Chapter

Role of Edible Insects as Food Source to Combat Food Security Challenges. Innovative and Traditional Approaches

Mahnoor Pervez and Farkhanda Manzoor

Abstract

World Food Security organization committee stated that food security exists when safe, healthy, and nutritious food is present to all human beings, to meet their dietary needs. There are four pillars of food security such as availability, access, utilization, and stability, while the nutritional dimension is considered integral to the concept of food security. Protein is an essential dietary component. It is required for the proper growth of individuals. Meat is an excellent source of protein. However, because of the increasing demand for meat and declining agricultural land. There is an urgent need to discover alternative ways to full fill public protein demand. Edible insects are the best alternative source of protein. They can be harvested in large amounts. Insect meals can replace scarce fishmeal as feed ingredients. Insects are not only a source of protein but also contained various nutrients and minerals such as iron, zinc, and selenium. People showed awareness of the importance of insects as an essential dietary element. Edible insect harvesting is a new emerging agriculture sector and needs the special attention of researchers and the government. Thus, insects require the use of commercial processing methods that will render the protein suitable for food/feed formulation, while maintaining the safety, nutritional and sensory quality of the final product.

Keywords: food security, food crisis, starvation, edible insects, cheap protein

1. Introduction

The term "food security" refers to the access to an adequate amount of food for meeting dietary energy needs that implies for many as self-sufficiency as producing required food domestically [1]. It is a basic right of a human being to have access to adequate production, availability, and food consumption to ensure adequate nutrients and food for all the people.

Food security ensures that all human beings have physical and economic accessibility to healthy and nutritious food to meet their daily dietary requirements and maintain an active healthy lifestyle. A country promises food security when it can ensure food availability balance between demand and supply to the nation, no matter what the price would be.

The five fundamental components of food security are availability, access, stability, nutritional status, and preference for food. All of them are prominently influenced by various factors such as political, physical, and economic within a community. Food availability and accessibility are two main aspects to ensure food security. Food security ensures an adequate amount of nutrients for every individual in the country. In many countries an adequate amount of food is available, but its availability is a real serious issue in some areas because of long droughts, political issues, mismanagement of resources, and unfertile land. These issues are most commonly observed in Asian countries.

The term accessibility refers to the capacity to produce and acquire an appropriate amount of healthy food for all individuals [2]. The availability of adequate food at the country/local level does not guarantee that all people have food accessibility and are food secure. Because various aspects such as low income, lack of roads, and infrastructure could restrict the accessibility of basic foodstuff. Hence, both availability and accessibility are essential and inter-linked parts of food security [1].

Stability is another important aspect that refers to a consistent supply of nutritious food at the national level as well as stability in access to food at the household and individual levels. Stability is directly affected by agricultural practices. Stability is ensured by storing food and enhancing shelf life. However, in developing countries economic crises are critical and only a small amount of food is stored for the whole year. Therefore, besides production, food stability ensures by better management, the formation of new laws and rules, market integration, and trade [3].

So, the above discussion concluded that food security ensures by the conformity of various dimensions such as availability, accessibility, stability, nutritional status, and preferences. It highlights the detail that reaching food security is a tough, multifaceted, and challenging phenomenon.

2. Challenges

Challenges in reaching food security points are a hot topic globally, as the world population is expected to touch more than 9 billion by 2050. So, it is an urgent urge to address and recognized the issues associated with food security [4]. It is suggested that to ensure the food security to meet the food demand of the future population, food production will need to see an upward trend by at least 70% in agricultural production. It is studied that globalization and current global environmental changes have a great impact on food production and distribution. Challenges can be coped by addressing the following issues such as,

- Reviving agricultural productivity growth to feed Asia's growing population.
- Ensure small-scale farmers with limited resources should be equipped with modern food technology practices.
- Addressing poor countries' malnutrition challenges in a sustainable and efficient manner.

Furthermore, the recent vulnerable food crisis raises the question of whether existing food policies in this era are sufficient or not. Scientists and researchers argue that finding a reasonably efficient and politically acceptable set of policies regarding food crisis challenges showed be done. All these policies also decrease prices that encourage farmers to respond with supply responses 3w.

2.1 Climate change

Climate changes are greater threat to agriculture and smooth food supply. The rising intensity of rainfall in some areas, hot temperature with drought conditions in other areas, and climate-related disaster shows that alteration in climate conditions have quantifiable effects on agriculture in a wide range of economies, crops, and farming systems [5]. A wide range of edible food crops such as wheat, rice, and corn are grown only within a narrow temperature range, which varies according to developmental stage, and slight fluctuation in temperature extremely affects the quantity and quality of crops. Scientific evidence revealed that as average temperatures rise then short periods of extreme heat will become more frequent and have more severe impacts on yields [6].

Extreme heat will pose a more severe risk to crop end yield than the impacts of variations in rainfall associated. Similarly, the effect of extreme temperature is intensified under drought conditions.

2.1.1 Temperature variations

In order to study the effect of rising temperature on the yield of the crop, a graph has been plotted among both by obtaining the data of corn crops from US countries from 1950 to 2005, which shows nonlinear relation among them as shown in **Figure 1**.

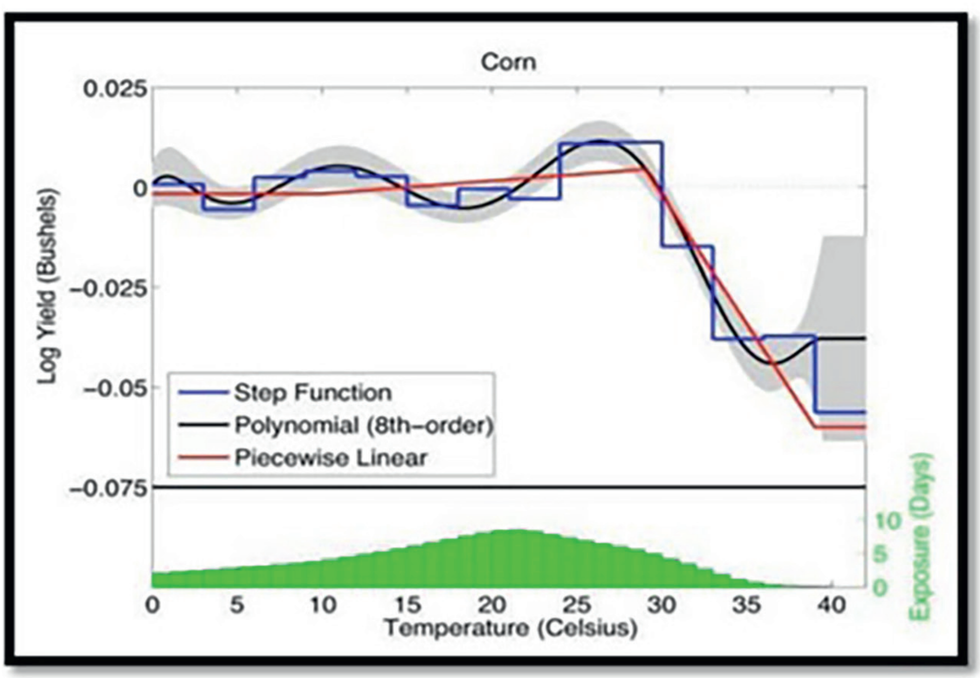

Figure 1.
Effect of rising temperature on crop yield.

