CHAPTER

2

Insects as a Source of Sustainable Proteins

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OUTLINE

2.1 INTRODUCTION

The importance of dietary proteins cannot be underestimated (Pihlanto and Korhonen, 2003). Proteins form the enzymes, transcription factors, antibodies, neurotransmitters, hormones, and a whole lot of other vital body components. Protein deficiency can lead to a gamut of illnesses (Bhutta and Sadiq, 2012), and undernutrition is killing millions of people annually. So far, most of the starvation and famine conditions are confined to developing countries. But, as climate change is causing erratic weather patterns, and the human population is poised to exceed 9 billion by 2050, global food insecurity looms on the horizon. At this rate of human population growth, conventional protein production from livestock, poultry, and fish cannot keep up (van Huis, 2013), so novel and affordable sources of proteins are being searched for. As sustainable meat substitutes, options like soybean, algae, insects, mycoproteins, among others, have been explored (Smetana et al., 2015). Each of these alternatives has their pros and cons. Particularly, insects, generally considered pests for agriculture and vectors of zoonotic diseases, have emerged as a prospective solution (Ramaswamy, 2015;

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Nadeau et al., 2015; van Huis et al., 2015). In the past half-decade, insects have drawn immense interest from diversified hierarchies.

Humankind consuming certain arthropods is not new. Especially crustaceans, which encompass crabs, lobsters, prawns, and shrimps, are considered as delicacies (Hadley, 2006). Krill (*Euphausia superba*), a marine crustacean, is being harvested for its oil, rich in omega-3 fatty acids, choline, and antioxidant astaxanthin (Maki et al., 2009; Barros et al., 2014). Aquaculture along with fishery, is a billion dollar sector. Bee (*Apis* sp.) products as honey, pollen, and propolis are dietary supplements (Al-Hariri, 2011; Rossano et al., 2012; Silva-Carvalho et al., 2014; Patel, 2016a). The cochineal insects (*Dactylopius coccus*)-derived dye carmine (the pigment carminic acid) is used in food processing (Voltolini et al., 2014). Apiculture (Verde, 2014) and cochineal insect farming (De León-Rodríguez et al., 2006; Ramos-Elorduy et al., 2011) are popular traditional practices. Also, crickets and mealworms are reared to feed zoo animals and birds (McClements et al., 2003). Silkworm (*Bombyx mori*, *Antheraea assamensis*, etc.) culture or sericulture, to harvest silk, is an age-old practice, and is a major part of some economies (Takeda, 2009; Tikader et al., 2013). Cantharidin, a topical vesicant from blister beetles (*Cantharis vesicatoria*), has been traditionally used to treat warts, calluses, and other skin conditions. Also, it is currently being used as a sexual stimulant (Torbeck et al., 2014). The horseshoe crab (*Limulus polyphemus*) hemolymph is harvested for multiple biomedical applications (Hurton et al., 2005).

In certain ethnic cultures and some Oriental countries, insects have been integral part of diet. But overall global consumption is minimal and often considered a taboo, insects being regarded as filthy and disease carriers (Sidali et al., 2018). But with changing times and the escalating need for additional protein sources, insects are being viewed in a new light. Their merits are outnumbering the demerits. Insects are rich in protein (40–75 g/100 g dry weight), and other micronutrients (Verkerk et al., 2007). Their "feed conversion ratio" is high, and turnover time is low (Premalatha et al., 2011; Nowak et al., 2016). Insect husbandry releases less greenhouse gases, while requiring less water and agricultural land (Van Huis and Dunkel, 2016). Black soldier fly (*Hermetia illucens*) can grow on organic materials, which is an added advantage as wastes are accumulating and their disposal is an additional problem (Wang and Shelomi, 2017). Insect farming is energy-efficient compared to livestock farming or aquaculture (Grau et al., 2017). Edible insects can be reared on organic byproducts (Lang and Barling, 2013). So, insect farming and entomophagy practices by humans are being promoted (Gahukar, 2011; Nadeau et al., 2015). Several countries are allocating funds and resources for insect-based protein food developments. While insects as the sources of protein and their relevance as human food are indisputable, some strong hiccups lie in the path of their popularization. The most important hurdles are "repulsion towards arthropods," which is psychological (Caparros Megido et al., 2016), and "allergenicity," which is of clinical significance. This chapter delves into the present status of insect-based protein foods, enumerates the roadblocks in the path of insects emerging as "sustainable protein source," and discusses the prospects.

2.2 ETHNIC AND MODERN ENTOMOPHAGY PRACTICES

The class Insecta includes the orders Coleoptera, Orthoptera, Hemiptera, Hymenoptera, Lepidoptera, Isoptera, Ephemeroptera, Odonata, and Mantodea (Chakravorty et al., 2011, 2013).

