION AND FUTURE PROSPECT

Edible insects, as an alternative source of protein, have prospects in meeting animal protein demand for the growing world population. Post COVID-19, the pandemic has further altered the access to and choices of nutritional foods. Thus, global intervention is needed to provide alternative sources of protein that can be used sustainably for both human and animal consumption. Edible insects have numerous nutritional, health, environmental, and socio-economic benefits compared to other protein sources. Notably, it has excellent characteristics that have regarded its usage to other protein sources, such as reducing the competition in animal consumption of conventional feed ingredients with humans, performance benefits, and reduction in animal production cost. Despite the health benefits of edible insects, their consumption may still be found disgusting to the masses. However, further research is needed to produce suitable insect-based food products. More so, for easy accessibility, there is a need for more markets. We believe that research on edible insects will increase public awareness of the need for sustainable livestock and food production locally and globally. One possible way to achieve this is to undertake similar work to understand a particular edible insect as an alternative source of protein. With decisions geared explicitly toward food and animal production sustainability worldwide, these would fill in the knowledge gaps identified and facilitate the widespread adoption of edible insects as food.

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