2.1.2 Ozone level

Increasing levels of ozone (O3) are another significant source of crop yield loss and an existing threat to Asian food security. In East Asia regions there is a significant increase in ozone level that has been recognized as a drastic factor on major crops and trees. Numerous studies document how global and regional yields of staple crops are being reduced by current O3 levels. Due to the increasing level of O3 in the US, the annual cost of edible crop production lost $4 billion to $2 billion [7]. Similarly, the total cost It has been estimated that the global loss of wheat, rice, corn, and soybean amounted to $14 billion–$26 billion in the year 2000, which is on a par with, and possibly higher than, crop losses presently caused by other aspects of climate change.

Tamburino et al. have discussed the approaches in the scientific literature on the vigorously debated problem of how to feed the world. There seems to be an increasing focus on food production by means of new innovative technologies [8].

2.2 Edible insects as protein source

Acheta domesticus, A. mellifera (honeybee), *Bombyx mori* (farmed silkworm), *Imbrasia belina* (mopane caterpillar), *Tenebrio molitor* (yellow meal worm), and *Rhynchoporus phoenicis* (African palm weevil) are the six most prevalent commercial edible insect species at the moment. The edible ratio of different orders is shown in **Figure 2**. Only the larvae of several species (*R. phoenicis*, *T. molitor,* and *I. belina*) are frequently ingested, as their rich lipids can produce a fascinating flavor. Because of its vigor, *T. molitor* production has been mechanized [9]. Only the adults of orthopterans, such as crickets, are commonly consumed. Swarming makes them extremely effortlessly harvest. Although, because they are common pests in most locations and are frequently exposed to pesticides throughout their lives, there is concern that may compromise food safety, which is the presence of latent pesticides.

Ingesting insects in a responsible and healthy manner has become a popular way to alleviate poverty. Insects that are edible play a vital part in a variety of food systems. In fact, in many underdeveloped countries, they have provided a critical supply of

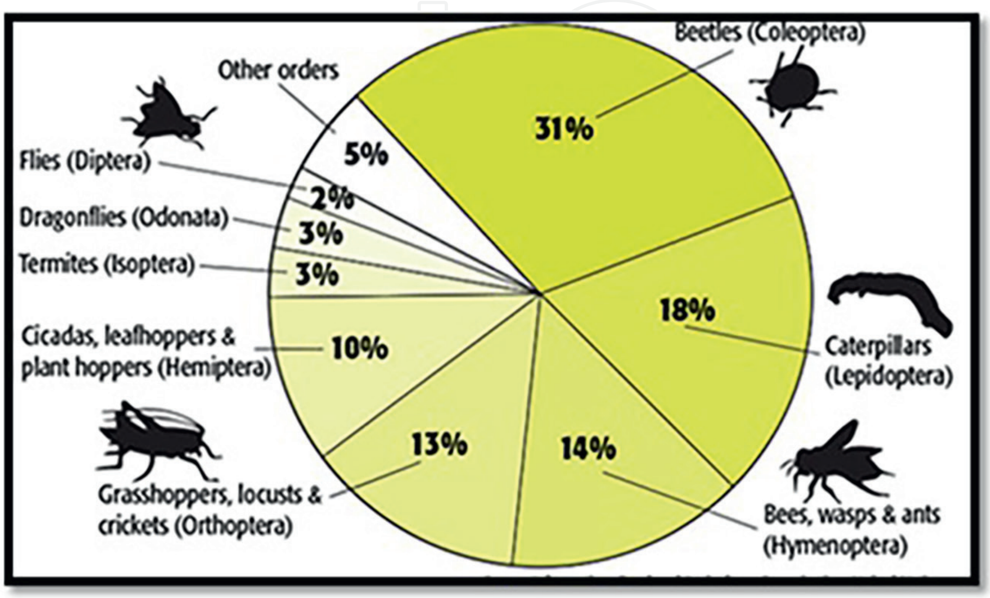

Figure 2.
Edible insect ratio of different orders.

essential nutrients. Insects have gained much attention in food sector because of their protein enrichment, high mineral, and vitamin content, and the unique ratio of polyunsaturated to saturated fatty acid value [10]. In most cases, edible insect proteins meet WHO essential amino acid content standards [9]. Furthermore, the digestive capacity of insect proteins is more than plant-based proteins like peanuts and lentils (53%), but less than animal-based proteins like beef and egg have 100% capacity.

Insect proteins are particularly appealing because they produce less greenhouse gas and ammonia, perhaps making them more environmentally benign [11]. Furthermore, because they are relatively quick, easy, and cheap to farm, they provide a new and accessible commercial potential for underdeveloped countries, making them the overall best alternative for ensuring food security with the world's ever-growing population [12]. Insect proteins offer a lot of good qualities, such as excellent nutritional content, and digestibility, and they are also environmentally beneficial. Furthermore, for including them in a variety of foods, their functional qualities must be properly evaluated at each stage of the development phase. In general, insects have apparent nutritional advantages. Their nutritional profiles are remarkably comparable to that of traditional animal meals [13]. Not only for humans but also for poultry, they offer huge potential as a source of nutrients and active chemicals.

Animal protein is abundant in all phases of the life of insects. It has been proposed that insects are significantly more sustainable when compare with other sources of animal protein, thus alleviating the pressure on the environment and the planet facing the need to full fill the feed the worldwide population, constantly increasing [14]. Bioactive compounds such as antioxidant agents, insulin regulators, and anti-inflammatory peptides are high-value products that can be obtained from insects [15].

The amino acid profiles of edible insects vary, which is indicated in **Table 1**. Although their amino acid contents are usually similar, edible insects typically contain more crude protein than regular meat. They can deliver vital amino acids at an appropriate level as food, with a digestibility of 76 to 96 percent [20]. The World Health Organization has reported the amino acid composition of certain edible insects (WHO 2007). Methionine, cysteine, and tryptophan are all missing or present in extremely little amounts in some insects. If these insects make up the majority of a meal, the diet must be balanced. Aside from these species, insects generally meet the WHO's amino acid recommendations. By ingesting a suitable variety of items, the majority of them can offer enough amounts of essential amino acids. With enough isoleucine, leucine, lysine, phenylalanine, threonine, valine, arginine, histidine, and tyrosine, all groups are qualified. When compared to other insects, Blattodea has the highest concentration of lysine, valine, methionine, arginine, and tyrosine. Coleoptera has a higher concentration of leucine than other protein sources, including animals. Similarly, Hemiptera has a higher concentration of phenylalanine than any other known protein source. Nymphs are usually the most plentiful source of nearly all sorts of amino acids when compared to edible insects at other stages [12]. They possess high arginine content that strengthens the immune system and enhances blood vessel and health function. Beef and pork are more prevalent in arginine as it is in cockroach nymphs i.e., *Blatta lateralis*.