Humans have consumed insects since the early days of evolution and before as their other primate ancestors. During the hunter-gatherer stage of mankind, insects were a major source of nutrition (Morris, 2008). Insects have been part of subsistence diets for millennia (Pal and Roy, 2014). They have served as an emergency food, as a staple, and as delicacies (Johnson, 2010). Until now, entomophagy, the practice of consuming insects, has been followed across the world (Raubenheimer and Rothman, 2013). Several ethnic food habits encompass insects (Bodenheimer, 1951; Costa-Neto and Dunkel, 2016). As per one report, about 1700 insects species are consumed globally (Chakravarthy et al., 2016), while as per another report, 2086 species are consumed by 3071 ethnic groups (Ramos-Elorduy, 2009). As per another report, 527 different insects are consumed across 36 countries in Africa, 29 insects in Asia, and 23 in the America. The eggs, larvae, pupae, and adults of several insects are consumed by frying, stewing, drying, smoking, steaming, blanching, and roasting (Chen et al., 2009). Snacks, beverage, and condiments are popular modes of insect consumption.

Fried honey bees (*Apis* sp.) are deemed a delicacy in parts of China (Hartmann et al., 2015). The black chafer beetle (*Holotrichia parallela* Motschulsky) and black ant (*Polyrhachis vicina* Roger) are traditionally consumed in China. In Cambodia, roasted crickets are a popular delicacy (Walia et al., 2018). The Japanese consume hachinoko (boiled wasp larvae), sangi (fried silk moth pupae), zazamushi (aquatic insect larvae), semi (fried cicada), and inago (fried grasshopper) (Nonaka, 2010; Césard et al., 2015). Dried *Tenebrio molitor*, *Oxya chinensis sinuosa*, *B. mori*, *Protaetia brevitarsis seulensis*, and *Verlarifictorus asperses* are consumed in Korea (Kim et al., 2017). About 164 insect species are consumed in Thailand (Boulidam, 2010; Hanboonsong, 2014). Rural Filipinos consume migratory locust, field crickets, mole crickets, carpenter ant eggs, coconut beetles grubs, June beetles, and katydids (Adalla and Cervancia, 2010). In Laos, weaver ant eggs, bamboo worms, crickets, and wasps are consumed (Barennes et al., 2015). In Borneo, more than 80 species of insects, including honey bee brood, grasshoppers and sago grubs, crickets, rice bugs, cicadas, termites, ants, and beetles, are consumed by the Kadazandusun, Murut, and Rungus people (Chung, 2008). The Vedda tribal people of Sri Lanka consume bee brood and larvae of *Apis dorsata*, *Apis cerana*, and *Apis florea* (Nandasena et al., 2010). Tribal people inhabiting the North Eastern part of India, as in Assam and Manipur, consume several insects to supplement their diet (Nath et al., 2005; Shantibala et al., 2014). In Manipur, they ingest *Lethocerus indicus*, *Laccotrephes maculatus*, *Hydrophilus olivaceous*, *Cybister tripunctatus*, and *Crocothemis servilia* (Shantibala et al., 2014). Green weaver ant (*Oecophylla smaragdina*) is consumed as a condiment. The edibility of 18 species of insects in the Kolhapur region of India has been reported (Sathe, 2015).

Emperor moth (*Gonimbrasia belina*) caterpillar (mopane worm) is consumed in Southern Africa (Okezie et al., 2010). African palm weevil (*Rhychophorus phoenicis*) larvae are consumed by some tribes (Elemo et al., 2011). The Azande and Mangbetu people of Congo (van Huis, 2017) and inhabitants of Limpopo Province, South Africa (Netshifhefhe et al., 2018) consume termites. In Nigeria, the termite (*Macrotermes natalensis*), African cricket (*Brachytrupes membranaceus*), and pallid emperor moth (*Cirina forda*) are popular insect foods (Agbidye et al., 2009). The Pangwe people in Guinea, Gabon, and Cameroon gather aquatic larvae of dragonflies. People living around Lake Victoria consume black ants (*Carebara vidua* Smith) (Ayieko et al., 2012).

Native American and Latin American tribes consume a large variety of insects (Navarro et al., 2010). Tukanoan Indians in the Northwest Amazon consumed over 20 species of insects which included beetle larvae (*Rhynchophorus*), ants (*Atta*), termites (*Syntermes*), and caterpillars (from the families Noctuidae and Saturniidae) (Dufour and Dufour, 1987). In Mexico, roasted ants, lime and chile cricket, grasshoppers (chapulines), mescal worms (gusanos de maguey), and insect eggs (escamoles) are traditional snacks. The leafcutter ant (*Atta laevigata*, *Atta cephalotes*, and *Atta sexdens*) is eaten in parts of Colombia and Brazil. Brazil, Colombia, Ecuador, Mexico, Peru and Venezuela are countries where insect consumption is prevalent.

