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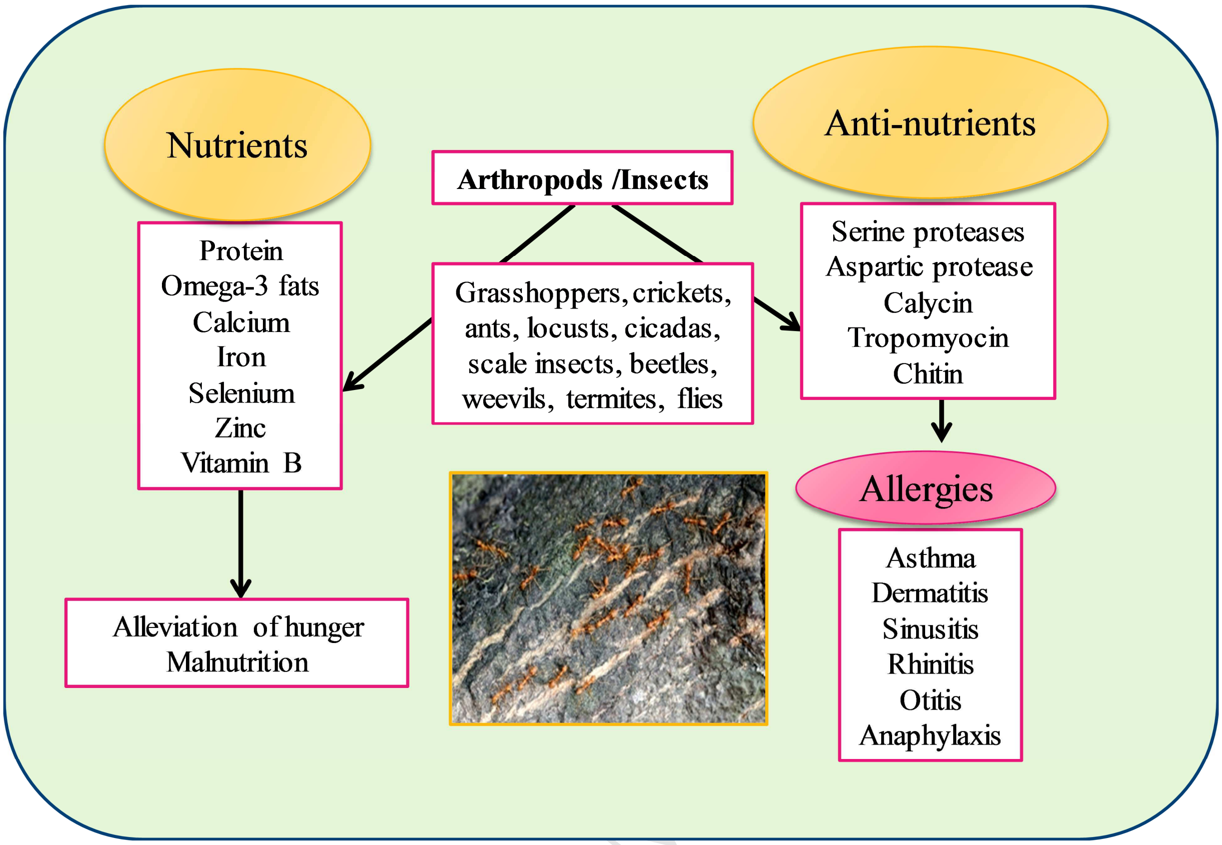
Nutrients
Arthropods /Insects
Anti-nutrients
Protein
Omega-3 fats
Calcium
Iron
Selenium
Zinc
Vitamin B
Grasshoppers, crickets, ants, locusts, cicadas, scale insects, beetles, weevils, termites, flies
Serine proteases
Aspartic protease
Calycin
Tropomyocin
Chitin
Allergies
Asthma
Dermatitis
Sinusitis
Rhinitis
Otitis
Anaphylaxis
Alleviation of hunger
Malnutrition

Edible insects as innovative foods: Nutritional and functional assessments

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Short running title: Edible insects as dietary components

Key words: Edible insects; Sustainable food; Protein; Allergen; Cultural taboo

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Abstract

In the face of rising population, food insecurity is emerging as a global challenge. Nutritious sources of food are frantically being searched for. Underutilized food candidates are being assessed for feeding the global population. In this regard, Arthropods, the largest phylum fits the bill, and holds tremendous promise, without harming the environment. Loaded in proteins, fat and minerals, the “edible insects” can alleviate hunger and malnutrition. In fact, in every country, entomophagy is practiced, though mostly among the low-income groups. However, few hiccups lie in the path of their popularization. Their allergenic tissues and pathogen-carrying traits impose threats to human health. Further, the aversion of the Western world towards the insects as a food article impedes their recognition as food. While some crustaceans as shrimp, lobsters, crabs, and krill are gourmet food articles, with high demand, the logicality of neglecting insects as likely food commodities appear to be a psychological perception. Researchers and global regulatory bodies are encouraging further investigations and inclusion of the edible-grade insects to diet. As this movement is at the early stages and given due impetus, it can play significant role in quenching world hunger and reducing the usage of lethal pesticides, this review has been woven around the objective of ‘insects as human food’.

