Edible insects: Alternative protein for sustainable food and nutritional security

H C D Tuhumury1,*

1Agricultural Product Technology Department, Faculty of Agriculture Pattimura University
Jl Ir. M. Putuhena Poka Ambon Maluku Indonesia 97233

* E-mail: hcdtuhumury@gmail.com

Abstract. Any food systems applied has to ensure that the food is secure for the people. Nutritional needs are considered integral to the food security concept and sustainability is also important. One of the nutritional needs in food is protein. Proteins mostly obtained from animal-based sources such as meat and fish, plant-based proteins, particularly legumes. However, the production of meat, more importantly ruminant meat is more and more argued for some issues including environment, food safety, and animal welfare. In order to ensure sustainable protein production, the dietary change would be to use alternative protein sources such as insects. In general, insects have high protein content and excellent production efficiency compared with other conventional protein food groups. It is necessarily important to develop the use of insects in various forms, including pastes or powders, concentrates or isolates which can be used further as ingredients or fortified agents in new food product formulations. This paper therefore explores the feature of edible insects as sustainable and viable food source that can contribute to food security including, types of edible insects as food and their nutritional compositions; and processing of edible insects. In conclusion, insects can contribute to sustainable food and nutritional security and be a part of the solution to protein shortages. Insect protein concentrates could potentially be an alternative protein source in food formulation.

1. Introduction

World population in 2020 has reached 7.8 billion people (UN data) and has been projected to reach over 9 billion by 2050 [1]. Population would grow geometrically, while food production would grow arithmetically. Therefore, the increase in population requires double the current food production. To make it even worse, the climate change and environmental destruction from industrial development have negatively impact the productivity of food, as more and more land used for food production are gradually decreasing [2]. Food production has a substantial environmental impact and any food system applied need to take this issue into account seriously. Any food systems applied has to ensure that the food is secure for the people. Therefore, food security should be carefully considered in any food production system. Food security is when all people, at all times have access to sufficient, safe, and nutritious food to meet their dietary needs for and active and healthy life. The four important pillars of food security are availability, access, utilization and stability.

Nutritional needs are considered integral to the food security concept and sustainability is also important. One of the nutritional needs in food is protein. Proteins mostly obtained from animal-based
sources such as meat and fish, plant-based proteins, particularly legumes. However, the production of meat, more importantly ruminant meat is more and more argued for some issues including environment, food safety, and animal welfare [3]. Deforestation, soil erosion, public health hazard, loss of plant biodiversity and water pollution are mainly the considerable impact of meat production sector. Due to these significant issues, the use of plant-based protein in the diet gained popularity. Yet, plant-based protein have been found to lack certain essential amino acids and to be less digestible than animal-based protein [4][5]. In order to ensure sustainable protein production, the dietary change would be to use alternative protein sources such as insects.

Insects can be considered as human food or as feed. The production of insects seems to be more sustainable than livestock production for some particular reasons: lower greenhouse and ammonia emissions, less land area needed, and potential to be grown on organic [3]. In general, insects have high protein content and excellent production efficiency compared with other conventional protein food groups [6]. Moreover, insects are encouraged as a good source of protein and micro and the production of edible insects in developing countries is supported by FAO of The United Nations. Edible insect protein also meet The WHO essential amino acid requirements [7] and are more digestible than plant-based and only little less digestible than animal-based protein [4]. Nevertheless, eating insects are mostly considered as unfavourable in most countries, especially in western countries. Therefore, it is necessarily important to develop the use of insects in various forms, including pastes or powders, concentrates or isolates which can be used further as ingredients or fortified agents in new food product formulations.

This paper therefore explores the feature of edible insects as sustainable and viable food source that can contribute to food security including, types of edible insects as food and their nutritional compositions; the advantage and disadvantage of edible insect production; and processing of edible insects.

2. Types of Edible Insects and Their Nutritional Composition

Evolution has created a large range of arthropod species adapted to their habitats over the past 400 million years. Of the 1.4 million animal species described on earth, approximately 1 million are insects. Just 5000 out of 1 million insect species mentioned can be considered harmful to crops, livestock or human being [3]. Among the insect species, there are insects which are edible.