Regional differences in insect-eating practices have been seen in the United States (Schrader et al., 2016).

Australian Aborigines have been consuming Bogong moth (*Agrotis infusa*), larvae of cossid moth (*Xyleutes leucomochla*), honeypot ant (*Melophorus bagoti* Lubbock), and carpenter ant (*Camponotus* spp.) (Yen, 2010; Warrant et al., 2016). Tribes in the New Guinea island, collect oviposits of the beetle *Rhynchophorus ferrugineus papuanus* from the sago palm (Ponzetta and Paoletti, 1997).

In the Carnia region of Italy, *Zygaena* moths are eaten as a seasonal delicacy. In the putrid cheese Casu Marzu, a traditional Sardinian sheep milk cheese, live larvae of cheese fly (*Piophila casei*) are present (Manca et al., 2015).

A review on termites records 43 species being used in the human diet (Figueirêdo et al., 2015). People consume locally-available insects to supplement their diet for hunger and taste, but insects are rich in nutrients as well. Insects are dense sources of carbohydrates, proteins, fats, minerals, and vitamins (Gahukar, 2011). They are particularly abundant in protein, containing 40–75 g/100 g dry weight (Verkerk et al., 2007). Also, insect meat has more polyunsaturated fatty acid than conventional meat (Van Huis, 2016). The minerals obtained from eating insects include K, Ca, P, Mg, Fe, Mn, and Zn. Organic compounds include 9-octadecenoic acid, ethyl oleate, cholesterol and n-hexadecanoic acid. Some other fatty compounds include hexadecanoic acid, ethyl ester, linoleic acid, ethyl oleate, oleic acid, and cholesta-3, 5-diene (Shen et al., 2006). A study found that the lipids from three Orthopterans, *Acheta domesticus*, *Conocephalus discolor*, and *Chorthippus parallelus*, contain much higher amounts of essential fatty acids than those of *T. molitor* larvae. *A. domesticus* and *C. discolor* contain linoleic acid in major quantities, while *C. parallelus* contains α-linolenic acid in major quantities (Paul et al., 2017). Fig. 2.1 shows some of the edible insect preparations. Not only interspecies biochemical compositions differ, but differences exist in the various stages of a species' life cycle, as the egg, larvae, pupae, and adult forms contain very different biochemical profiles.

2.3 ISSUES WITH INSECTS-BASED PROTEIN AND THE SOLUTIONS FOR THEM

Food neophobia prevents people from ingesting new things (Demattè et al., 2014). Consuming a new plant-based food is easier than that of a fauna-based food. When it comes to insects, disgust is a major factor (Hamerman, 2016; Menozzi et al., 2017), and neophobia is high (Caparros Megido et al., 2016). People in Western countries have had

FIGURE 2.1 Edible insect preparations.

access to other source of proteins, so they have not had to ingest insects. As a result, they are not conditioned to consume insects with ease, and consider insect eating as culturally inappropriate (Tan et al., 2016). Experts predict that controlled exposure to insect-based foods can help overcome the repulsion. Chopping insects into ready-to-eat preparations obtained a better response than the whole forms (Caparros Megido et al., 2016). Whole forms evoke rejection because of the characteristic cuticle, antennae, wings, strong odor, crawling, filthy habitats, etc. Insects use their pheromones to communicate and for defense, so emit unpleasant smell (Suwannapong and Benbow, 2011). Ground insect powder was used as an additive in cookies, crackers, and protein bars (Smetana et al., 2016). Based on a study involving response towards cricket flour—based chips, it was derived that the exposure to processed insect products can increase consumer willingness to taste, compared to unprocessed insects (Hartmann and Siegrist, 2016). In a study conducted in Australia, incorporating insects into familiar products like biscuits or cookies gained better appeal (Wilkinson et al., 2018). In a survey among the Belgian population, the participants mostly showed neophobia, but also partial willingness for insect preparations with flavor and crisp texture (Caparros Megido et al., 2014). People who do not consume pork or beef can consume their derivative gelatin. Similarly, while blended in a known food, insect extract can obtain better acceptance. Japanese relish sushi and sashimi and the Hawaiians consume ahi-poke where fish is largely raw. Western consumers are showing interest towards them, though infections of parasitic helminth (roundworm, tapeworm, and fluke) from the raw fish consumption have been reported (Kaneko and Medina, 2009). Sea urchin roe is considered a gourmet food, though it has been associated with IgE-mediated allergy (Rodriguez et al., 2007). Palm civet coffee or kopi luwak is an expensive coffee, even though the bean is collected from the droppings of civet cat (Onishi, 2010). Such examples of seemingly gross yet popular food abound. Approval of insects as food is an acquired taste, so transitioning into insectivore requires time and exposure (Hartmann and Siegrist, 2016). Furthermore, food habits are culturally-ingrained, reflected by halal (Islam), kosher (Jewish), and vegetarian (Hindus and Jainism). So, acceptance of insects is sure to be sluggish. So far, insect farming and marketing as food, is highly unregulated. Legislatives supporting their safety and nutrition can make them popular (Van Huis and Dunkel, 2016).