Insects have a lot of lipids in them. The fatty acid content of several edible insects varies greatly. Aside from the acids indicated in **Table 2**, trace amounts of additional acids, such as odd-numbered fatty acids, even-numbered saturated fatty acids, and some unsaturated fatty acids, have been detected in some insects. These acids are thought to be insignificant. On a dry weight basis, the fat content of insects in embryonic stages ranges from 8 to 70%. Different sources of meat, including all groups of

Species	Stage	Crude protein %	Essential amino acids							
			lle	leu	lys	Met	Phe	Thr	Trp	Val
C. barbatus	Larvae	41.0	5.80	10.0	5.70	2.00	4.70	4.00	0.70	7.00
Tenebrio molitor	Larvae	48.0	4.00	6.90	4.90	1.20	3.20	3.60	1.00	5.90
Hermetia illucens (Soldier fly)	Larva	49.0	4.00	6.60	5.60	1.40	3.80	3.60	1.10	5.60
M. domestica (House fly)	Pupa	62.0	3.50	5.30	5.20	2.60	4.20	3.20		3.40
M. domestica	Larva	54.0	3.20	5.70	6.90	2.20	5.00	3.30	3.20	4.40
A. mellifera (honeybee)	Adult	51.0	5.60	9.60	6.60		0.90	5.50	0.00	6.90
A. mellifera	Larva	42.0	6.00	9.40	7.00		0.80	6.10	0.00	6.20
Acheta domesticus (cricket)	Adult	62.0	2.60	4.50	3.50	0.90	1.40	2.20	0.40	3.70
S. histrio (grasshopper)	Adult	60.0	5.30	8.70	5.70	0.70	4.40	4.00	0.60	5.10
Beef			5.10	8.40	8.40	2.30	4.00	4.00		
Pork			4.90	7.50	7.90	2.50	4.10	5.10		
Chicken	Broiler breast		4.20	6.90	7.80	2.10	2.50	3.70		4.60
Amino acid requirement in human nutrition			30.0	59.0	45.0	16.0		23.0	6.0	39.0

Ile Isoleucine, Leu Leucine, Lys Lysine, Met Methionine, Cys Cysteine, Phe Phenylalanine, Tyr Tyrosine, Thr Threonine, Trp Tryptophan, Val Valine, Arg Arginine, His Histidine.
The data were summarized by the following references: [9, 13, 16–19].

Table 1.
Amino acid content of common edible insects (% in crude protein of dry weight).

insects, have identical fatty acid contents [23]. Lepidopteran and Heteropteran larvae have a higher fat content than other edible insects. When compared to insects at other stages, an excellent reservoir of fatty acid is larvae. Adults are generally slender, with a fat level of less than 20%. Triacylglycerol is the most common type of fat found in insects [16]. More than 80% of all fats are made up of saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs). Palmitic acid and stearic acid make up the majority of SFAs in insects at various times. Adults' SFA levels are often greater than MUFA levels, despite the latter being healthier for human diets. In insects, oleic acid, a prevalent monounsaturated fatty acid in the human diet, has the highest concentration of MUFAs. It aids in the reduction of blood pressure in humans and has significant potential in the treatment of inflammatory, immunological, and cardiovascular illnesses [24]. In contrast to pork, beef, and insects at previous stages, adult insects are the greatest site of polyunsaturated fatty acids (PUFAs) with the risk of surpassing SFAs as food.

Insects are also excellent providers of vitamins and minerals. Biochemical substances such as vitamins A, B1–12, C, D, E, and K, which are required for normal

Species	Crude fat %	Saturated fatty acids			Monosaturated Fatty acids		Polyunsaturated fatty acids	
		C14:0	C16:0	C18:0	C16:1	C18:1	C18:2	C18:3
Tenebrio molitor Larvae	38.0	0.39	28.2	0.89	5.98	60.6	2.84	0.18
Hermetia illucens Larva	26.0	99.8	13.2	2.02	4.08	12.8	13.9	0.52
M. domestica Pupa	15.5	3.20	27.6	2.20	20.6	18.3	14.9	2.10
M. domestica Larva	24.3	6.83	26.7	2.31	25.9	21.7	16.4	0.00
A. mellifera Adult	12.3	0.60	14.4	9.30	2.6	45.2	7.80	
Bombyx mori pupa	35.0	0.10	24.2	4.50	1.7	26.0	7.30	36.3
Beef		32.2	0.77	16.7	18.8		36.10	6.16
Pork		41.0	3.43	16.7	43.0	2.93	7.29	1.71
Chicken		33.3	1.33	21.6	46.6	0.27	14.0	0.67
Amino acid requirement in human nutrition		26.9		22.6	30.8		14.95	1.50

SFA saturated fatty acids: C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid. MUFA: C16:1 n7 – palmitoleic acid; C18:1 n9 – oleic acid. PUFA: C18:2 n6 – linoleic acid; C18:3 n3 – α-linolenic acid.
The average data of each order are bold. The data were summarized by the following references: [9, 13, 16–18, 21, 22].

Table 2.
Fat content (%) of common edible insects (% in crude fat of dry weight).

growth and health, could be provided by them [17]. Caterpillars, for example, are particularly high in B1, B2, and B6 [9]. Vitamins A and D are abundant in bee brood (pupae) [25]. *Rhynchophorus ferrugineus*, the red palm weevil, is high in vitamin E. [26]. Edible insects include a wide range of micronutrients, including iron, magnesium, manganese, phosphorus, potassium, selenium, sodium, and zinc [9]. Mineral elements are found in varying amounts in different insects. Most insects have a low calcium content (less than 100 mg/g dry matter), while larvae of house flies and adults of melon bugs have a high calcium content. Immature insects such as pupae and larvae are preferred as food sources because they are abundant in amino acids and fatty acids. These nutrients not only give high nutritious value but also provide a unique splendid flavor [27].

In addition to humans, edible insects also provide the best feed source for aquaculture and livestock. Fowls fed on grains are less nutritional than the fowls that are fed on insects, which provide a good protein source [28]. Moreover, they can also be used as a feed source in areas where the vegetable feed is costly [29]. Soy diet feeding of farmed insects is extremely expensive, yet insect food can provide efficient nourishment at minimum cost. Proteins are more sustainable by recycling biomass during insect production [30]. Yellow mealworms have long been utilized as a source of food [31].

However, while edible insects have been marketed as an environmentally benign protein source in the West, eating insects is still seen as a sign of poverty in underdeveloped countries where entomophagy is a traditional practice. This may be seen in many Asian nations, such as Mexico, where insect ingestion is popular in urban and tourist regions but outlawed in rural ones. Despite the high desire for edible insects, their planting and harvesting are still restricted because farmers fail to recognize their nutritional worth [32]. A successful plan must be considered to boost the inclusion of insects in everyday diets.