Beetles (Coleoptera) are the most common insects eaten worldwide (31 percent). This is not surprising considering that about 40 percent of all recognized insect species are present in the group. The types of edible insects around the world can be seen in Table 1.

| Order     | Species                        | Percentage |
|-----------|--------------------------------|------------|
| Coleoptera| Beetles                        | 31         |
| Lepidoptera| Caterpillars                  | 18         |
| Hemynoptera| Bees, wasps, ants             | 14         |
| Orthoptera| Grasshoppers, locusts, crickets | 13         |
| Hemiptera| Cicadas, leafhoppers, planthoppers, scale insects and true bugs | 10         |
| Isoptera| Termites                      | 3          |
| Odonata| Dragonflies                   | 3          |
| Diptera| Flies                         | 2          |
| Other | -                             | 5          |

Source : Cerritos, 2009 [8]

Caterpillar consumption (Lepidoptera), is estimated at 18%. At 14%, bees, wasps and ants (Hemynoptera) are in third place. Grasshoppers, locusts and crickets (Orthoptera) follow these;
termite (Isoptera) and dragon flies (Odonata) are each 3% [8]. Approximately 1,417 species can be eaten. Insects are eaten in their adult or larva stage.

Edible beetles are of many types, including aquatic beetles, wood-boring larvae, and dung beetles (larva and adults). [9] described 78 species of edible aquatic beetles, primarily belonging to the families Dytiscidae, Gyrinidae, and Hydrophilidae. Only the larvae of these animals are usually eaten. The palm weevil, Rynchophorus, a significant palm pest throughout Africa, southern Asia and South America, is by far the most common edible beetle in the tropics. The weevil of the palm R. Phoenicis is included in the use of sound in harvesting in tropical and equatorial Africa, R. Ferrugineus in Asia (Papua New Guinea, Indonesia, Japan, Malaysia, the Philippines and Thailand. In Indonesia, especially in Papua, and Maluku, there are two species of palm weevil, usually called sago grub/sago worm, and in their adult stage they are distinguished by the color. The R. billineatus is black while R. ferrugineus is brown[10]. The larvae of this insects are traditional delicacies in both areas.

For Lepidoptera, during their larval periods (i.e. as caterpillars), butterflies and moths are usually consumed. But adult butterflies and moths are often eaten, too. Indigenous Australians have been recorded to eat moths of the cutworm Agrotis infusa (the Bogong moth) and have been observed to eat hawkmoths (Daphnis spp. and Theretra spp.) after cutting the wings and legs in the Lao People's Democratic Republic.

In countries like Thailand and Cambodia, in addition to the arachnid scorpions, people enjoy grasshoppers, crickets, ants, bamboo borers (Omphisa fuscidentalis) [11]. These insects are sold in Bangkok in markets that visitors seek as exotic food. Weaver ant larvae, bamboo worms, crickets, and wasps are eaten by many ethnic groups in Laos. In India, some tribes eat red ants, hornets, and termites[12].

The nutritional values of edible insects can vary depending on their metamorphic stage, habitat and diet even within the same category of species. They are highly variable due to the large range of species. Also, the preparation and processing methods including drying, boiling or frying used prior to consumption, like most foods, can also affect nutritional composition. Nutrient composition for approximately 200 edible insects were compiled by [13]. Many edible insects supply satisfactory quantities of protein and energy. They also fulfill human needs for amino acids. Not to mention the mono and polyunsaturated fatty acids and they also rich in micronutrients such as iron, magnesium, phosphorous, manganese, selenium, and zinc. Insects also contained significant amount of vitamin including riboflavin, biotin, pantothenic acid, and folic acid.

The protein contents of insects from different orders have been evaluated by [14]. The average protein content was in the range of 13-77%. The protein contents per insect order can be seen in Table 2.