Anaphylaxis is a life-threatening allergic condition, which can be triggered by insects (Kemp and Lockey, 2002). Case studies of anaphylaxis after the consumption of chapuline have been documented (Sokol et al., 2017). Hymenoptera (bees, wasps, hornets, yellow-jackets, and ants) sting-caused allergy, has been observed (Przybilla and Ruëff, 2010). House dust mites (*Dermatophagoides pteronyssinus*), cockroaches (*Blatella germanica*, *Periplaneta americana*), and moths have allergens that can provoke IgE-mediated hypersensitivity in atopic individuals (Arlian, 2002; Kim and Hong, 2007; Okezie et al., 2010). These allergens can be serine proteases (trypsin, chymotrypsin, collagenase) (Wan et al., 2001; Sudha et al., 2008; Dumez et al., 2014), aspartic proteases, chitinases, calycin, troponin, tropomyosin, arylophorin, glutathione-S-transferases, and chitin (Arlian, 2002; Hindley et al., 2006; Jeong et al., 2006; Kim and Hong, 2007; Reese et al., 1999), among others. Mosquitoes have salivary gland proteins such as D7 protein family, adenosine deaminase, serpin, and apyrase (Doucoure et al., 2013). The saliva and secretions of flea, grain weevil, black fly, bluebottle fly, horse fly, bedbugs, cockroach, head louse, butterfly caterpillars, or silkworm have immunogenic components as well (Buczylko et al., 2015). The medical potential of antimicrobial peptides (AMP) from insects have been explored (Patel and Akhtar, 2017). The α-helical AMPs melittin, cecropin, abaecin, moricin, formaecin, and ponericin have been studied regarding their pathological and antibacterial roles (Chen and Lin-Shiau, 1985; Sousa et al., 2013). The peptides may have potential to inhibit microbes, but also have human cytotoxicity as well (Tonk and Vilcinskas, 2017). Also, insect protease inhibitors can inhibit human chymotrypsin, elastase, and plasmin (Wan et al., 2013; Negulescu et al., 2015). Some of these insects are not edible, but they share the same protein repertoire, which indicates the immunogenicity of the edible insects. Insects have storage proteins which are important for their metamorphosis and egg production (Telang et al., 2002). Storage proteins are synthesized in fat bodies and then secreted into the hemolymph. These vital proteins are hexameric glycoproteins which include hemocyanin, arylphorin, etc. Arylphorin is a major cockroach allergen (Arruda et al., 2001; Kim et al., 2003) and it possesses mitogenic properties as well (Hakim et al., 2007). Hexamerin1B, another insect storage protein in *Gryllus bimaculatus* (field cricket), can induce allergy (Srinroch et al., 2015; Pener, 2016). Not only insects, but plants also contain storage proteins which have exerted allergenicity towards humans. Peanut vicilin allergen Ara h 1, cashew vicilin-like Ana o 1 (Wang et al., 2002), conglutin beta in *Lupinus* sp. (Goggin et al., 2008), 7S and 11S globulins of soybean are all some of the allergenic storage proteins in plant-based foods (Shewry and Jones, 2006). However, it seems plant-origin storage proteins are easier to inactivate by cooking, compared to those of insects.

Lipocalin family of β-barrel proteins are transport proteins with allergenicity (Chudzinski-Tavassi et al., 2010). Insect lipocalins induce IgE production in atopic individuals. Nitrophorins are salivary heme proteins, from a lipocalin homology family, that are present in blood-sucking insects, which transfer nitric oxide (NO) to the victim, causing vasodilatation, sequestering histamine, and inhibiting blood coagulation (Ascenzi et al., 2002).

Insect exoskeleton chitin is an immunotoxin and a neurotoxin which, if regularly exposed to, can cause profound illnesses (Patel and Goyal, 2017; Patel et al., 2017). Even the inhalation of chitin particles can provoke the immune, neural, and endocrine systems. Chitin is the substrate of host chitinase, which is crucial for inhibiting infectious agents, but can damage host tissues as well. Enzymes work in cascade, so it can unleash a range of other aberrant enzyme activity. It would not be wrong to regard chitin as an endocrine disruptor or estrogenic agent. It is a top-grade inflammatory agent, and likely to induce excess cytochrome oxidase production. Aromatase is a cytochrome P450 enzyme that converts androgens (C19) into estrogens (C18) (Patel, 2017a). Estrogen is mitogenic and proliferative in nature and may cause breast cancer, prostate cancer, ovarian cancer, gastric cancer, pituitary cancer, polycystic ovary syndrome, diabetes, endometriosis, osteoporosis, Alzheimer's disease, and schizophrenia, among others (Patel et al., 2018).

