# Processing and the bioactive compound of edible insects for animal and human food- a Review

L. Purnamasari[1,2], J.F. dela Cruz[3], I.S. Nam [2], S.G. Hwang[2*]

[1] Department of Animal Husbandry, Faculty of Agriculture, University of Jember, Indonesia; [2]School of Animal Life Convergence Science, Hankyong National University, Anseong 17579, Republic of Korea; [3] Department of Basic Veterinary Sciences, College of Veterinary Medicine, University of the Philippines Los Baños, Laguna, 4031, Philippines
*Corresponding author e-mail: sghwang@hknu.ac.kr

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## Abstract

This review shows and compares the nutritional composition and bioactive compounds of edible insects by different processing technologies. Edible insects have proteins and bioactive compounds that have different functionalities. Insects can be good sources of sustainable raw materials for alternative food and feed. Processing facilities and storage are intended to ensure food/feed safety, quality and extend the shelf life of edible insect products. In addition, issues related to entomophagy and possible risks that must be taken into account when consuming edible insects are also discussed.

**Keywords**: bioactive compound; edible insect; feed; food; process

# 1. Introduction

The increase in human population from year to year will have an impact on the scarcity of agricultural land, forests, water, biodiversity, and nutritional resources. Food sustainability is one of the basic needs. Based on the World Food and Agriculture Organization (FAO) data, the total human population worldwide in 2050 will reach 9 billion people. The demand for food needs will increase up to 70% of current needs (Zielinska, et al., 2015). Conventional protein sources will not be sufficient for future food needs. Currently, as many as 870 million people in the world are malnourished (FAO, 2012). Without a good waste management system, an explosion population can cause environmental damage. Advances in technology and science encourage innovation for improving the environment on earth which is also useful in fulfilling human food needs.

Nowadays, insects have been used as an alternative food (entomophagy), as a protein source in several regions in Asia, Africa, Australia, and Latin America. Insects are expected to be a solution to global food problems, especially the lack of protein sources (Van Huis et al., 2013). Advantages of entomophagy were high feed-conversion efficiency of insects from the rearing on organic waste, adding value to waste, and decreasing environmental contamination (Lange and Nakamura, 2021). According to Global market insight, globally the market for insects that can be eaten by humans will increase by 23.8 percent from 2019 to 2023 with the largest markets in Asia and Europe (Stull et al. 2018). Government regulations in buying and selling food products of insect origin have also not encountered obstacles.

According to the World Food and Agriculture Organization of the United Nation, 1900 species of insects have been popular and safe for human consumption, including grasshoppers, crickets, Madagascar cockroaches, and Tenebrio (Lammers, et al., 2019). This insect product is accessible, palatable, and presented in the whole form, insect flour, insect protein extract, and insect oil that have a high concentration of amino acids, healthy fatty acids (Rutten et al., 2016) minerals, vitamins, and fiber (Lange and Nakamura, 2021). Insect cultivation also does not require a large area of land, costs a lot, and produces less ammonia and greenhouse gases, making it safer for the environment (Poma et al., 2017). The production of insect peptides has been focused on antioxidant, antihypertensive, anti-inflammatory, antidiabetic, and antimicrobial properties (Borges et al., 2022). Edible insects have the potential to become a major global future food and part of a strategy for achieving food security worldwide (Van Huis, 2015; Sun-Waterhouse et al, 2016). This review shows and compares edible insects' nutritional composition, processing technology, and bioactive compounds. In addition, issues related to entomophagy and possible risks that must be considered when consuming edible insects are also discussed.