3. Edible insect farming

The rising demand for edible insects has generated a problem: how to produce more edible insects in a cost-effective, safe, and long-term manner [33]. Due to a shortage of availability, accessibility concerns arise, limiting prospects for increased trade [34]. This necessitates a technological shift from wild harvesting to indoor agriculture. Traditional and scientific understanding is necessary for the supply of insects through large-scale cultivation for this purpose [35].

Harvesting edible insect species at different phases from wild woods, fields, and waterways can provide huge diversity of edible bug species [36]. These cultivators have the knowledge and experience to determine the right timing, circumstances, and host vegetation to obtain precise culinary species while minimizing environmental impact [37]. Insects are primarily taken from fields for personal consumption, which has a minimum impact on the environment and helps keep insect populations stable over time. Practicing traditional insect harvesting has been done in Mexico prior to the pre-Hispanic period when insects were considered as an essential food source rather than pests, and more than 400 wild insect species were taken from terrestrial environments [38]. Harvesting varies by species and is dependent on the level of growth (eggs, pupae, larvae, or adults), season (rain or dry), and destination (forest, desert, or agricultural fields). For example, pupae of the ant species *Limetopum apicuatum* are gathered during the warm dry season (February to May) [39] and when the rainy season begins, grasshoppers of the species *Sphenarium purpurascen*s (chapulines) are physically picked from fields [34].

Many edible insects are affected by agricultural intensification, owing to mechanization, tree clearing, and pesticide use. Insect populations have declined worldwide as a result of pesticides, with a 67 percent reduction in invertebrate numbers in the previous 40 years [40]. If pesticide controls were removed, a specific grasshopper species' potential production in Mexico would earn about US$350,000 in annual income and provide enough protein to feed nearly 9 million people [41].

Changes in the trophic chain are creating ecological degradation as a result of uncontrolled overharvesting [42]. Increased demand for a few insect species has resulted in more aggressive collecting tactics, with little regard for ensuring sustainable collection during reproductive periods—a practice that threatens to decrease or perhaps abolish native biodiversity [33]. Due to the extreme demands of honey ants and wood grubs, the adoption of energy approaches in agriculture could minimize or even eliminate the usage of pesticides, resulting in a positive environmental impact [32].

Because of the environmental and health dangers, more edible wild insect species are being semidomesticated in a more sustainable, less time-consuming, and consistent manner, mostly in traditional consumer countries where the warm, wet weather is suitable for cultivation [43]. Outdoor farming involves breeding insects in old trees, sawdust, and forest wastes, which can provide a semi-confined habitat as well as a food source. Bamboo caterpillars in Thailand mate in nylon net cages suspended across developing bamboo stalks. Bamboo caterpillars are commonly sold in local markets in plastic boxes [33]. Semidomesticated bees are raised in wooden hives, ancient tree trunks, and other containers in Africa and Asia.

Many edible insect species are partially cultivated, but some are fully cultivated for a variety of reasons, including:

- They have a short life cycle.
- They can be easily reared in small containers,
- Can be consume animal manure rather than grains.

4. Processing technologies

The edible insect industry is growing quickly, and supply of new goods is growing every day [44]. The manufacturing process begins with raw insect post-harvesting and finishes with the creation of foodstuffs and wastes, some of which have been retrieved and recovered as by-products [31]. Different methods are employed in the food edible industries, depending on the species used and the ultimate product desired; however, the majority of them may be classified under relatively modest operations such as blanching, drying, and storage.

4.1 Blanching

Blanching is the process in which food is immersed in boiling water for a short period of time, then removing it and placing them into ice water to stop the thermal process [45]. On the industrial and artisanal scale, it is utilized as a pre-treatment for inactive degradative enzymes and to lower bacterial counts that lead to food spoilage and food poisoning. Wynants and his friend submerged *Alphitobius diaperinus* (beetle) in a bath of water heated to 90 degrees celsius till the temperature reached 88 degrees celsius (5 min). As an outcome, the total microbial count is reduced, and pathogens are missing [46].

Blanching diminishes quantities of mesophilic bacteria, yeast, and molds considerably; nevertheless, it is unsuccessful at removing or even reducing mesophilic bacterial spores. Blanching has also been shown to lower lactic acid bacteria levels and total psychrotrophic bacteria counts [47]. Chemical composition variations take longer to notice, owing to the leaching of soluble elements that might impact protein levels [48]. Some proteins go through structural changes during the boiling process, including denaturation, crosslinking, and associations with lipids and carbohydrates. As a response, the proportion of hydrophilic sites available for water binding might well be reduced, and sorption properties may be changed, necessitating a more detailed protein study [49].

To minimize the quality loss and reduce the antimicrobial effects, each bug species must be treated with a blanching procedure. Blanching edible insects should lessen the microbiological dangers connected with their intake, and it might be augmented with ways to diminish bacterial spores quantity [50]. However, in order to suit the needs of customers and the processing industry, these treatments must preserve the nutritional value of the food as well as other crucial quality characteristics including texture and color.

4.2 Drying

The most extensively utilized technology for extending the shelf life of foods is drying. Traditional processes (such as roasting, frying, and sun-drying) are used in modern ways (for example, freeze-drying and microwave-assisted drying). Drying can lower total water content and, as a result, the amount of water available for metabolizing activities, such as enzymatic reactions and responses triggered by spoilage bacteria. Water action has a direct impact on microbial proliferation (aw). At aw 0.65, the vast majority of bacteria remain dormant. When aw is low, microorganisms slow down their development, but when water conditions improve, they can resume their progress [51, 52]. Reducing free water enhances dry matter concentration without harming tissues or the physical look of foods and is a key stage in the recovery of food products [53].

Solar, freeze-drying, and oven-drying are the popular techniques for drying entire edible insects, whereas freeze-drying, oven-drying, and nontraditional drying methods are mostly utilized for insect flours and powders. One of the chosen strategies for boosting human consumption of insects, mostly in Western countries, is drying and grinding whole, clearly recognized food insects into unrecognizable powders [54]. Drying extends the life of a product during distribution and storage.

Sun drying, one of the oldest drying methods, avoids microbiological contamination and even decreases or eliminates hazardous substances like neurotoxins; it also enhances the product's overall nutritional quality by inhibiting the enzyme protease inhibitors [55]. Furthermore, smoking is a curative and heating procedure that is regarded as one of the oldest methods for preserving all types of meat. The raw material is subjected to smoke created by wood pyrolysis. Insects are smoked in a dry environment, and a curing implementation is carried out concurrently with drying. The combined action of enzymes and heat promotes protein and lipid modifications during the process [56].

Irrespective of the blanching and drying techniques used on insects, they must be reheated prior to eating to remove any remaining bacteria. Total bacteria, Enterobacteriaceae, Staphylococcus, Bacillus, yeasts, and molds have all been reported to be eliminated by boiling dried insects for 30 minutes [47].