Table 2. Crude protein content by insect order

| Insect order | Stage | Range (% Protein) |
|--------------|-------|------------------|
| Coleoptera   | Adults and larvae | 23-66 |
| Lepidoptera  | Pupae and larvae  | 14-68 |
| Hemiptera    | Adults and larvae | 42-74 |
| Homoptera    | Adults, larvae, and eggs | 45-57 |
| Hymenoptera  | Adults, larvae, pupae, and eggs | 13-77 |
| Odonata      | Adults and naiad  | 46-65 |
| Ortotreta    | Adults and nymph | 23-65 |

Source: XiaoMing, 2010 [4]
The amino acid compositions of edible insects are good in replacing cereal proteins. Amino acids such as lysine and tryptophan and threonine are well represented in some edible insect species. These amino acids are often lack in cereal protein which are essential staple food around the world. For instance, several caterpillars, palm weevil larvae, and aquatic insects have lysine score higher than 100 mg per 100 g protein [15].

Edible insects are also important source of fat. The quality and structure of oils extracted from several insects were investigated by [16]. Their oils are rich in fatty acids that are polyunsaturated. For example African palm weevil (Rhynchocoris phoenicis) had a fat content of 54% with 38% palmitoleic acid (MUFA) and 45% linoleic acid (PUFA). In landlocked developing countries with lower access to fish, insects could play an important role contributing the polyunsaturated fatty acid such as oleic, linoleic and α-linolenic acid.

The mineral and vitamin contents of edible insects are greatly varied across species and orders. Edible insects are excellent source of iron. Many edible insects have an iron content equal to or greater than that of beef. Some examples, iron content of locusts, and mopane caterpillar have respective iron content of 8-20 mg, and 31-77 mg per 100g compared to beef with 6 mg iron per 100 g [15], [17]. Since they are rich in iron, the inclusion of them in the diet could improve iron status, especially to prevent anemia in developing countries. Insects are also commonly believed to be good sources of zinc. Palm weevil larvae has 26.5 mg zinc compared to beef with 12.5 g zinc per 100 g of dry weight [15]. Bukkens [15] also showed for a whole range of insects that thiamine (also known as vitamin B1) ranged from 0.1 mg to 4 mg per 100 g of dry matter. Vitamin B12 occurs only in food of animal origin and is well represented in mealworm larvae, Tenebrio molitor and house crickets. Many species have very low levels of vitamin B12.

In summary, edible insects are highly nutritious and Highly nutritious and cheapest source of animal protein and fat which is comparable to milk and meat. Insect proteins are highly digestible (between 77% and 98%) Protein has high lysine and threonine and limited levels of either tryptophan or methionine. The fat content ranges from 7% to 77%, rich in ω-3 and ω-6 compared to cattle and pigs, and has low cholesterol level. They also have high thiamine and riboflavin than whole bread or an egg. Insects can also be a source of fiber due to their high chitin content has high Fe, Zn can alleviate deficiency in women's diet i.e. pregnant women and vegetarian diet. Due to high protein, polyunsaturated fatty acids, and micronutrients of the edible insects, the consumption of these materials are endorsed by FAO and European Commission (EC) as the availability of nutritious food is becoming increasingly difficult [18].

3. Processing of Edible Insects
The FAO has started to encourage edible insects as feasible dietary alternatives for humans, which has ignited a surge of interests in edible insects [19]. By 2023, the global edible insect market is projected to hit USD 522 million [20]. However, negative perceptions of insects limit the expansion of its global market. Novice consumers view insects as a disgust, ignore insects as a daily food in the diet, and fully disregard their nutritional value [3].

Therefore, as the availability of edible insect grows, insect-based ingredients should be developed rather than consuming the products that still retain their original appearance. Incorporating edible insects into already familiar foods maybe more acceptable to an insect-phobic culture, and using insects as food ingredients is beneficial for the development of long-term business models. One example in our context in Maluku, Indonesia is incorporating sago grub as flesh ingredients in poplar snack food, sago crackers [21].