# 2. Nutritional properties

### *2.1. Nutritional value*

Many conditions influence the nutritional content. Most insects have different nutritional profiles based on their phases such as egg, larva, pupa, or adult. Crude protein content ranges from 20% to 70% in dry matter higher than in most plants and commercially produced meat, milk, poultry, and egg products (Rumpold & Schluter, 2013). The effect of diet is important for fatty acid content. Adding a source of omega 3 or 6 fatty acids to insect diets, increase the ratio of omega 3 or 6 which is optimal for human health (Oonincx et al. 2020). Environmental conditions also influence the nutrient content of edible insects, such as temperature, humidity, and even light conditions (Van Huis, 2020). For example, low ultra-violet irradiation increased vitamin D levels inhouse cricket and yellow mealworm (Oonincx et al., 2018). That's why edible insects are often used for fortification programs. The nutritional value of common edible insects as a food and feed constituent is shown in Table 1.

Edible insects can also be a source of certain micronutrients, such as iron, calcium, magnesium, phosphorus, manganese, zinc, selenium, and a source of vitamins, such as riboflavin, biotin, pantothenic acid, and in some cases, folic acid (Nowak et al, 2016; Rumpold & Schlüter, 2013). Carbohydrates forms in insects mainly chitin and glycogen (Ojha et al, 2021a), and have more unsaturated fatty acids than saturated fatty acids (de Castro et al, 2018).

### *2.2. Insects eligible for animal feed*

Insects as a feed are popular nowadays. They can use organic waste such as kitchen waste, manure, and plant-origin waste to provide protein and energy sources for animal feed and are environmentally friendly products (Purnamasari & Khasanah, 2022). Feed availability is one of the main factors of the sustainability livestock business. Insects have appeared as alternative feed ingredients, fully or partially replacement for another source of protein or energy for several livestock species. Feeding trials conducted on livestock and fish diets concluded that insect meal could replace the main protein sources such as soybean meal and fishmeal without having negative effects on growth performance and meat quality. The effect of edible insects on animal performance are shown in Table 2. The European Food Safety Authority (EFSA) reports on the risks of using insects as food and animal feed that depend on the insect spesies used.

*2.3. Food security*

Most edible insects are currently harvested in the wild. It is estimated that close to 2000 species of insects are edible in a variety of forms and consumed at different life stages including eggs, larvae, pupae, or adults (Sun-Waterhouse et al, 2016). The most consumed insect types include beetles (31%); caterpillars (18%); ants, wasps, and bees (14%); locusts, crickets, and grasshoppers (13%); scale insects, leafhoppers, true bugs, cicadas, and planthoppers (10%); dragonflies (3%); termites (3%) and flies (2%) (Imathiu, 2020). Edible insects as food constituent are shown in Table 3.

**Table 1**. Nutritional value of common edible insects as a food and feed constituent.

| Insect | Crude protein (%) | Fats (%) | Ca (g/kg DM) | P (g/kg DM) | literature |
|---|---|---|---|---|---|
| Black soldier fly larvae | 36.2-65.5 | 4.6-34.3 | 1.94-4.12 | 1.0-6.27 | (Shumo et al, 2019; El-Hack et al, 2020) |
| Housefly larvae | 28.63-63.99 | 20.76-37.78 | 0.49-4.7 | 1.27-16.0 | (Gadzama and Ndudim, 2019; Hussein et al, 2017) |
| Mealworm | 32.87-63.34 | 3.59-32.7 | 0.43-0.80 | 5.2-8.08 | Ravzanaadii et al, 2012 |
| House Cricket | 63.1-71.9 | 12.9-21.7 | 0.15-1.1 | 0.1-1.79 | Kulma et al, 2019; Udomsil et al, 2019 |
| grasshopper | 11.04-57.3 | 8.5-10.46 | 1.3-2.02 | 1.1-6.33 | Ochieng et al, 2022; Paul et al, 2016 |
| Silkworm pupae | 60.7-62.76 | 24.3-31.4 | 0.63-5.17 | 2.72-8.53 | Gangopadhyay et al, 2022; Herman et al, 2022 |