Some moths and butterflies, such as Burnet moths (*Zygaena filipendulae*), contain toxic hydrogen cyanide in their tissues (Zagrobelny and Møller, 2011), and monarch butterfly (*Danaus plexippus*) larvae contain the cardiac glycoside cardenolide (Petschenka and Agrawal, 2015). Cardenolide manipulates the Na(+)/K(+)-ATPases, which can affect blood pressure and electrolyte balance (Patel, 2016b).

These allergens and venoms can provoke the human immune system in a myriad of ways. They can disrupt cell membranes, cleave tight junction proteins between the epithelial cells, manipulate the cytoskeleton, and induce cytokine proliferation (Chapman et al., 2007; Navarro-Garcia et al., 2010; Kempkes et al., 2014; Zhang et al., 2014). The immune activation can cause asthma, dermatitis, urticaria, sinusitis, rhinitis, otitis, etc. (Arshad, 2010), or even anaphylaxis (Asokananthan et al., 2002; Macan et al., 2003; Ichikawa et al., 2009; Ahmed et al., 2010). Insect venom causing mastocytosis (Bonadonna et al., 2010) has been documented. Females seem to be particularly hypersensitive to insect allergens due to their higher level of estrogen and better immune defense (Patel et al., 2018). Also, individuals with inflammatory diseases are more likely to show sensitivity toward the allergens as the host proteins are highly glycosylated and they recognize the insect proteins. It is an evolutionary adaptation to protect the stressed body from further threats by escalating immune surveillance. Like methylation of proteins is akin to an off switch, glycosylation, due to the presence of N- and O-linked oligosaccharides, alters protein properties. Reports are emerging that hyperglycosylation prolongs the circulation of coagulation factor IX (Bolt et al., 2012).

In silico analyses have revealed that all living organisms, viruses to humans and in between all, possess some evolutionarily conserved protein domains (Patel, 2017b). These motifs are pivotal in "offense and defense," and so are strictly conserved. Some of such virulent protein domains in insects include chitin-binding domain (ChtBD3) (Patel et al., 2017). The allergens often cause cross-reactivity, so the sensitive individuals should not consume insects (Pier and Lomas, 2017). Incidences of allergic reactions on consumption of silkworm pupae, cicadas, and crickets have been reported in China (Feng et al., 2018). Caterpillars, sago worm, locust, grasshopper, bee, etc., have also been associated with insect allergy (de Gier and Verhoeckx, 2018). The allergen proteins are so stable that even thermal processing and digestion cannot eliminate all of them (de Gier and Verhoeckx, 2018). So, food processing of the insects ought to be rigorous and the products should have warning labels like other allergy-inducing foods. Insect allergy is also a cause of occupational health problems. Systemic allergic reactions in beekeepers has been documented (Ludman and Boyle, 2015). Post-hire asthma instances among insect-rearing workers have been observed (Suarthana et al., 2012). Those rearing the insects ought to be aware of the risks (Pener, 2016). Both potential consumers and breeders ought to be cognizant of the risks of embracing insects, as the immune sensitization may not manifest immediately, but after a certain titer of IgE antibodies are formed. Once the antibodies are formed, and inflammasomes are activated, it takes years to restore the immune system homeostasis (Patel and Meher, 2016). Even after exposure to the allergens is discontinued, the health hazards continue to occur

Also, insects are vectors of human pathogens such as viruses (Campos et al., 2015), bacteria (Hager et al., 2006), protozoa (Takeo et al., 2009), fungi, and nematodes. Food pathogens such as *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium perfringens*, enterohemorrhagic *Escherichia coli*, *Listeria monocytogenes*, and *Salmonella* spp. have been found associated with crickets (Walia et al., 2018). Insects being protein dense often serve as substrates for fungal growth. Dried insects in Zambia have been detected with aflatoxin-producing fungi. Aflatoxins elaborated by *Aspergillus flavus* are carcinogenic (Barrett, 2005). In the study, above 10 μg/kg aflatoxin was detected in *Gynanisa maja*, *Gonimbrasia zambesina*, and *Macrotermes falciger* (Kachapulula et al., 2018). The insect families Muscidae, Glossinidae, Culicidae, and Phlebotominae are vectors for diarrhea, myiasis, sleeping sickness, filariasis, malaria, leishmaniases, and bartonellosis, among others (Burgess, 2010).

So, a complete risk assessment of the edible insects-based food candidates must be carried out, before recommending them for mass consumption (Belluco et al., 2015; Grabowski and Klein, 2016). In fact, the European Union (EU) has published an edible insect food safety guide (Robinson, 2015). Other publications also have discussed the risk and safety aspects (Marshall et al., 2016).