Introduction

As world population surges ahead, food security becomes a gigantic challenge. Hunger and malnutrition is a perpetual problem of poverty-stricken regions. As nutritional deficiency is the root cause of numerous other pathologies, ensuring adequate nourishment for all, is an urgent need. In this regard, arthropods especially edible insects as a protein source is being mulled (Nadeau, Nadeau, Franklin, & Dunkel, 2015; Arnold van Huis et al., 2015). Some arthropods members, especially the crustaceans, are not only food, but are expensive delicacies. Crabs, lobsters, prawns, and shrimps are farmed and exported for their overwhelming demands (Hadley, 2006). The marine crustacean krill (*Euphausia superba*) oil is emerging as a pharmaceutical agent and a substitute of fish oil, owing to its high omega-3 fatty acids, choline and antioxidant astaxanthin contents (Barros, Poppe, & Bondan, 2014; Maki et al., 2009). Bee (*Apis* sp.)-regurgitated honey, pollen and propolis are expensive dietary supplements (Al-Hariri, 2011; Patel, 2016a; Rossano et al., 2012; Silva-Carvalho et al., 2014). Fried honey bees are deemed a delicacy in parts of China. Fig. 1A shows a beehive on a tree. Apiculture is a popular livelihood practice. The scaly cochineal insects (*Dactylopius coccus*) growing on prickly pear cacti are the source of red dye carmine, used in wide array of food products including yoghurts, candies, cupcakes, coffees (Voltolini, Pellegrini, Contatore, Bignardi, & Minale, 2014). The pigment carminic acid is the source of the red dye. In countries like Mexico, these insects are farmed (De León-Rodríguez, González-Hernández, Barba de la Rosa, Escalante-Minakata, & López, 2006; Ramos-Elorduy et al., 2011).

Other arthropods are not as mainstream food items, though they have been significant part of diet across different cultures. Entomophagy is practiced in countries spanning almost all continents (Raubenheimer & Rothman, 2013). The eggs, larvae, pupae, and adults of several arthropods, especially edible insects, are consumed in different forms. Ethnic groups have been consuming them since ages.

Apart from the nutritional benefits of edible arthropods, especially edible insects, consumption, they have suddenly caught the attention of food development and regulation bodies for other potent reasons. It is unanimously agreed that edible insects can provide ecological and economic advantages as well. These edible insects can be a cheaper substitute of the expensive animal proteins. It can bolster the fragile food supply. Edible insects farming can reduce the pressure from agriculture, aquaculture and animal husbandry, by requiring less turnover time, land, water or feed (Premalatha, Abbasi, Abbasi, & Abbasi, 2011). Also, consumption the arthropod/edible insects, which are the major agricultural pests, can lead to low usage of pesticides. These chemicals are polluting the environment, triggering a wide array of human illnesses. So, eradicating the pests by ingesting them, appears to be a very promising solution. This new energy-efficient, sustainable way of growing food is exciting but beset with pragmatic issues such as pathogenic microorganisms, anti-nutritional factors, allergenicity, and most importantly consumer distaste. Hence, this review discusses the possibilities and pitfalls of 'edible insect as future human food'.