**Table 2**. The effect of edible insects on animal performance

| Animal | Treatment | Result | Source |
|---|---|---|---|
| broiler chicken | Replacing soybean meal with mealworm larvae meal or with silkworm pupae meal | did not negatively affect growth performance and sensory meat quality | Pietras et al, 2021 |
| White leg Shrimp | Replace partially the fishmeal Black Soldier Fly meal | Improve live performance, gut histology, have immune modulating effects, have antimicrobial properties which benefit animal health. | Hermes et al., 2022 |
| juvenile channel catfish | Replace 100% fishmeal with cricket meal | did not negatively affect growth performance; increased crude protein content; enhanced liver antioxidant activities. | Fan et al, 2023 |
| broiler chicken | Replacing soybean meal with up to 150 g/kg grasshopper meal | did not negatively affect growth performance on broiler weight gain and feed intake | Wang et al., 2007 |
| pigs | 19% full-fat BSFL in a balanced diet for post-weaning pigs | minor effects on growth performance, general gut function, and gut health | Håkenåsen et al, 2021 |
| Muscovy ducks | Substitution of corn gluten meal with 9% defatted black soldier fly larva meal | did not affect the slaughter traits or the meat quality, although it did affect the meat fatty acid profile. | Gariglio et al, 2021 |

**Table 3**. Edible insects as a food constituent.

| Edible insect | | Source |
|---|---|---|
| Mealworm larvae (*Tenebrio molitor* L) | mealworms can replace 50% of the meat in burger patties | Megido et al. 2016 |
| Mealworm (*Tenebrio molitor* L);<br>House Cricket (*Acheta domestica* L.);<br>Buffalo worm (*Alphitobius diaperinus* P.) | In addition, 10% of Insect flours can be used for the enrichment of the wheat bread (increase lysine and a well-balanced level of other amino acids) | Kowalski et al. 2022 |
| Cricket flour (*Acheta domesticus* L.);<br>Mealworm flour (*Tenebrio molitor* L.);<br>chickpea flour (*Cicer arietinum* L.) | Substitution of wheat flour with 5% insect flour improves the dough's rheological properties and bread characteristics | Cappelli et al. 2020 |
| edible insects, Alphitobius diaperinus and Tenebrio molitor or pea protein | Enrichment protein from edible insects induced a higher release of amino acid during the in vitro gastrointestinal digestion | Igual et al, 2021 |
| Powdered mealworm and buffalo worm larvae | Enrichment of the powdered edible insect increases the bread's antioxidant capacity and reduces the glycemic index | Gaglio et al, 2021 |
| cricket powder | The addition of cricket powder to an oat biscuit attributes fatty and cheesy flavour | Biró et al, 2020 |

*2.4. Environmental sustainability*

The world's population is predicted to increase every year, increasing the need for food. Meanwhile, increasing human population and climate change reduce the productive land resources available for producing food. This will create food insecurity in low-income countries and increase the food security gap between high-income and low-income countries (Lloyd, et al. 2011). Edible insects can play a key role in the fight against global warming due to low methane production (Van Huis & Dunkel, 2017). Insect production has environmental advantages over livestock production such as less land and water utilization, lower greenhouse gas emissions, and higher feed conversion efficiency (van Huis and Oonincx, 2017). Harvesting edible insects from nature caused overexploitation which can endanger future harvests and threatens their availability (Yen, 2009).