Fig. 2.2 presents the merits and demerits of insect-based foods.

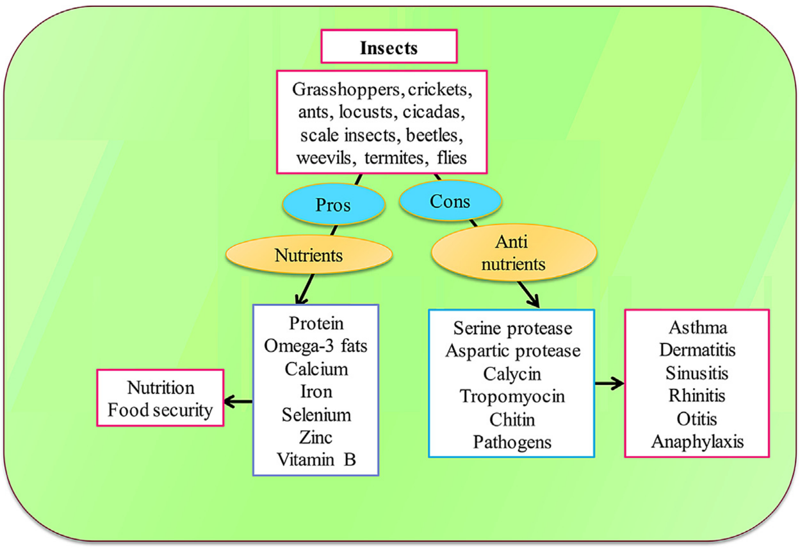

FIGURE 2.2 The merits and demerits of insect-based food.

2.4 LOOKING AHEAD AND DISCUSSION

Despite the hurdles in the path, insects as a sustainable food source are an optimistic prospect (Sun-Waterhouse et al., 2016). Food futurists believe that insects as an alternative protein source will claim a major niche in the next few years. The UN FAO is recommending the consumption of insects to mitigate food insecurity (Costa-Neto and Dunkel, 2016; Nowak et al., 2016). The US Department of Agriculture (USDA) is willing to fund edible insect research (LIGMAN, 2015). Entomoculturing and entomophagy is part of the "One World – One Health" (OWOH) movement as well (Yates-Doerr, 2015). United Nations (UN) and NGOs are promoting insect-based food availability in regions with food insecurity. Undernutrition-afflicted countries like Congo can benefit from insect-based foods. In a pilot study, school children were provided with biscuits containing 10% cricket powder (Homann et al., 2017). Another study in Nigeria determined the protein quality of common edible insects such as moth caterpillar, termite, cricket, and grasshopper, finding them to be substitutes for dietary protein (Oibiokpa et al., 2018).

China and Thailand have numerous insect farms, both small and medium enterprises, and industrial scale farms. Thailand is a leader at insect farming, with an estimated 20,000 food insect farms, mostly rearing crickets and palm weevils (Hanboonsong et al., 2013). Cricket farming in Thailand, Cambodia, Lao People's Democratic Republic (Lao PDR), the Democratic Republic of the Congo (DRC), and Kenya was studied, and in most countries their infancy status was reported (Halloran et al., 2018). In Latin America, chapuline farming is common, given its popularity as a food. The European Commission (EC) is also promoting the inclusion of insects in food (Finke et al., 2015). The Netherlands is open to the integration of insects in food (House, 2016) and insect farming practices are rising (De Goede et al., 2013). The Dutch populace are being motivated to include crickets, worms, and caterpillars as nutritious protein sources (Tagliabue, 2011). Canada-based Entomo Farms raises crickets and mealworms for food. The North American Coalition for Insect Agriculture (NACIA), comprises stakeholders who arrange conferences to promote insect agriculture. Many startups in California (United States) are selling insect-based food products. In fact, insect farming has been present in almost every continent, as animals in captivity and pets are fed with them. Now, with the new wave of insect-based food consumption by humans, the safety and hygiene dimensions are being emphasized, and human-grade insect farms are being set up. The edible insect business is now a more than $20 million industry (Hoffman, 2014). Entrepreneurs across the world are attempting to rear edible insects and to take them mainstream (Costa-Neto and Dunkel, 2016). Insects in the mass rearing facilities are prone to viral diseases, which requires adequate knowledge to avert the problem (Maciel-Vergara and Ros, 2017). To make insects into edible products, they are subjected to sun drying, freeze-drying, grinding, defatting, and acid hydrolysis (Kim et al., 2016). Each processing technique is likely to affect the biochemical composition of the insect biomass differently. In a study of sun-dried edible black ant, out of the 28 organic components, five were lost while four were formed. Fatty acids, aldehyde, and alkanes appeared during the sun drying (Li et al., 2009).