Arthropods/edible insects as dietary component across the globe

Literature search reveals that consuming arthropods/edible insects is not unique to a geographical region but is a pervasive practice. Almost all Native American and Latin American tribes subsisted on insects (Navarro, Prado, Cárdenas, Santos, & Caramelli, 2010). Kutzadika people inhabiting the Mono Lake region of California ate kutzavi, the alkali fly (*Ephydra hians*) pupae (Fig 1D). One variation of the preparation was named ‘cuchaba’. The Maidu people (Digger Indians) of Northern California consumed jet-black carpenter ants (*Camponotus* spp.). Paiute Indians inhabiting California's Owens Valley consumed Pandora moth (*Coloradia pandora*) larvae. Mealy plum aphid (*Hyalopterus pruni*)-exuded honeydew was harvested by some Native Indian tribes for usage as sugar. Mormon cricket (*Anabrus simplex*), a crop-destroying katydid swarm was another food item for people in Midwest of the USA. In countries like Thailand, and Cambodia, they relish arthropods like grasshoppers, crickets, ants, bamboo borers (*Omphisa fuscidentalis*), palm weevil larvae, and scorpions (Hanboonsong, Jamjanya, & Durst, 2013). Fig. 1E and 1F shows crickets and grasshoppers on garden plants. In Bangkok, these insects are sold in markets which travelers try as exotic foods. Spiders are relished by some in Vietnam. In Laos, several ethnic groups consume weaver ant eggs, bamboo worms, crickets, and wasps (Barennes, Phimmasane, & Rajaonarivo, 2015). In India, red ants, hornets, and termites are consumed by some tribes. Red weaver ant (*Oecophylla smaragdina*) chutney (a condiment), known as ‘chapura’ is a delicacy among tribal in Central India. Fig. 1B shows the ants on a tree. In North East India hornet (*Vespa* sp.) grubs are consumed. In Arunachal Pradesh, tribal like Nyishi, Galo, Nocte, Shingpo, Tangsa, Deori and Chakma of Arunachal Pradesh consume many insects from Coleoptera, Orthoptera, Hemiptera, Hymenoptera, Lepidoptera, Isoptera, Ephemeroptera, Odonata and Mantodea orders (Chakravorty, Ghosh, & Meyer-Rochow, 2011, 2013). Common red tree dwelling weaver ant (*Oecophylla smaragdina*) and termites (*Odontotermes* sp.) consumed by the tribals were found to be nutrient-dense (Chakravorty, Ghosh, Megu, Jung, & Meyer-Rochow, 2016). Chapulines, the grasshoppers (*Sphenarium* sp.) are relished in parts of Mexico and Central America (Handley et al., 2007). Even, these fried insects are sold as snacks. Other insect genera to be of food importance in Mexico include Phassus, nopal worm (*Laniifera cyclades*), *Latebraria* *amphipyroides*, *Arsenura armada*, and *Spodoptera* spp. (Ramos-Elorduy et al., 2011). Mezcal, a distilled alcoholic beverage made from the maguey plant (*Agave americana*) is served with a larva of a moth tequila worm (*Hypopta agavis*) (De León-Rodríguez et al., 2006). A survey of locals in Bondo district of Kenya revealed that they consume onyoso mammon (ant), oyala (termite), ogawo (termite), agaor (termite), and onjiri mammon (cricket). These insects had good quantity of iron (18 to 1562 mg/100), zinc (8 to 25 mg/100 g) and calcium (33 to 341 mg/100 g), the often deficient nutrients in this region (Christensen et al., 2006). An emperor moth (*Gonimbrasia belina*) caterpillar, known as the mopane worm is consumed in Southern Africa (Okezie, Kgomotso, & Letswiti, 2010). African palm weevil (*Rhychophorus phoenicis*) larvae are consumed by some tribes. Biochemical assays of the deffated larvae revealed the composition to be of 66.3% protein, 1,025 mg/100 g potassium and 685 mg/100 g phosphorus (Elemo, Elemo, Makinde, & Erukainure, 2011). The Azande and Mangbetu people of Congo relish the termites or 'white ants' (Arnold van Huis, 2017). The Pangwe people in Guinea, Gabon, and Cameroon gather aquatic larvae of dragon flies. In Nigeria, a termite species *Macrotermes natalensis*, African cricket, *Brachytrupes