*2.5. Food safety*

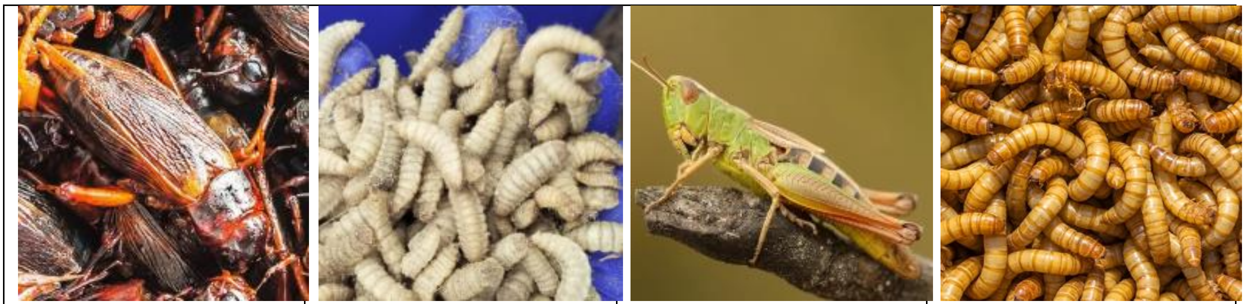
More than 2000 species of insects identified as edible and safe for human consumption (Jongema, 2017). The increasing use of edible insects as a food source, food safety issues, and the potential dangers of insect consumption has become a concern. Edible insects also have risk factors for human health as well as other animal and plant-based foods (van der Fels-Klerx et al. 2018). The issues of consuming edible insects is shown in Table 4. These risk factors were allergens (Ribeiro et al. 2018) and chemical and biological contaminants (Poma et al 2017; Houbraken et al 2016) which are influenced by insect species, harvest stage, feed substrate used, and production method (Murefu et al 2019). Hazard-free feed substrates are essential in enhancing the food safety of edible insects (Lange and Nakamura, 2021). Tropomyosin-free or arginine kinase-free strains may be major targets for future edible insect breeding (Nakajima and Ogura, 2022).

**Table 4**. Issues of consuming edible insects

| Risk Factors | | Source |
|---|---|---|
| Allergens | Chitin<br>Myosin heavy chain, Alpha-amylase,<br>Tropomyosin<br>Arginine kinase, pyruvate kinase, Hexamerin, Enolase | Francis et al., 2019<br>Verhoeckx et al., 2013,<br>Hall and Liceaga, 2021<br>Pali-Schöll et al, 2019 |
| microorganisms | bacteria: - *Salmonella*<br>- *Enterobacteriaceae*<br>- *Campylobacter*<br>Viruses: iridoviruses, parvoviruses, dicistroviruses, iflaviruses, reoviruses<br>Parasites: - *Lecithodendridae*, *Plagiorchidae*<br>- *Toxoplasma* spp. | Leffer et al 2010<br>Colman et al 2012<br>Wales et al 2010<br>King et al, 2012<br><br>Chai et al 2009<br>Percipalle et al 2005 |
| pesticides | Organochlorines (dioxins), organophosphorus (sumithion and malathion), chlorinated (benzene hexachloride), lindane, aldrin | De Paepe et al., 2019 |
| mycotoxins | Aspergillus spp., Penicillium spp, fusarium | Simpanya et al., 2000<br>Schabel, 2010 |
| Heavy metals | Cadmium, Mercury, Arsenic, Lead, Selenium<br>Polybrominated diphenyl ethers | Murefu et al., 2019 |
| Antinutritional compounds | Tannins, Thiaminases, phytases | Shantibala et al, 2014 |
| Veterinary drugs | Salicylic acid, metoprolol, niacarbazin, paracetamol | De Paepe et al., 2019 |