For the economic viability of insects in the food sector, better rearing, harvesting, and processing tools and techniques ought to be developed (Rumpold and Schlüter, 2013). Diet optimization for the insects can enhance their biomass. As genetic engineering has improved crop yield (Khan et al., 2013), the development of less immunogenic and more meat-containing edible insects by genetic manipulation can be very economical.

Nowadays, interested consumers are purchasing edible insects online. Mixed bag of grasshoppers, crickets, silk worms, and sago worms are marketed as energy snacks like granola bars. Cricket powder is sold and recommended to be mixed with flour for baking purposes. Chocolate-coated roasted crickets or mealworms, and insect lollipops are some of the innovative products being marketed. Even global leaders like Amazon are selling these products. Although at present there are only a handful of insect-based food traders, such as ecoEat, Don Bugito Prehispanic Snackeria, Mercado Mio, Newport Jerky Company, Hotlix, Merci Mercado, Candy Crate, Thailand Unique, EntoVida, and Meat Maniac, soon new establishments are likely to emerge. Renowned chefs are serving insect-laced recipes like cricket-sprinkled salads, mealworm lettuce wraps, cricket fried rice, mescal worm tacos, fried dragonflies, ant egg tostada, mealworm-peppered noodles, silkworm powder-flavored broth, etc. Cookbooks, featuring the culinary uses of insects are being published (Linn, 2014). Experimenting with insects has just begun and possibilities abound. In a study, sausage fortified with mealworm larvae and silkworm pupae was evaluated (Kim et al., 2016). In an insect-eating festival held in the Philippines, various agricultural pest insects were processed into chayote bars. rice cakes, burgers, sandwich fillers, etc., and presented to people (Sabado and Aguanta, 2014). In a festival in Switzerland, pizzas were served topped with mealworms and beetle larvae (Wallace, 2010). Even countries like the Czech Republic are showing interest in including insects in the diet (Bednarova et al., 2010).

Human societies are appearance-conscious. The same insect product that will be normally dismissed as repulsive might attract attention if it is claimed that it prevents obesity, skin wrinkles, hair loss, or restores fertility. Similarly, anticancer, antidiabetic, and immunity building claims can raise the acceptance of insect-based foods. It will not be surprising if traders adopt this path for profits. Silkworm moth (*B. mori* L.) larvae was being evaluated as an animal protein source for astronauts on space missions (Tong et al., 2011). Apart from silkworm, the hawkmoth, the drugstore beetle, and the termite are considered candidates for space agriculture (Katayama et al., 2008).

It appears that compared to the whole insects or their crushed forms, there is lower aversion and better prospects for acceptance for bioactives extracted from them. Insects elaborate proteins and AMP for immune defense (Slocinska et al., 2008; Ezzati-Tabrizi et al., 2013), which might be exploited as dietary supplements. Lipid extracted from meadow grasshopper (*C. parallelus*) was found to have an interesting fatty acid composition (Paul et al. 2015). However, the immunogenicity or immunosuppressive aspect of the extracted components must be addressed as not all proteins are benign and health-promoting, but can be perceived as antigens. Astaxanthin from krill is known to be an antioxidant. However, recent studies have revealed that astaxanthin by virtue of its oxidative stressor elimination might resolve immunopathology, but can exert an immune depressive effect (Dhinaut et al., 2017). Other studies have shown how astaxanthin feeding suppresses the expression of inflammatory cytokines, including nuclear factor (NF)-κB, tumor necrosis factor (TNF)-α, and interleukin (IL)-1β. While insects no doubt are protein-rich, the ingestion of inadequately prepared insects can cause immune activation and inflammatory diseases. The FDA and other regulatory bodies ought to keep a tab on unscrupulous merchandise and marketing.

Every new application of an object requires imparting education on the merits and demerits. In every element, there is a trade-off. If the risks are too high, the element is not worth applying for the new use. Some of the merits and demerits have been discussed earlier. Host factors are different, so the response to a substance can vary. Insects are allergenic as discussed previously. Therefore not all human beings are expected to fare well after insect consumption. The way a lot of people cannot consume seafood, shrimps, and crabs for hypersensitivity reasons (Lopata et al., 2010), some will not be fit to consume insects. However, different processing techniques might neutralize the allergens and make them amenable for mass consumption. In fact, if the allergenicity issue can be taken care of, insects can be a superfood, a way better substitute to canned, frozen, food additive-laced packaged foods. Ethnic people have been consuming them for a long time, and are thriving. To urban people in developed countries, insects are a novelty. Those who can savor shrimps or clams should not have a psychological issue with the consumption of insects. Apart from a sustainable protein source, insect farming can lower the burden on the environment, and can provide livelihood opportunities to many (Halloran et al., 2017). By choice, few people would have consumed insects, but protein requirements can lead to their consumption. Food insecurity looms, but the situation is still under control. Maybe in the next few decades, the availability of nutritious foods will be challenging, and insects will have to be coerced onto the human dietary platter. So, this time period ought to be directed towards the safety evaluation of insects, developing facilities, and processing the edible insects into human consumption-worthy food objects. In fact, future meat options are likely to include cultured meat and imitation meat, apart from insect meat (Alexander et al., 2017). Table 2.1 presents a list of insects that are or have been consumed in different regions of the world. This is a fraction of the actual list, as the exact picture is elusive and exhaustive.