membranaceus*, and pallid emperor moth *Cirina forda* are popular insect foods (Agbidye, Ofuya, & Akindele, 2009). In Carnia region of Italy, moths of the Zygaenidae family, such as *Zygaena* are eaten as seasonal delicacy. Among European countries, the Netherlands is open to the integration of insects in food (House, 2016). Australian Aborigines traditionally subsisted on Bogong moth (*Agrotis infusa*), larvae of cossid moth (*Xyleutes leucomochla*), and honeypot ant (*Melophorus bagoti* Lubbock and *Campanoyus* spp.) (Warrant et al., 2016). The leafcutter ant (*Atta laevigata*, *Atta cephalotes*, and *Atta sexdens*) is eaten in parts of Colombia and Brazil. The adult beetle (*Holotrichia parallela* Motschulsky) is traditionally consumed in China. On nutritional analysis, the beetle tissue was found rich in protein (70%) and minerals (Yang et al., 2014). Traditional Chinese Medicine (TCM) formulations include cicada chitin (Seabrooks & Hu, 2017). As per a study, hundreds of insect species spanning 96 genera, 53 families and 11 orders, which encompass eggs, larvae, pupae and adults, are consumed in China, by frying, stewing, boiling and braising (Chen, Feng, & Chen, 2009). In Japanese culture, many insects are relished and even served in restaurants. Some popular once include hachinoko (boiled wasp larvae), sangi (fried silk moth pupae) and zazamushi (aquatic insect larvae), semi (fried cicada) and inago (fried grasshopper) (Césard, Komatsu, & Iwata, 2015). Casu Marzu (putrid cheese), a traditional Sardinian sheep milk cheese, as its name suggests includes maggots containing live larvae of cheese fly (*Piophila casei*), a part of the cheese fermentation process. This cheese has been found very rich in bioactive compounds γ-aminobutyric acid (GABA) (Manca et al., 2015). Acorns from a variety of oak trees are consumed as flour, after leaching the tannin part out. Some of the acorns are inhabited by the larvae of acorn weevils (*Curculio* sp.). These larvae arerich in fat and protein, which foragers consume. Insects induce gall formation in leaves of several plants. Leaf galls are induced in zebrawood (*Pistacia integerrima*) by chalcidoid wasps (Samra, Ghanim, Protasov, Branco, & Mendel, 2015). These galls have folkloric usage as asthma, diarrhea, psoriasis, fever, liver disorders therapeutics, among others (Uddin, Rauf, Al-Othman, et al., 2012; Uddin, Rauf, Arfan, et al., 2012; Ullah et al., 2014). Abundance of monoterpenes in the galls offer antimicrobial effects (Gerchman & Inbar, 2011; Rand, Bar, Ben-Ari, Lewinsohn, & Inbar, 2014). Fig. 1C shows galls in oak trees. Even stink insects (Hemiptera order) are consumed. The taste of the insects varies depending on the biochemical composition and preparation process. The processing ways of the edible insects for eating purposes include drying, smoking, steaming, blanching, roasting, and cooking (Chen et al., 2009). The consumers describe the foods to vary in taste from mushy, soft, to crispy, crunchy. The flavors have been described as chicken-like, herring-like, almond-like, potato-like etc. Honey, cake, beverage flavoring, drinks among other usages of insects have been documented. The consumption of edible insects in various forms far exceed the meager published literature. The information presented here are just a miniscule fraction of the edible insects in nourishing human throughout the course of evolution. Books can be referred to for further information on ethnic food habits encompassing insects (Bodenheimer, 1951; Costa-Neto & Dunkel, 2016). With the availability of other food sources, arthropods/edible insects disappeared from the food platter. Fig. 1 shows some edible insects **(A**) Honey-containing beehive on a fig tree (B) Red ants on mango tree bark (C) Wasp galls on scrub oak tree (D) Alkali flies on the shore of Mono lake (E) Cricket on lily plant (F) Juvenile grasshopper on hibiscus plants.