5. Production and processing of edible insect protein

Protein-enriched ingredients of edible insects have been obtained by using a procedure that has five basic steps which are:

- Initial treatment
- Defatting
- Solubilization and recovery of protein
- Purification of protein
- Drying

5.1 Initial treatment

The preliminary developmental stage is very contingent on the source product, in which entire insects are freeze-dried or roasted in the oven, pulverized, and mesh sieve to generate a fine powder that enhances protein solvent interaction in the subsequent steps [57].

5.2 Defatting

The form and substance of the precursor material have a big impact on the defatting process. For a few existing low-fat items, this step may simply be skipped [58]. The protein recovery and purity of the final product are directly affected by eliminating fat from the sample. Protein-lipid interactions restrict protein solubility due to the hydrophobic nature of lipids [59]. At the laboratory scale, the defatting procedure also increased insect protein output [60]. *T. molitor* and *Hermetia illucens*, for example, had their protein content increased from 57.8 ± 1.2 percent to 64.6 ± 0.3 percent and 34.7 ± 0.2 percent to 44.9 ± 1.4 percent, accordingly, due to hexane defatting process [61]. Defatting is an important step in making insect-based protein-enriched foods, given these findings and the high-fat content of most edible insects [62].

5.3 Solubilization and recovery of protein

To adjust protein solubility, the pH and ionic strength of the solubilization media are frequently changed to extract proteins from either constituent of defatted wheat. Because most food materials, including legumes and insects, have an isoelectric point (pI) of between 4 and 5, excessive pH values cause the protein surface to become charged, enhancing both electrostatic repulsion between proteins and protein-water associations [63–65]. To increase protein solubility, ionic strength can also be changed. Salt ions operate as a “shield” for proteins with opposing surface charges at low ionic strength (0.5–1 M), enhancing protein-water association and water solubility [66]. This method is known as salting in. The protein solution is normally centrifuged or gently eluted to complete the solubilization process. Proteins and other water-soluble constituents are retrieved from the supernatant, whereas water-insoluble polysaccharides and other minor components are eliminated from the pellet [54].

5.4 Purification of protein

Purifying specific proteins from an isolate or concentrate using chromatographic techniques is a helpful technique. Ion exchange, reversed-phase, and affinity chromatography rely on the variable affinity of proteins for the immobile stage [62, 67], and gel filtration chromatography isolates proteins by molecular weight [63]. Although chromatographic purification technologies have yet to be utilized on insects for food. For example, ion exchange chromatography was used to partially purify arginine kinase from yellow mealworms [68].

5.5 Drying

Drying can be used as the first step in the creation of insect flour and even the final step in the production of protein concentrates or isolates. Oven drying, fluidized bed drying, and microwave drying, for example, can all be utilized to dry solid samples and are thus utilized to make flour from whole insects prior to grinding. Depending on the study, the experimental setup and parameters may vary greatly. For example, it was found that oven-drying parameters for various insects ranged from 40 to 80°C for 7 to 48 hours, or till consistent weight was achieved [69]. Microwaves were used to dry *T. molitor* or *H. illucens* in a few articles comparing various drying processes. Depending on the experimental setup, microwave drying parameters ranged from 0.5 to 2 kW for 30 seconds or up to 20 minutes [70]. Fluidized bed drying, however less widespread, has been recorded as an alternate drying method for insect flour manufacture [18].

6. Contribution of insects to food and feed security

The contribution of edible insects in augmenting food supply is unpredictable. There is an extreme need to increase the traditional animal feed such as soy, grains, and fishmeal by using alternative sources. It is estimated that by 2030, over nine billion people and billions of animals will need to be fed. Furthermore, massive livestock production can cause land and water pollution and their overgrazing can also cause forest degradation that imparts a negative impact on our climate and damage our environment more rapidly. In order to reduce this rapidly destroying environment, alternative ways to feed livestock must be explored in which the consumption of edible insect provide innovation. For addressing food and feed security, insect farming is always the best option. Insects are ubiquitous, have high and rapid growth rates, and impart less environmental imprint throughout their lifecycle. They have high nutritional value, can be raised on a variety of different waste streams, and do not require any specific land for cultivation. In the coming decade, the usage of insects as poultry and aquaculture fodder is projected to be more common.

The usage of insects for feeding purpose is beneficial for us from health, environmental, and social perspective [71] which are described as follow:

6.1 Health benefits

Insect nutrition is determined by their life stage (metamorphic stage), habitat, and feed. It is commonly agreed, however, that:

- As insects possess high-quality protein and have high nutritional value so they are extremely useful for undernourished children as a food supplement. It has been indicated that insects have high fat content and they are also abundant in micronutrients.

- Insects have a lesser tendency of spreading zoonotic diseases, such as H1N1 (bird flu) and BSE (bovine spongiform encephalopathy) (mad cow disease).

6.2 Environmental benefits

- Because insects are cold-blooded, they have high feed to meal conversion rates. The estimated feed to meal conversion rate of insects is 2:1 as compared to calves whose estimated conversion ratio is 8:1.

- Most insects are likely to produce fewer greenhouse gases than typical animals. Pigs, for example, create 10–100 times the amount of greenhouse emissions per kilogram of body weight as mealworms.
- Insect farming requires less area than traditional animal husbandry.

6.3 Social benefits

- Harvesting and rearing technology is inexpensive, thus collecting insects and growing them require little technical or capital investment.
- Gathering insects from the wild, cultivating them, and selling them as street food can be a source of income for the lowest people of society.
- In industrialized, transitional, and developing economies, insect gathering, and farming can provide entrepreneurship prospects.
- Insects are reasonably easy to process for food and feed. Some species can be eaten in their entirety. Insects can also be ground into meals or made into pastes, and their proteins recovered.

7. Challenges and perspectives in insect food

One of the highly efficient protein sources is considered to be edible insects, which provide a chief source of protein for the future. The biggest challenge for consuming insect food is the neophobia that is associated with insect food [72]. Besides these, various other challenges are also present in consuming insects that have discussed below.

7.1 Aversion to insect consumption

Neophobia and disgust associated with trying insect is the biggest challenge to their integration into the food industry [73]. Studies showed that the two major barriers to consuming insects are neophobia and disgust, however, disgust plays a major role in comparison to neophobia [74]. In order to resolve this, scientists suggested it is more beneficial to enhance the quality, taste, and appearance of food.

7.2 Processing

Harvestation of insects has been done on a larger scale primarily for human consumption or pet and livestock feed [75]. As the utilization of insects has been increasing day by day so it is necessary to use more advanced and efficient processing methods to extract protein. Information about processing methods for yielding pure insect protein remains scarce and mainly performed at the laboratory level [76]. However, the purity and the quantity of insect protein solely depend on insect species, processing techniques, and rearing methods used. This future study emphasizes for extracting more insect protein by using optimal processes.