TABLE 2.1 Some Common Edible Insects and Their Common Names

No.	Scientific Name	Common Name
1.	*Acheta domesticus*	House cricket
2.	*Agrotis infusa*	Bogong moth
3.	*Anabrus simplex*	Mormon cricket
4.	*Apis* spp.	Honey bees
5.	*Arsenura armada*	Giant silk moth
6.	*Atractomorpha psittacina*	Slant-faced grasshopper
7.	*Bombyx mori*	Silkworm moth
8.	*Brachytrupes membranaceus*	Tobacco cricket
9.	*Brontispa longissimi*	Coconut leaf beetles
10.	*Camponotus* spp.	Jet-black carpenter ants
11.	*Carebara vidua* Smith	Black ant
12.	*Cirina forda*	Pallid emperor moth

(*Continued*)

TABLE 2.1 (Continued)

No.	Scientific Name	Common Name
13.	*Chorthippus parallelus*	Meadow grasshopper
14.	*Coloradia pandora*	Pandora moth
15.	*Corcyra cephalonica*	Rice moth
16.	*Crocidolomia pavonana*	Cabbage worm
17.	*Crocothemis servilia*	Scarlet skimmer
18.	*Cybister tripunctatus*	Three-punctured diving beetle
19.	*Ephydra hians*	Alkali fly
20.	*Gonimbrasia zambesina*	Bulls eye silk moth
	Gonimbrasia belina	Emperor moth
21.	*Gryllotalpa africana*	Mole crickets
22.	*Gynanisa maja*	Speckled emperor
23.	*Hermetia illucens*	Black soldier fly
24.	*Holotrichia parallela* Motschulsky	Black chafer beetle
25.	*Hydrophilus olivaceous*	Water scavenger beetle
26.	*Hypopta agavis*	Tequila worm
27.	*Laniifera cyclades*	Nopal worm
28.	*Latebraria amphipyroides*	–
29.	*Leptocorisa oratorius*	Rice bug
30.	*Lethocerus indicus*	Giant water bugs
31.	*Liometopum apiculatum*	–
32.	*Locusta migratoria*	Locusts
33.	*Macrotermes falciger*	Termites
	Macrotermes natalensis	
	Macrotermes michaelseni	
34.	*Melophorus bagoti*	Honeypot ant
35.	*Odontotermes* sp.	Termites
36.	*Oecophylla smaragdina*	Red weaver ant
37.	*Omphisa fuscidentalis*	Bamboo borers
38.	*Oxya chinensis*	Chinese grasshopper
39.	*Patanga succincta*	Bombay locusts
40.	*Piophila casei*	Cheese fly

(*Continued*)

TABLE 2.1 (Continued)

No.	Scientific Name	Common Name
41.	*Polyrhachis vicina* Roger	Black ant
42.	*Protaetia brevitarsis seulensis*	White-spotted flower chafer
43.	*Rhynchophorus ferrugineus*	Asiatic palm weevil
	Rhynchophorus phoenicis	African palm weevil
44.	*Schistocerca gregaria*	Desert locust
45.	*Scotinophara coarctata*	Malaysian black bug
46.	*Sphenarium* sp.	Grasshoppers
47.	*Tribolium castaneum*	Red flour beetle
48.	*Verlarifictorus aspersus*	–
49.	*Xyleutes leucomochla*	Cossid moth
50.	*Zygaena* sp.	Burnet moth

CONCLUSION

Food trends keep evolving, and if certain impediments in the path of mass adoption of insect diet can be addressed, insects can become a substantial part of the human diet. Going by the significant spike in the number of publications on the potential of insects as human food, the rising interest and fund allocations, can be gauged. Research projects and partnerships are being forged and entrepreneurs are establishing insect farms and facilities. The interest in insects as human food has been stirred in academia, the food sector, as well as among the general public (Evans et al., 2015). It can be anticipated that insects can be a regular part of the food production chain in the next few years. Surveys, food fests, and symposia are being held to create consumer awareness and to familiarize people to the emerging novel edible protein source (Liu and Zhao, 2018). Chefs, insect farmers, and nutrition experts are collaborating to formulate novel insect-based food preparations. Despite the hurdles and genuine concerns, opinions are cohesive that insects have the potential to be used as a functional food source. If the above-voiced concerns can be resolved, and nutritional analyses optimized, insects can be a sustainable protein food source, and can generate an alternative food industry with less pressure on environmental resources.

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