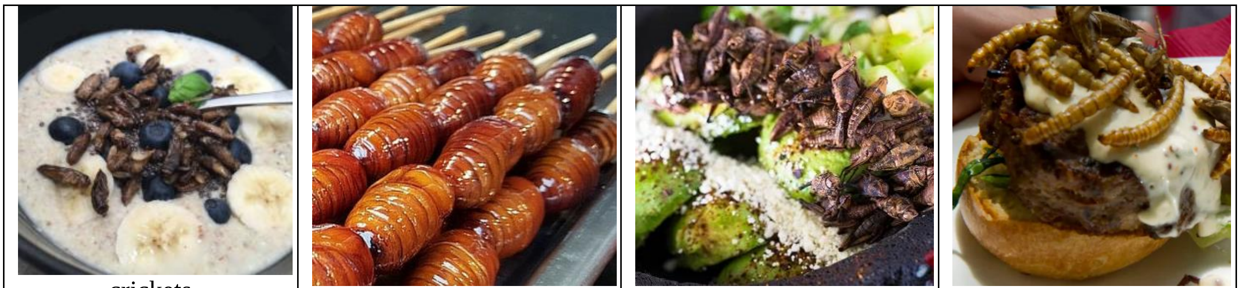
*2.6. Consumer acceptance*

Entomophagy is still unpopular and is associated with disgust and neophobia (Modlinska et al, 2021). Highly food neophobic individuals are usually much less inclined to try insect-based products (Dagevos, 2021). However, adopting insects as a new food source is not devoid of challenges. Although entomophagy is common in many developing countries such as Switzerland, Mexico, Japan, Thailand, and various countries in Africa (Meshulam-Pascoviche et al, 2021) evidence-based information is still scarce regarding their safety, techno-functionality, and digestibility (Baiano, 2020; Kooh et al., 2020). In addition, edible insects have low consumer acceptability due to disgust, habits, social influences, and cultural taboos (Sun-Waterhouse et al., 2016). In Western cultures, insects are viewed as pests, dangerous, dirty, and disgusting (Looy et al, 2014). Factors that can influence consumers' desire to try edible insects are appearance, taste, quality, and safety (Wilkinson et al., 2018). Several studies reported the use of edible insects for meat-protein replacement (Scholliers et al; 2020), fortification of meat products (Kim et al; 2022), fabrication of meat analogs (Cho and Ryu, 2021), and meat emulsion (Kim et al, 2017). The edible insect contributes to the nutritional enrichment of bakery products such as for gluten-free products, cereal-based products, and innovative ingredients (Borges et al, 2022). The live edible insect shown in figure 1 and the dishes made from the edible insect are shown in figure 2.



| crickets | Black soldier fly | Grasshopper | mealworm |
|---|---|---|---|
| Simon, 2019 | Peveto, 2020 | Jones, 2022 | Minchin, 2021 |

**Fig 1**. The live edible insects



| crickets | Sago worm | Grasshopper | mealworm |
|---|---|---|---|
| Hackewitz, 2018 | Okpala, 2016 | Oaklander, 2015 | Brussels, 2021 |

**Fig 2** The dishes made from the edible insect

# 3. Processing of edible insects

Insects can be eaten whole and processed into powder, granules, or paste (Ojha et al., 2021a). The growing interest in edible insects in many countries as an alternative food source for human consumption motivated farmers to develop insect rearing facilities. These insect-producing facilities are intended for human consumption to ensure food safety and quality of the edible insect products (Rumpold and Schluter, 2013). Insect processing and storage are very important in several aspects, such as microbial safety, toxicity, palatability, and inorganic compounds to increase the acceptance of insects and insect products, extend the shelf life of insect products (Kröger et al. 2022), and eliminate any insect divulging features like appearance or smell (Meshulam-Pascoviche et al, 2021). Different edible insects have a variety of sensory attributes (flavor and texture) depending on insect growth, diets and feed conversion, disease resistance (Jansson and Berggren, 2015), processes, and product formulation (Mishyna et al., 2020). Generally, the edible insects' taste is described as nutty and mild, while the texture varies from soft to crispy (Ruby et al., 2015).

## *3.1. Drying*

Drying is the easiest way to keep the edible insect a long self-life. This process is need to be done properly to reduce potential microbial, chemical, and allergic hazards while maintaining nutritive properties and acceptance by consumers (Kröncke et al, 2019). The different methods for drying the edible insects are shown in Table 5.