Insects are increasingly being seen as the food of the future to replace conventional animal protein consumption. In the Netherlands, attempts to encourage eating insects include experiments aimed at customizing insects for western tastes, with certain insects such as locusts and mealworm being sold at retail markets. One important effort to eliminate visual associations and improve palatability is to grind insects into powder or meal. Researchers have also looked into the functional properties of insects protein such as gelling ability, foam capacity, emulsion capacity, and solubility in different buffers or solvents [6], [7], [22]. These experiments would make it easier to use edible insects as a food ingredient in conventional foods.
The simplest processing technique for edible insects is the traditional ways of cooking it. Steaming, roasting, smoking, baking, stewing, frying, and curing are some of the typical edible insect cooking methods. Sometimes blanching is used before these procedures to reduce the number of foodborne microorganisms and inactivate enzymes. Obviously, each technology produces products with distinct sensory and nutritional characteristics [23].

The processing of edible insects begins with insects post-harvesting and ends with the production of food products. Despite the fact that the number of current processes in the edible food industry is enormous and varies depending on the species used and the final product to be produced, the majority of them can be classified into relatively small number of operations based on the same basic principles including blanching and drying.

Blanching is used a pre-treatment for most commercialized edible insects, both on an industrial and artisanal scale, to reduce microbial counts and inactivate degradative enzymes that cause food poisoning and spoilage. It is done by immersing the food in boiling water for a brief period of time, then extracting it and immersing it in ice water or putting it under cold running water to avoid the thermal process [24]. To boost antimicrobial effects with minimal quality loss, blanching treatments should be customized to each specific insect species and be combined with techniques to reduce the presence of bacterial spores However, in order to meet the needs of customers and industrial manufacturing, these procedures must retain the nutritional value of the products as well as other essential quality characteristics including texture and color [25].

Drying methods usually applied in the processing of edible insects including sun-drying, freeze-drying, and oven-drying. These techniques can be used for drying either whole edible insects or insects flours and powders. One of the preferred technologies for increasing human consumption of insects, mostly in Western countries, is drying and grinding whole, perfectly recognizable edible insects into unrecognizable powder[26]. However, all the drying methods caused changes in protein, fat, and fiber content. The most visible quality changes during drying is color. For example, powder made from the larvae of T. molitor had decreased lightness when oven-dried compared to freeze-dried [27].

Different drying technologies have an effect on certain consistency parameters in addition to reduction in water content. The drying technology used and the technical conditions applied could affect protein functional properties, lipid oxidation, and color. Therefore, what technology chosen should consider the way insects will be eaten either whole, powdered ingredient, or sole ingredient. Among all insect products, insect protein is important. However, their functional properties must be carefully tested during transition process in order to integrate them into various foods. Depending on the raw material and its proximate composition, protein-enriched ingredients such as edible insect flour/powder are obtained using various methods and techniques. Nonetheless, a general 5-step food protein processing procedures, including: 1. Pre-treatment; 2. Defatting; 3. Solubilization and recovery of protein; 4. Purification; and 5. Drying [4].

Protein concentrates and isolates have desirable functional properties depending on their origin and processing, and thus may be used in food formulation. Proteins, on the other hand, from complex structures that interact with other elements including proteins, fats, carbohydrates, and minerals. Functional properties of insect proteins also in accordance with other protein functionality such as solubility, emulsification, foam formation, gelation, water-holding capacity, and oil absorption capacity.

Edible insects may be considered a novel protein source in the food industry, as some insect products functioned similarly to traditional food proteins, as mentioned above. However, when these insects are added to food matrices, their functional properties are still largely unknown. Some insect flours, defatted flours and protein concentrates have been incorporated in food matrix including meat products and analogs[28], snack[29], pasta[30], and bread[31].

4. Prospects and Challenges
One of the challenges of consuming edible insects is the food safety. Microorganism, allergic reactions, and toxicity. For microbial safety, insect gut, body surface, and mouthpart is considered as a main habitat for microorganisms which can act as pathogenic vector. Despite the fact that insect-specific pathogenic microorganisms pose no threat to human health, they can only colonize insect cells
or tissues. Contamination of human pathogenic microorganisms does, however, occur, and this contamination can be managed by carefully managing breeding conditions [32].