7.3 Allergenicity

Another main issue associated with edible insects is allergy. Anaphylactic reactions have been found in several studies after eating edible insects; these reactions may have been triggered by the existing link between insects and arthropods (such as shrimps and dust mites). Purines are made up of hydrogen, carbon, and nitrogen, as well as adenine and guanine, and are found in proteins. Uric acid is just another product of purine metabolism in humans that can be hazardous to gout sufferers. Undeniably cross allergic reactions to crustaceans and house dust mite protein have been associated with various insects. Co sensitivity and cross-reactivity between crustaceans, house dust mite, and edible insects have been studied and it was found that tropomyosin and arginine kinase are the major proteins responsible for allergic reactions [77]. Broekman *et al.* studied allergic reactions corresponding to insect consumption [78]. Different methods such as enzymatic hydrolysis and thermal treatment have been used to reduce the intensity of various allergens in various studies that are somehow effective [21].

7.4 Microbial hazards

One of the most serious challenges is the microbial hazards that are associated with edible insects. It has been found that total account of mesophilic aerobes is very high approx. to 7–8 Log10 CFU per gram in some edible insects parallel to that present in vegetables and fresh herbs [22]. Moreover, another serious hygienic concern is Enterobacteriaceae and found at the level of 106–1012 CFU/g [79], which is extremely high. To decrease the level, scientists suggest that prior to eating insect have been fasted for a day or it also greatly depend on food processing and rearing conditions [76]. Furthermore, edible insects might also possess a wide range of pathogens and spoilage bacteria that can be reduced by the processing step.

7.5 Environment

In using edible insects as a source of novel protein studies have been conducted by many scientists from an environmental point of view as environmental pollution is a serious issue [80]. Additionally, life cycle assessment of different insects provides lower environmental impact as compared to broiler but shows high environmental effect in contrast to plants [81].

7.6 Religious view about entomophagy

Food practices are influenced by culture and religious beliefs. The practice of eating insects is cited throughout religious literature in the Christian, Jewish and Islamic faiths. The consumption of insects depends on religion and ethnicity. It is a taboo among Muslims [82]. In the sacred books of the Christian, Jewish, and Islamic religions, there are different fragments related to entomophagy. Entomophagy in ancient times is a noted in the New Testament of the Bible with reference to John the Baptist, who appeared totally depended for his food on locusts and honey. In the Holy Bible use of locusts, crickets, and grasshoppers as food is mentioned as well as crickets and grasshoppers (Leviticus 11:22). In Islamic traditions, evidence of the use of insects as food extends to locusts and bees. In Judaism four species of locusts are recognized as kosher; that is, permitted for use as food [12, 83]. Entomophagy is also present in Jewish literature. Eating certain species of kosher locusts was largely accepted in ancient times.

7.7 Future directions

People should be educated about the importance of insects. The proper industry should be developed. A comparative analysis of the nutritional value of insects and red meat found that, in general, the value in regard to protein content, essential amino acids, and unsaturated fatty acids was similar [84]. People should have awareness that insects may prevent micronutrient deficiencies and play a role in the management of chronic diseases, such as cardiovascular disease, diabetes, and cancer [85].

Author details

Mahnoor Pervez* and Farkhanda Manzoor
Department of Zoology, Lahore College for Women University, Lahore, Pakistan

*Address all correspondence to: mahnoorentomology@gmail.com

References

[1] Per P-A. Food security: Definition and measurement. Food Security. 2009, 2009;**1**:5-7

[2] Timmer CP. The macro dimensions of food security: Economic growth, equitable distribution, and food Price stability. Food Policy. 2000;**25**:28

[3] FAO (Food and Agriculture Organization). The Sate of Food Insecurity in the World 2001. Rome: Food and Agriculture Organization of the United Nations; 2002

[4] Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food security: The challenge of feeding 9 billion people sciences. Science. 2010;**327**(5967):812-818

[5] Westra S, Alexander L, Zwiers F. Global increasing trends in annual maximum daily precipitation. Journal of Climate. 2012;**23**:3904-3918

[6] Schlenker W, Roberts M. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academy of Sciences. 2009;**106**(37):15594-15598

[7] The Royal Society. Ground-Level Ozone in the 21st Century: Future Trends, Impacts and Policy Implications. Science Policy Report 15/08. London: The Royal Society Science Policy; 2008

[8] Tamburino L, Bravo G, Clough Y, Nicholas KA. From population to production: 50 years of scientific literature on how to feed the world. Global Food Security Index. 2020;**24**:100346

[9] Ramos-Elorduy J, Gonzalez EA, Hernandez AR, Pino JM. Use of *Tenebrio molitor* (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. Journal of Economic Entomology. 2002;**95**(1):214-220

[10] Rumpold BA, Schluter OK. Nutritional composition and safety aspects of edible insects. Molecular Nutrition and Food Research. 2013;**57**(5):802-823

[11] Oonincx DG, van Itterbeeck J, Heetkamp MJ, van den Brand H, van Loon JJ, van Huis A. An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS One. 2010;**5**(12):e14445

[12] Van Huis A. Potential of insects as food and feed in assuring food security. Annual Review of Entomology. 2013;**58**(1):563-583

[13] Raubenheimer D, Rothman JM. Nutritional ecology of entomophagy in humans and other primates. Annual Review of Entomology. 2013;**58**:141-160

[14] Guine FPR, Correia PR, Coelho., Costa, C. A. The role of edible insects to mitigate challenges for sustainability. Open Agriculture. 2021;**6**(1):24-36

[15] Beatriz A, Acosta E, Reyes A, Cristina MR, Dolores R, Celeste CIH. Benefits and challenges in the incorporation of insects in food products. Frontiers in Nutrition. 2021;**8**:687712

[16] Arrese EL, Soulages JL. Insect fat body: Energy, metabolism, and regulation. Annual Review of Entomology. 2010;**2010**

[17] Kourimska L, Adamkova A. Nutritional and sensory quality of edible insects. NFS Journal. 2016;**4**:22-26

[18] Kroncke N, Böschen V, Woyzichovski J, Demtroder S, Benning R. Comparison of suitable drying processes for mealworms (*Tenebrio molitor*). Innovative Food Science & Emerging Technologies. 2018;**50**:20-25

[19] Kulma M, Plachy V, Kourimska L, Vrabec V, Bubova T, Adamkova A, et al. Nutritional value of three Blattodea species used as feed for animals. Journal of Animal and Feed Sciences. 2016;**25**(4):354-360

[20] Belluco S, Losasso C, Maggioletti M, Alonzi C, Ricci A, Paoletti MG. Edible insects: A food security solution or a food safety concern? Animal Frontiers. 2015;**5**(2):25-30

[21] Pali-Scholl I, Meinlschmidt P, Larenas-Linnemann D, Purschke B, Hofstetter G, Rodriguez-Monroy FA, et al. Edible insects: Cross-recognition of IgE from crustacean- and house dust mite allergic patients, and reduction of allergenicity by food processing. World Allergy Organization Journal. 2019, 2019;**12**(1):100006