As nutritious food availability becomes increasingly difficult, Food and Agriculture Organization (FAO) is planning and suggesting the consumption of insects (Nowak, Persijn, Rittenschober, & Charrondiere, 2016). European Commission (EC) is also considering its increased usage in food. These endorsements are supported due to the high protein, micronutrients, and 'feed conversion ratio' of the edible insects (Nowak et al., 2016). Though the wriggling caterpillars or filthy-looking adult arthropods/edible insects do not appear as food in first glance, human diet is all about learned food practices and acquired tastes. These aspects have been discussed later in details.

Inherent risks of entomophagy

Among issues that mar the food potential of arthropods/edible insects, their allergenicity and pathogenicity risks are worth-assessing. House dust mites (*Dermatophagoides pteronyssinus*), cockroaches (*Blatella germanica*, *Periplaneta americana*), bees, crustaceans, and moths have large repertoires of allergens that provoke IgE-mediated hypersensitivity in predisposed individuals (Arlian, 2002; Kim & Hong, 2007; Okezie et al., 2010). Insect allergy has been a major cause of occupational health problem. Systemic allergic reactions in beekeepers has been documented (Ludman & Boyle, 2015). These allergens belongs to the biochemical class of serine proteases (trypsin, chymotrypsin, collagenase) (Dumez et al., 2014; Sudha, Arora, Gaur, Pasha, & Singh, 2008; H Wan et al., 2001), aspartic protease, chitinases, calycin, troponin, tropomyosin, arylophorin, glutathione-S-transferase, and chitin (Arlian, 2002; Hindley et al., 2006; Jeong, Hong, & Yong, 2006; Kim & Hong, 2007; Reese, Ayuso, & Lehrer, 1999). These allergens disrupt cell membranes, cleave tight junction proteins (occludins) between epithelial cells, induce cytokine proliferation, and provoke immune cell infiltration, among an array of other immune manipulations (Chapman, Wünschmann, & Pomés, 2007; Kempkes, Buddenkotte, Cevikbas, Buhl, & Steinhoff, 2014; Zhang, Zeng, & He, 2014). Chitin, the arthropod exoskeleton is known to trigger tissue inflammation by activating the expression of host chitinases (Da Silva, Pochard, Lee, & Elias, 2010; Wang et al., 2013). Asthma, dermatitis, urticaria, sinusitis, rhinitis, otitis etc. result from the exposure to these allergens (Arshad, 2010). Some of the allergens are capable of causing anaphylaxis as well (Ahmed, Minhas, Namood-E-Sahar, Aftab, & Khan, 2010; Asokananthan et al., 2002; Ichikawa et al., 2009; Macan, Plavec, Kanceljak, & Milkovic-Kraus, 2003). This severe allergy is the resultant of the manipulation of human cytoskeletal elements like actin which controls autophagy, endocytosis, endosomal maturation, among other critical functions (Navarro-Garcia, Sonnested, & Teter, 2010). Scorpion and spider venoms are chymotrypsin-like serine proteases that can cause skin necrosis, human blood coagulation and death (Devaraja, Nagaraju, Mahadeswaraswamy, Girish, & Kemparaju, 2008; Louati, Zouari, Miled, & Gargouri, 2011; Veiga et al., 2000). The allergens arginine kinase, glyceraldehyde 3-phosphate dehydrogenase hemocyanin were detected in *Macrobrachium rosenbergii* (giant freshwater prawn) while the allergen hexamerin1B was detected in *Gryllus bimaculatus* (field cricket) (Srinroch, Srisomsap, Chokchaichamnankit, Punyarit, & Phiriyangkul, 2015). Arthropod body fluids also have protease inhibitors, belonging to β-barrel fold, knottins, and Bowman–Birk family. Knottins exist as antimicrobial proteins in plants, some examples being thionins (Taveira et al., 2016), defensins (Ermakova et al., 2016; Tantong et al., 2016), cyclotides, 2S albumin-like proteins, lipid transfer proteins (LTPs), and knottin-peptides (Nguyen et al., 2015). A conserved domain in this protein topology include a cysteine-rich domain Knot1, which occurs in arthropod defensins (Gracy et al., 2008). The arthropod protease inhibitors can be of Kazal-type (termite) (Ohmuraya &

Yamamura, 2011) or Kunitz-type (spider, tick) (Chmelar, Calvo, Pedra, Francischetti, & Kotsyfakis, 2012; Liu et al., 2015). These inhibitors are capable of blocking human chymotrypsin, elastase, and plasmin (Negulescu et al., 2015; Hu Wan et al., 2013). Some moths and butterflies contain toxic hydrogen cyanide in their tissues, as result of feeding on cyanogenic plants. Burnet moths (*Zygaena filipendulae*) are one of such insects that can metabolize cyanogenic glucosides linamarin and lotaustralin from the Fabaceae family plants (Zagrobelny & Møller, 2011). Monarch butterfly (*Danaus plexippus*) larvae feed on common milkweed (*Asclepias syriaca* L.), which causes the accumulation of plant cardenolide in the butterflies (Petschenka & Agrawal, 2015). As cardenolide is a type of cardiac glycoside, birds avoid devouring on these butterflies. So, if human consumes these butterflies, they are likely to be harmful, by meddling with sodium-potassium pumps (Na^+/K^+-ATPase) (Ogawa, Shinoda, Cornelius, & Toyoshima, 2009).

As all organic material are susceptible to pathogenic contamination, the microbial analysis of the food item is required. Improper handling and rearing of arthropods might increase the chance of contracting the infections. Several arthropods/edible insects carry pathogenic viruses (Campos, Bandeira, & Sardi, 2015), bacteria (Hager et al., 2006), protozoa (Takeo et al., 2009), fungi, and nematodes. Arthropods are vectors for a large number of zoonotic diseases such as malaria, Lyme disease. Also, insects are parasitized by fungi, exposure to the mycotoxins of which can be perilous for human health. The *in silico* analysis of cockroach allergens showed the phylogenetic conservation of the quintessential virus, and bacteria virulence domains such as AAA, BRLZ, BTAD, ChtBD3, HALZ, HAMP, HELICc, Hr1, LRRCT, RAB, RUN, Tryp_SPc, WR1, VKc, and VWC among others (Patel, 2016b). Details on these pathogenesis-mediating protein domains can be obtained from SMART (Simple Modular Architecture Research Tool) website (Ponting, Schultz, Milpetz, & Bork, 1999). In this regard, various forms of insect products were analyzed. The dried and powdered forms had higher counts of microbes than the deep-fried, spiced and cooked ones. The dried products had coliforms, *Serratia liquefaciens*, *Listeria ivanovii*, *Mucor* spp., *Aspergillus* spp., *Penicillium* spp., and *Cryptococcus neoformans* (Grabowski & Klein, 2016). Another heating step of these products might fix the pathogenesis risk. Chapuline consumption has been associated with lead poisoning (Handley et al., 2007).