Some edible insects had allergic cross-reactive proteins with arachnids and crustaceans, which are known as arthropods, in allergic reactions. Furthermore, food dye carmine is derived from the bodies of female cochineal insects, and this dye can cause allergic reactions in some patients. We must pay attention to the unknown possible allergens found in edible insects, given that only a few studies on allergic reactions to edible insects have been conducted. More research and investigation is needed to determine the hazards of substances such as allergens and toxic substances, as well as their effects on pathological symptoms in humans [32].

Other important challenge is the consumer acceptance. One of the most significant obstacles to their integration into food products is Westerners' inability to try edible insects. Insects are marketed as a delicacy in some experimental restaurants. Most consumers are repelled by the idea of eating them. Food neophobia and disgust are two major barriers to insect consumption. Therefore, it is necessary to understand consumer psychology and desires, and adjust their preparation strategies accordingly such as innovative development of insect-based food [33].

Despite the challenges mentioned above, a number of scientists believe insects have the potential to be a sustainable food source. The production of insect-based protein powder is expected to be more environmentally friendly than traditional protein-rich foods. In order to maximize the potential of the edible insect proteins, optimizing insect rearing and harvesting is therefore critical. Depending on the insect species, rearing methods, and processing techniques used, data on protein content and functionality varies greatly. Future research should concentrate on determining the best processing conditions for producing insect protein isolates that are ideal for food formulation, have good functional properties, are cost-effective, and are environmentally sustainable.

5. Conclusions
Edible insects with their nutritional composition especially high protein content and all the essential amino acids, are a promising alternative protein source for the world's increasing population. Insects can contribute to sustainable food and nutritional security and be a part of the solution to protein shortages. Since whole insects are still unpopular in Western cultures, insect protein concentrates may be a viable alternative protein source in food formulation.

References
[1] Grafton R Q, Daugbjerg C and Qureshi M E 2015 Towards food security by 2050 Food Secur. 7 179–83
[2] van Huis A and Oonincx D G A B 2017 The environmental sustainability of insects as food and feed. A review Agron. Sustain. Dev. 37 43
[3] van Huis A 2015 Edible insects contributing to food security? Agric. Food Secur. 4 20
[4] Gravel A and Doyen A 2020 The use of edible insect proteins in food: Challenges and issues related to their functional properties Innov. Food Sci. Emerg. Technol. 59 102272
[5] Sarwar G 1997 The Protein Digestibility–Corrected Amino Acid Score Method Overestimates Quality of Proteins Containing Antinutritional Factors and of Poorly Digestible Proteins Supplemented with Limiting Amino Acids in Rats J. Nutr. 127 758–64
[6] Zielińska E, Karaś M and Baraniak B 2018 Comparison of functional properties of edible insects and protein preparations thereof LW7 91 168–74
[7] Bußler S, Rumpold B A, Jander E, Rawel H M and Schlüter O K 2016 Recovery and techno-functionality of flours and proteins from two edible insect species: Meal worm (Tenebrio molitor) and black soldier fly (Hermetia illucens) larvae Heliyon 2 e00218
[8] Cerritos R 2009 Insects as food: an ecological, social and economical approach. CAB Rev. v. 4
[9] Ramos-Elorduy J, Moreno J M P and Camacho V H M 2009 Edible aquatic Coleoptera of the world with an emphasis on Mexico J. Ethnobiol. Ethnomed. 5 11
[10] Köhler R, Irias-Mata A, Ramandey E, Purwestri R and Biesalski H K 2020 Nutrient composition of the Indonesian sago grub (Rhynchophorus bilineatus) Int. J. Trop. Insect Sci. 40 677–86
Nutritional/Textural Properties of Durum Wheat Pasta Enriched with Cricket Powder

insect formulation and process conditions on microstructure, texture and digestibility of extruded
Emerg. Technol. larvae and silkworm pupae as a novel protein ingredient in emulsion sausages
behaviour of larvae of yellow mealworm (Tenebrio molitor) and the effects on their quality
product application of the Theory of Planned Behaviour to predict the consumption of an insect
Microbiological Load of Edible Insects Found in Belgium

impingement blanching (SSIB) in agricultural products processi

Edible Larvae of Sago Palm Weevils

Extracted Protein from Edible Insect Larvae and Their Interaction with Transglutaminase

edible insect food industry: challenges and future pricing/promotion strategies

van Huis A 2011 An Ex

consumed in Africa: potential sources of polyunsaturated fatty acids

Villeneuve, Pierre, Fann

Species Suitable for Animal or Human Consumption

van Huis A, van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G and Vantomme P