[22] Fasolato L, Cardazzo B, Carraro L, Fontana F, Novelli E, Balzan S. Edible processed insects from e-commerce: Food safety with a focus on the Bacillus cereus group. Food Microbiology. 2018;**76**:296-303

[23] Bukkens SGF. The nutritional value of edible insects. Ecology of Food and Nutrition. 1997;**36**(2-4):287-319

[24] Sales-Campos H, Reis de Souza P, Crema Peghini B, Santana da Silva J, Ribeiro Cardoso C. An overview of the modulatory effects of oleic acid in health and disease. Mini Reviews in Medicinal Chemistry. 2013, 2013;**13**(2):201-210

[25] Finke MD. Nutrient composition of bee brood and its potential as human food. Ecology of Food and Nutrition. 2005;**44**(4):257-270

[26] Bukkens SG, Paoletti MG. Insects in the human diet: Nutritional aspects. In: Ecological Implications of Minilivestock; Role of Rodents, Frogs, Snails, and Insects for Sustainable Development. Enfield, USA: Science Publishers, Inc; 2005. pp. 545-577

[27] Tang C, Yang D, Liao H, Sun H, Liu C, Wei L, et al. Edible insects as a food source: A review. Food Production, Processing and Nutrition. 2019;**8**(1):1-8

[28] Jozefiak D, Jozefiak A, Kieronczyk B, Rawski M, Swiatkiewicz S, Dlugosz J. Insects - a natural nutrient source for poultry - a review. Annals of Animal Science. 2016;**16**(2):297-313

[29] Krishnan R, Sherin L, Muthuswami M, Balagopal R, Jayanthi C. Seri waste as feed substitute for broiler production. Sericologia. 2011;**51**(3):369-383

[30] Awoniyi TAM, Adetuyi FC, Akinyosoye FA. Microbiological investigation of maggot meal, stored for use as livestock feed component. Journal of Food, Agriculture and Environment. 2004;**2**(3-4):104-110

[31] Liu Y-S, Wang F-B, Cui J-X, Zhang L. Recent status and advances on study and utilization of Tenebrio molitor. Journal of. Environmental Entomology. 2010;**32**:106-114

[32] Ramos-Elourdy J, Pino-Moreno JM, Martinez-Camacho VH. Could grasshoppers be a nutritive meal. Food and Nutrition Sciences. 2012;**3**:164-175

[33] Gahukar RT. Entomophagy and human food security. International Journal of Tropical Insect Science. 2011;**31**(3):129-144

[34] Shelomi M. Why we still don't eat insects: Assessing entomophagy promotion through a diffusion of innovations framework. Trends in Food Science & Technology. 2015;**45**(2):311-318

[35] Raheem D, Carrascosa C, Oluwole OB, Nieuwland M, Saraiva A, Millan R, et al. Traditional consumption of and rearing edible insects in Africa, Asia and Europe. Critical Reviews in Food Science and Nutrition. 2018;**59**(14):1-20

[36] Van Huis A, Oonincx DGAB. The environmental sustainability of insects as food and feed. A review. Agronomy for Sustainable Development. 2017;**37**(5):43

[37] Durst PB, Hanboonsong Y. Small-scale production of edible insects for enhanced food security and rural livelihoods: Experience from Thailand and Lao People's Democratic Republic. Journal of Insects as Food and Feed. 2015;**1**(1):25-31

[38] Cerritos R, Cano-Santana Z. Harvesting grasshoppers *Sphenarium purpurascens* in Mexico for human consumption: A comparison with insecticidal control for managing pest outbreaks. Crop Protection. 2008;**27**(3):473-480

[39] Lara-Juarez P, Rivera JRA, Lara PC, Reyes-Aguero JA. Collecting pupae (escamoles) of *Liometopum apiculatum* (Hymenoptera, Formicidae, Dolichoderinae) in the San Luis Potosi high plain, Mexico. Interciencia. 2018;**43**(11):763-769

[40] Payne CLR, Van Itterbeeck J. Ecosystem services from edible insects in agricultural systems: A review. Insects. 2017;**8**(1):E24

[41] Cerritos-Flores R, Ponce-Reyes R, Rojas-Garcia F. Exploiting a pest insect species *Sphenarium purpurascens* for human consumption: Ecological, social, and economic repercussions. Journal of Insects as Food and Feed. 2014, 2014;**1**(1):75-84

[42] Gahukar, R. T. Edible insects farming: Efficiency and impact on family livelihood, food security, and environment compared with livestock and crops. 2016;7:85-111

[43] Varelas V, Langton M. Forest biomass waste as a potential innovative source for rearing edible insects for food and feed – A review. Innovative Food Science & Emerging Technologies. 2017;**41**:193-205

[44] Van Thielen L, Vermuyten S, Storms B, Rumpold BA, Van Campenhout L. Consumer acceptance of foods containing edible insects in Belgium two years after their introduction to the market. Journal of Insects as Food and Feed. 2018;**5**(1):35-44

[45] Xiao H-W, Bai J-W, Sun D-W, Gao Z-J. The application of superheated steam impingement blanching (SSIB) in agricultural products processing—A review. Journal of Food Engineering. 2014;**132**:39-47

[46] Wynants E, Crauwels S, Verreth C, Gianotten N, Lievens B, Claes J, et al. Microbial dynamics during production of lesser mealworms (*Alphitobius diaperinus*) for human consumption at industrial scale. Food Microbiology. 2018;**70**:181-191

[47] Vandeweyer D, Lenaerts S, Callens A, Van Campenhout L. Effect of blanching followed by refrigerated storage or industrial microwave drying on the microbial load of yellow mealworm larvae. Food Control. 2017;**71**:311-314

[48] Niamnuy C, Devahastin S, Soponronnarit S. Changes in protein

compositions and their effects on physical changes of shrimp during boiling in salt solution. Food Chemistry. 2008;**108**(1):165-175

[49] Derossi A, Severini C. Understanding the drying kinetic and hygroscopic behaviour of larvae of yellow mealworm (*Tenebrio molitor*) and the effects on their quality. Journal of Insects as Food and Feed. 2016;**2**(4):233-243

[50] Caparros Megido R, Desmedt S, Blecker C, Bera F, Haubruge E, Alabi T, et al. Microbiological load of edible insects found in Belgium. Insects. 2017;**8**(1):12

[51] Grabowski NT, Klein G. Microbiology of cooked and dried edible Mediterranean field crickets (*Gryllus bimaculatus*) and superworms (*Zophobas atratus*) submitted to four different heating treatments. Food Science and Technology International. 2016;**23**(1):17-23

[52] Grabowski NT, Klein G. Microbiology of processed edible insect products—Results of a preliminary survey. International Journal of Food Microbiology. 2017;**243**:103-107

[53] Lamidi RO, Jiang L, Pathare PB, Wang YD, Roskilly AP. Recent advances in sustainable drying of agricultural produce: A review. Applied Energy. 2019;**233-234**:367-385