Fig. 2 presents some nutrients, allergens and anti-nutrients in arthropods. Attractive nutritional composition of a food commodity is not enough if they lack in safety. So, the complete risk assessment of the edible insects-based food candidate must be carried out, before recommending for food (Grabowski & Klein, 2016). As the inclusion of insects in food platter increases, EU edible insect food safety guide has been published (Robinson, 2015).

Current scenario and scopes of entomophagy

This section presents the current state of entomophagy, undergoing research efforts, and scopes ahead. Mealworms, the larvae of the mealworm beetle (*Tenebrio molitor*) are some of the top suggested insects of food candidature (Nowak et al., 2016). These insects are reported to be high in protein, polyunsaturated fats, and minerals (copper, sodium, potassium, iron, zinc and selenium). This Coleoptera beetle could be bred on bocaiuva (*Acrocomia aculeata*) pulp flour (Alves, Sanjinez-Argandoña, Linzmeier, Cardoso, & Macedo, 2016). The larva of the coconut borer (*Pachymerus nucleorum*) could also be grown on the bocaiuva fruit kernel (Alves, Sanjinez Argandoña, Linzmeier, Cardoso, & Macedo, 2016). Among other insect candidates, common housefly *(Musca domestica*), the black soldier fly (*Hermetia illucens*), locusts (*Locusta migratoria, Schistocerca gregaria, Oxya spec*., *Pachytylus migratorius* etc.) and silkworms (*Bombyx mori*) are prominent. This standing arises from their biomass, and amino acid composition (Stamer, 2015). Housefly and black soldier fly, for their interesting nutritional composition were suggested promising for feline and canine foods (Bosch, Zhang, Oonincx, & Hendriks, 2014).

Going by the published literature, the topic of 'arthropods/edible insects as food candidate' has garnered huge amount of attention in the past few years. Surveys, panel tests, food fests, and symposiums have led to immense insights. Arthropods especially some of the edible insects are consumed by billions of people worldwide, mostly in low-income countries. The need to supplement their low-nutrient diet has led to the inclusion of the insects, since ages. Like most habits, it has become inherent part of their subsistence now. Western world has access to other sources of nutrients, so entomophagy is rather new to them. Though lobsters, shrimp, crayfish, crabs are relished. Based on the research findings, it is agreed that revulsion towards the edible insects-based food is the result of mindset. Disgust, a psychological conditioning, rejects the creepy-crawlies as edibles (Hamerman, 2016; Menozzi, Sogari, Veneziani, Simoni, & Mora, 2017). Food neophobia, the tendency to decline novel or unknown foods is a common human trait (Demattè, Endrizzi, & Gasperi, 2014). Arthropod especially edible insects based-food neophobia is particularly high (Caparros Megido et al., 2016). Females were particularly averse towards the insect-based food (Caparros Megido et al., 2016). They preferred beef burgers over insect burgers (Caparros Megido et al., 2016). Masking the gross looks or promoting in a appealing name has often improved the acceptance of a food by the consumers. Incorporation of the minced insects into ready-to-eat preparations and frequent exposure in the form of food fests etc. is suggested as steps to reduce the repulsion (Caparros Megido et al., 2016). Another study also reports that communicating with potential consumers regarding the environmental benefits of eating edible insects products positively modulates their ingestion propensity (Verneau et al., 2016). Educational campaigns can prime people for adopting entomophagy and can help them overcome their repulsion (Costa-Neto & Dunkel, 2016; Hamerman, 2016). Some researchers suggest the name 'Shrimp of the land' for some insects, as a way to make them appear appetizing. Usage of the terms 'novelty foods', 'super foods', 'low carbon footprints' might be catalyst in gaining public approval as well. Many of the abhorred foods of the past are expensive, popular specialty foods now, such as truffles (Patel, 2012a), huitlacoche (Patel, 2016c), quinoa (Maradini Filho et al., 2015), seaweeds (Patel, 2012b), krill oil (Tandy et al., 2009), among others. The French are known to relish frog legs, and snake wine is popular in several South Asian countries.