## *3.2. Fermentation*

The fermentation process was adding microorganisms as a starter culture that can inhibit the growth of spoilage organisms and pathogens during storage and improve the nutritional and organoleptic properties of the food (Bourdichon et al, 2012). The fermentation of blanched mealworm beetle, *T. molitor*, was shown to improve the microbial status of the insects. Fermented powders of mealworms also increase the free amino groups that be attributed to proteolytic degradation of proteins during fermentation (Borremans, et al., 2020)

**Table 5**. Different drying methods for edible insects

| Methods | | Source |
|---|---|---|
| Sun-drying | Leaving the larvae under the sun for some period | Ojha et al, 2021b |
| Microwave processing | Heating using an 800-watt microwave for 25 min | Purnamasari et al, 2021 |
| Freeze drying | lab scale freeze-dryer for 48 hours to constant mass | Purschke et al, 2018 |
| Oven-drying | 80℃ for 12 hours and 24 hours, 60℃ for 24 hours, and 100℃ for 12 hours can reduce the pathogen bacterial and fungal<br>Low-temperature long time (50℃, 62 hours) and High-temperature short time (90℃, 1.5 hours) | Grabowski and Klein, 2016<br>Melis et al., 2018 |
| Roasting | Using pan-roasting or stainless pot | Manditsera et al, 2019 |
| Frying | Dry pan-frying for 30 min | Ssepuuya et al, 2016 |
| smoking | Smoking is a curing and thermal process 80℃, 40 min, moisture 5.1% | Vandeweyer et al, 2018 |
| Dry fractionation | Lower energy consumption, less structural changes in protein, drying methods that do not need any additional chemicals or water for the separation | Sweers et al. 2022 |

### *3.3. Blancing*

Blanching is a deactivating treatment in the food industry on hot water or steam at temperatures ranging between 70 and 150 °C in a short time. Blanching treatments can slow down and even block enzymatic browning of *T. molitor* and *Znzymeophobas morio* (Mancini et al. 2019). Blanching allows the inactivation of vegetative microorganisms (but not bacterial spores) (Ojha et al, 2021b). The blanching method increases Omega-3, Omega-6, flavonoids, and sterols levels of *Ruspolia differens* (Ochieng et al, 2022).

### *3.4. Defatting*

Defatting enriches the protein content and improves the functional properties of edible insects, lighter color, and lower browning index (Mishyna et al, 2018). Defatting then extraction processing is the way to achieve high-quality characteristics of edible insects before adding the protein from it as an improver in food, medicine, and cosmetics manufacture (Xing et al., 2018). The defatting step can be performed by mechanical pressing before the milling or by supercritical carbon dioxide extraction, which can also reduce undesirable flavor intensity (Wang & Shelomi, 2017).

### 3.5. Pulsed electric fields technology (PEF)

Pulsed electric fields technology (PEF) is an alternative method for better preservation and maintenance of fresh-like quality aspects of food (Syed et al., 2017). Pulsed electric field (PEF) technology provides high-quality nutrition and sensorial attributes to the consumers by a non-thermal process involving short electricity pulses for microbial inactivation. It involves the generation of electric fields (5-50kV/cm) with the help of short high voltage pulses (μs) between two electrodes that lead to microbial inactivation at temperatures lower than thermal methods (Wouters et al, 2001). Pulsed electric fields (PEF) pretreatment of insect biomass (Hermetia illucens) increases larvae' drying rate pre-treated with PEF at 2 and 3 kV/cm; 5, 10, and 20 kJ/kg wet basis. After pressing, free total amino acids are higher and do not affect the amino acid profile and fatty indices. Pre-treatment before insect drying using PEF decreases the drying time and keeps the content of functional ingredients (Alles et al., 2020)

### 3.6. Marination

Marination can extend the shelf life by at least 7 days (Borremans, et al., 2018). The marination process involves injecting or soaking the foods with a seasoned solution that can improve the food's juiciness, tenderness, aroma, and flavor (Pathania et al., 2010).