Nowak V, Persijn D, Rittenschober D and Charrondiere U R 2016 Review of food
composition data for edible insects Food Chem. 193 39–46

van Huis A, van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G and Vantomme P
2013 Edible insects: Future prospects for food and feed security. (Rome: Food and Agriculture
Organization of the United Nations)

Han R, Shin J T, Kim J, Choi Y S and Kim Y W 2017 An overview of the South Korean
edible insect food industry: challenges and future pricing/promotion strategies Entomol. Res. 47 141–51

Tuhumury H, Souripet A and Nendissa S 2020 Effects of Sago Starch Types on Crackers from Edible Larvae of Sago Palm Weevils Indones. Food Sci. &amp; Technol. J. 4 1–5

Kim T-K, Yong H I, Jang H W, Kim Y-B and Choi Y-S 2020 Functional Properties of Extracted Protein from Edible Insect Larvae and Their Interaction with Transglutaminase Foods 9 591

Melgar-Lalanne G, Hernández-Álvarez A-J and Salinas-Castro A 2019 Edible Insects Processing: Traditional and Innovative Technologies Compr. Rev. Food Sci. Food Saf. 18 1166–91

Xiao H-W, Bai J-W, Sun D-W and Gao Z-J 2014 The application of superheated steam impingement blanching (SSIB) in agricultural products processing – A review J. Food Eng. 132 39–47

Caparros Megido R, Desmedt S, Blecker C, Béra F, Haubruege É, Alabi T and Francis F 2017 Microbiological Load of Edible Insects Found in Belgium Insects 8 12

Menozzi D, Sagari G, Veneziani M, Simoni E and Mora C 2017 Eating novel foods: An application of the Theory of Planned Behaviour to predict the consumption of an insect-based product Food Qual. Prefer. 59 27–34

Azzollini D, Derossi A and Severini C 2016 Understanding the drying kinetic and hygroscopic behaviour of larvae of yellow mealworm (Tenebrio molitor) and the effects on their quality

Kim H-W, Setyabrata D, Lee Y J, Jones O G and Kim Y H B 2016 Pre-treated mealworm larvae and silkworm pupae as a novel protein ingredient in emulsion sausages Innov. Food Sci. Emerg. Technol. 38 116–23

Azzollini D, Derossi A, Fogliano V, Lakemond C M M and Severini C 2018 Effects of formulation and process conditions on microstructure, texture and digestibility of extruded insect-riched snacks Innov. Food Sci. Emerg. Technol. 45 344–53

Duda A, Adamczak J, Chelmińska P, Juszkiwcz J and Kowalczewski P 2019 Quality and Nutritional/Textural Properties of Durum Wheat Pasta Enriched with Cricket Powder Foods 8
[31] Osimani A, Milanović V, Cardinali F, Roncolini A, Garofalo C, Clementi F, Pasquini M, Mozzon M, Foligni R, Raffaelli N, Zamporlini F and Aquilanti L 2018 Bread enriched with cricket powder (Acheta domesticus): A technological, microbiological and nutritional evaluation *Innov. Food Sci. Emerg. Technol.* **48** 150–63

[32] Kim T-K, Yong H I, Kim Y-B, Kim H-W and Choi Y-S 2019 Edible Insects as a Protein Source: A Review of Public Perception, Processing Technology, and Research Trends *Food Sci. Anim. Resour.* **39** 521–40

[33] Patel S, Suleria H A R and Rauf A 2019 Edible insects as innovative foods: Nutritional and functional assessments *Trends Food Sci. Technol.* **86** 352–9