Another big hurdle in popularity of insect-based foods is their standing as culturally-inappropriate (Tan, Fischer, van Trijp, & Stieger, 2016). Many religions insist on 'kosher', 'halal', 'vegan' (Costa-Neto & Dunkel, 2016; Fischer, 2008), and these creatures do not fall in that groups. The judgments towards the insect-based foods are made based on these rules as well as conventional eating habits (Tan et al., 2015). Beyond sensory liking, a broader mindset is needed to accept the edible insects as food (Tan et al., 2016). A study based the reaction of Chinese and German testers to cricket-based food was conducted. For their cultural habits, the Chinese testers were open to the products, while the Germans were less willing to try. However, it was found that adequate processing of the insects encouraged their eating (Hartmann, Shi, Giusto, & Siegrist, 2015). In a blind sample tasting encompassing 97 young adults, insect burger received similar response as plant-based burgers (Schouteten et al., 2016). Another study based on cricket-based snacks reflected that the degree of processing influenced the willingness to consume them. The testers preferred the flour and bits of the insect-based snacks than the products mixed with other ingredients (Gmuer, Nuessli Guth, Hartmann, & Siegrist, 2016). Based on the finding, the researchers suggested that the establishments promoting insect-based food ought to attempt to understand the consumer psychology, preferences and modulate their preparation strategies accordingly (Gmuer et al., 2016). For increasing consumer appeal, innovative developments of insect-based foods are suggested essential by researchers (Shelomi, 2015). In an exposition in Milan, Italy in 2015, the attitudes of various countries on insect-based foods was presented (Shelomi, 2016). While Angola (Africa) showcased certain insects as part of their traditional cuisine, European countries like Belgium and the Netherlands presented their vision of insect-based food development (Shelomi, 2016). Legislatives supporting them as edible and nutritious can play a big role in their wider popularity (Van Huis & Dunkel, 2017). In fact, a survey of consumers in Kenya, regarding termite-based food products, received a better affirmative response, when the product was recommended by officials (Alemu, Olsen, Vedel, Pambo, & Owino, 2017). Many startups, even in Western world such as California (USA), British Columbia (Canada), are offering edible insect-based food products.

Increasing number researchers are optimistic regarding the potential of insects as a sustainable food source (Sun-Waterhouse et al., 2016). The generation of insect-based protein powder is predicted to be environmentally beneficial than convention protein-rich food products (Smetana, Palanisamy, Mathys, & Heinz, 2016). For sustainable production of the arthropods especially edible insects, rearing and harvesting is crucial (Costa-Neto & Dunkel, 2016). Thailand is at the forefront of farming food-grade insects, such as crickets and palm weevils (Hanboonsong et al., 2013), while countries like the Netherlands are following suit. As per an article, by 2014, edible insect business has already swelled into a $20 million industry (Hoffman, 2014). Yet, entomo-culture is a new area, and need to be researched. Mass-rearing, and post-harvest technologies need to be developed (Rumpold & Schlüter, 2013). Given the low cost involved in the insect farming, it can be a livelihood opportunity for people in low-economy regions. Entomo-culturing and entomophagy even falls within the scope of 'One World - One Health' (OWOH) movement (Yates-Doerr, 2015). This movement encourages collaborations to mitigate global threats (Gibbs and Anderson 2009).

Relevance of entomophagy

Many of the arthropod ingestion habit started to get rid of the nuisance insects or plantation pests, such as the red ants, grasshoppers, and locusts. Also, during the hunter-gatherer phase of evolution, human did not have much choice of food, unlike now. Starved of food, they had developed the habit to supplement their food with locally- and seasonally-available insects. Over a long period of time, they acquired a taste for them. Even today, iron-deficient individuals suffering from a condition ‘pica’ eat insects, among other random, non-food things (Advani, Kochhar, Chachra, & Dhawan, 2014). The above fact has been mentioned to relate that in the past, before agriculture and industrialization, when food was in scanty, hunger forced mankind to feed on diverse nutritional sources. However, with the progress of civilization ample food options led to the decline in entomophagy practice.

Like most problems in science, entomophagy is a novel idea with pros and cons. While several of them are good sources of nutrition, especially proteins, they are endowed with health risks too. Most of them have chitin and human cytoskeleton-manipulating enzymes. May be proper cooking techniques can deactivate the allergenic proteins. Still individuals atopic to them ought to avoid them. People tolerant to the arthropods especially edible insects can benefit from them as a source of nutrition. Entomophagy can rise in popularity, if comparative studies on the nutritional value of food-grade edible insects and other nutritious food sources, such as animal proteins, are conducted.