### 3.7. Cold Atmospheric Pressure Plasma (CAPP)

Cold atmospheric pressure plasma was a nonthermal technology for inactivating a wide range of microorganisms such as bacteria, spores, and viruses. This technology was effective for decontamination and modification of fresh and dry agricultural products (Bußler et al, 2016). CAPP can facilitate the decontamination of foods from mycotoxins, pesticides, allergens, and other toxic contaminants (Gavahian and Khaneghah, 2020)

*3.8. Storage*

Freezing was the common killing method for insects (-20℃). Frozen whole edible insects (<-18 ℃) are usually found in the markets (Ojha et al, 2021b). Some edible insect such as lepidopteran larvae and adult of grasshoppers and termites are collected and stored in cups, bags or plastic trays for marketing purposes (Gahukar, 2020).

# 4. Bioactive compounds in edible insects

The wide applicability of proteins from edible insects as the future trend of bioactive compounds or peptides will require the large-scale production of insect bioactive peptides to represent a promising biotech business. The successful use of such protein ingredients depends upon their ability to fulfill one or more functionality requirements, such as good solubility, emulsion/foam stabilization, and/or gel formation (da Silva Lucas et al, 2020). Bioactive peptides are naturally produced by dietary proteins during the gastrointestinal process that may contain 2–20 amino acids, which are inactive within the sequence of the original protein, and can be released by enzymatic hydrolysis, solvent extraction, and microbial fermentation (Najafian & Babji, 2012). Edible insects have antioxidant, anti-inflammatory, antiangiogenic, antihypertensive, antilipidemic, and antiinflamatory that are linked to the prevention and/or reduction of metabolic syndrome or multiple pathologies (del Hierro, et al. 2022; Anusha and Negi, 2022).

Antimicrobial peptides and cyclic dipeptides have been isolated from insects as essential building blocks in organisms (Yan, et al, 2021). In the Amazon, the larvae of *Rhynchophorus palmarum* from the weevil beetle is one of the edible insects that grow in palm fruits that are high in antioxidant activity (Jaramillo-Vivanco et al, 2022). Larvae *R. palmarum* has Vitamin E as a powerful lipophilic antioxidant activity as the main biochemical function of α-tocopherol. As a chain-breaking antioxidant, α-tocopherol prevents the propagation of polyunsaturated fatty acid (PUFA) oxidation reactions in membranes and helps maintain membrane integrity (Järvinen and Erkkilä, 2016).

Insect teas are rich in phytochemicals and could be used as a promising source of natural antioxidants involving 33 flavonoids and 14 phenolic acids (Zhang et al., 2022). *Hydrillodes morose* feeding on *Platycarya strobilacea* produces Huaxiang insect tea in Sanjiang County of Guangxi province, *Aglossa dimidiate* feeding on *Malus sieboldii* produces Sanye insect tea in Chengbu County of Hunan province, and *Pyralis farinalis* feeding on *Litsea coreana* produces Hawk insect tea in Chishui County of Guizhou province. Insect tea is originated from insect excreta and unique in Chinese tea culture (Xu et al., 2013). Extracts from the edible insects *Acheta domesticus* and *Tenebrio molitor* exhibited antioxidant activity and have inhibitory activity of lipase (del Hierro, 2020). The American cockroach, *Periplaneta americana* is the largest cockroach pest species. It is used for wound healing and antiangiogenesis for cancer, ulcers, and wounds treatment (Yan et al., 2021).

*Conclusion*

Insects have been popular and safe for animal feed and human consumption. Most insects have different nutritional profiles based on their phases such as egg, larva, pupa, or adult. Edible insects also have risk factors for human health as well as other animal and plant-based foods. Insects can be eaten whole and processed into powder, granules, or paste. Edible insects have antioxidant, anti-inflammatory, antiangiogenic, antihypertensive, antilipidemic, and anti-inflammatory.

*Author Contributions*

L.P., S.G.H., I.S.N., and JF.C. conceptualization, Formal analysis, Investigation, and Writing.

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