[54] Menozzi D, Sogari G, Veneziani M, Simoni E, Mora C. Eating novel foods: An application of the theory of planned behaviour to predict the consumption of an insect-based product. Food Quality and Preference. 2017;**59**:27-34

[55] Niassy S, Fiaboe KKM, Affognon HD, Akutse KS, Tanga MC, Ekesi S. African indigenous knowledge on edible insects to guide research and policy. Journal of Insects as Food and Feed. 2016;**2**(3):161-170

[56] Tiencheu B, Womeni HM, Linder M, Mbiapo FT, Villeneuve P, Fanni J, et al. Changes of lipids in insect (*Rhynchophorus phoenicis*) during cooking and storage. European Journal of Lipid Science and Technology. 2013;**115**(2):186-195

[57] Zielinska E, Karas M, Baraniak B. Comparison of functional properties of edible insects and protein preparations thereof. A review of literature. Lebensmittel-Wissenschaft und-Technologie-Food Science and Technology. 2018;**91**:168-174

[58] Boye J, Zare F, Pletch A. Pulse proteins: Processing, characterization, functional properties and applications in food and feed. Food Research International. 2010;**43**(2):414-431

[59] Azagoh C, Ducept F, Garcia R, Rakotozafy L, Cuvelier ME, Keller S. Mezdour,.Extractionandphysicochemical characterization of Tenebrio molitor proteins. Food Research International. 2016;**88**(Pt A):24-31

[60] Choi BD, Wong NAK, Auh JH. Defatting and sonication enhances protein extraction from edible insects. Korean Journal for Food Science of Animal Resources. 2017;**37**(6):955-961

[61] Bubler S, Rumpold BA, Jander E, Rawel HM, Schluter OK. 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. 2016;**2**(12):e00218

[62] Tzompa-Sosa DA, Yi L, van Valenberg HJF, van Boekel MAJS, Lakemond C, n M. M. Insect lipid profile: Aqueous versus organic solvent-based

extraction methods. Food Research International. 2014;**62**:1087-1094

[63] Boye J, Barbana C. Protein processing in food and bioproduct manufacturingand techniques for analysis. In: Dunford NT, editor. Food and Industrial Bioproducts and Bioprocessing. USA: John Wiley & Sons, Ltd., Publication; 2012. pp. 85-113

[64] Lam ACY, Can Karaca A, Tyler RT, Nickerson MT. Pea protein isolates: Structure, extraction, and functionality. Food Reviews International. 2018;**34**(2):126-147

[65] Singhal A, Karaca AC, Tyler R, Nickerson M. Pulse proteins: From processing to structure-function relationships. Grain Legumes. 2016;**2016**(8):56-78

[66] Duong-Ly KC, Gabelli SB. Chapter seven - salting out of proteins using ammonium sulfate precipitation. In: Lorsch J, editor. Methods in Enzymology. Vol. 541. USA: Elsevier Inc; 2014. pp. 85-94

[67] Urh M, Simpson D, Zhao K. Chapter 26 affinity chromatography: General methods. In: Burgess RR, Deutscher MP, editors. Methods in Enzymology. Vol. 463. USA: Elsevier Inc; 2009. pp. 417-438

[68] Francis F, Doyen V, Debaugnies F, Mazzucchelli G, Caparros R, Alabi T, et al. Limited cross reactivity among arginine kinase allergens from mealworm and cricket edible insects. Food Chemistry. 2019;**276**:714-718

[69] Melgar-Lalanne G, Hernandez-Alvarez AJ, Salinas-Castro A. Edible insects processing: Traditional and innovative technologies. Comprehensive Reviews in Food Science and Food Safety. 2019;**18**(4):1166-1191

[70] Huang C, Feng W, Xiong J, Wang T, Wang W, Wang C, et al. Impact of drying method on the nutritional value of the edible insect protein from black soldier fly (*Hermetia illucens L.*) larvae: Amino acid composition, nutritional value evaluation, in vitro digestibility, and thermal properties. European Food Research and Technology. 2018;**245**(1):11-21

[71] Kuyper E, Vitta B, Dewey K. Novel and underused food sources of key nutrients for complementary feeding. A&T Tech Brief. 2013;**6**:1-8

[72] Jensen NH, Lieberoth A. We will eat disgusting foods together – Evidence of the normative basis of Western entomophagy-disgust from an insect tasting. Food Quality and Preference. 2019;**72**:109-115

[73] Verbeke W. Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. Food Quality and Preference. 2015;**39**: 147-155

[74] La Barbera F, Verneau F, Amato M, Grunert K. Understanding westerners' disgust for the eating of insects: The role of food neophobia and implicit associations. Food Quality and Preference. 2018;**64**:120-125

[75] Van Huis A, van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, et al. Edible Insects - Future Prospects for Food and Feed Security. FAO Forestry Paper. Vol. 1712013. Rome: Food and Agriculture Organization of the United State

[76] Zhao X, Vazquez-Gutierrez JL, Johansson DP, Landberg R, Langton M. Yellow mealworm protein for food purposes - extraction and functional properties. PLoS One. 2016;**11**(2):e0147791

[77] Ribeiro JC, Cunha LM, Sousa-Pinto B, Fonseca J. Allergic risks of consuming edible insects: A systematic review. Molecular Nutrition & Food Research. 2018;**62**(1):1-12

[78] Broekman H, Verhoeckx KC, den Hartog Jager CF, Kruizinga AG, Pronk-Kleinjan M, Remington BC, et al. Majority of shrimp-allergic patients are allergic to mealworm. The Journal of Allergy and Clinical Immunology. 2016;**137**(4):1261-1263

[79] Fernandez-Cassi X, Supenu A, Jansson A, Boqvist S, Vagsholm I. Novel foods: A risk profile for the house cricket (*Acheta domesticus*). EFSA Journal. 2018;**5**:137-157

[80] Oonincx DG, van Broekhoven S, van Huis A, van Loon JJ. Feed conversion, survival and development, and composition of four insect species on diets composed of food by-products. PLoS One. 2015;**10**(12):e0144601

[81] Smetana S, Schmitt E, Mathys A. Sustainable use of *Hermetia illucens* insect biomass for feed and food: Attributional and consequential life cycle assessment. Resources, Conservation and Recycling. 2019;**144**:285-296

[82] Djouffa KML, Saidou C, Ali A, Mohammadou BA. Tchiegang C. Edible insects in the Adamawa and eastern regions of Cameroon: Collection, processing and consumption. Journal of Insects as Food and Feed. 2021;7(12):483-494

[83] Govorushko S. Global status of insects as food and feed source: A review. Trends in Food Science and Technology. 2019;**91**:436-445

[84] Orkusz A. Edible insects versus meat-nutritional comparison: Knowledge of their composition is the key to good health. Nutrients. 2021;**13**(4):1207

[85] Nowakowski AC, Miller AC, Miller ME, Xiao H, Wu X. Potential health benefits of edible insects. Critical Reviews in Food Science and Nutrition. 2021;**2**:1-10