Otherwise, this invertebrate phylum is the most successful and abundant in the globe, dominating soil, water and air. Learning ways to add them to food platter can be a significant solution in the face of the 'food dearth'. Also, this present 'taboo' is judged to be more nutritious and less toxic than many of current market foods, replete with chemicals additives, antibiotics and hormones. For example, synthetic food dyes prevalent in processed food are made from coal tar sludges. Attention deficit hyperactivity disorder (ADHD) in children has been consistently linked to these artificial dyes in foods (Rippere, 1983).

Suggesting novel foods, based on arthropods/edible insects, might be an interesting area in food development. Generalization does not hold true in any science concept. Similarly, arthropods might not be entirely unsuitable or suitable for food. May be not all, but certainly some insects are worth incorporating into food, as proven by a myriad studies. Their processing routes and the dosage consumed are important determinants in this regard.

Ultimately, just like personal choices of non-vegetarian, vegan or vegetarian mode of eating, the adoption of entomophagy depends on the consumer. When it comes to food, like religion, the views are fiercely guarded. The same individuals, who relish shrimps, doling out a large sum on these foods, can be averse at the thought of eating crickets. Some cultures dislike mushrooms, while others enjoy penicillium-fermented blue cheese. Some people enjoy the tripe, and snouts of animals, while others shiver at the mention of it. Expecting everybody to eat insect-based food is naive. But in the impoverished region with food shortage, encouraging the farming of edible insects can be life-saving, and economy-boosting. Farming of the arthropods especially edible insects are easy for their high fecundity, and less required space. The high turn-over rate and the maximum utilization of space renders ‘food-grade edible insects rearing’ a lucrative option.

Perception of the Western World towards this dietary choice should not matter much, as they are not facing the same constraints of food insecurity. Of course, the entomophagous groups ought to be educated regarding the risks of handling allergeniferous and pathogen-transmitting arthropods. To gather more epidemiological data of the ill-effects of arthropod consumption, additional surveys, case studies and cohort assessments ought to be conducted. Funding bodies are providing funds to research on this aspect. In coming times, significant improvement in the usage of the arthropods especially edible insects as alternative nutrition source is expected to escalate. In this arrangement, everybody wins, and environmental balance can be restored.

Conclusions

'An individual's perception of bizarre food is nutritious delicacy for another individual'. Edible insects symbolize this truth. For thousands of years, mankind has derived nourishment from these critters. They hold enormous potential to be developed as food. However, safety evaluations are needed. If researchers find ample nutritional benefits, with negligible risks, overcoming the feeling of 'disgust' will not be difficult. This review is likely to be a groundwork for that vision.

Declaration

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References

Advani, S., Kochhar, G., Chachra, S., & Dhawan, P. (2014). Eating everything except food (PICA): A rare case report and review. *Journal of International Society of Preventive & Community Dentistry*, *4*(1), 1–4. https://doi.org/10.4103/2231-0762.127851

Agbidye, F. S., Ofuya, T. I., & Akindele, S. O. (2009). Some edible insect species consumed by the people of Benue State, Nigeria. *Pakistan Journal of Nutrition*, *8*(7), 946–950. https://doi.org/10.3923/pjn.2009.946.950

Ahmed, A., Minhas, K., Namood-E-Sahar, Aftab, O., & Khan, F. S. (2010). In Silico Identification of Potential American Cockroach (Periplaneta americana) Allergens. *Iranian Journal of Public Health*, *39*(3), 109–15. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3481629&tool=pmcentrez&rendertype=abstract

Al-Hariri, M. T. (2011). Propolis and its direct and indirect hypoglycemic effect. *Journal of Family & Community Medicine*, *18*(3), 152–4. https://doi.org/10.4103/2230-8229.90015

Alemu, M. H., Olsen, S. B., Vedel, S. E., Pambo, K. O., & Owino, V. O. (2017). Combining product attributes with recommendation and shopping location attributes to assess consumer preferences for insect-based food products. *Food Quality and Preference*, *55*, 45–57. https://doi.org/10.1016/j.foodqual.2016.08.009

Alves, A. V., Sanjinez-Argandoña, E. J., Linzmeier, A. M., Cardoso, C. A. L., & Macedo, M. L. R. (2016). Food Value of Mealworm Grown on Acrocomia aculeata Pulp Flour. *PloS One*, *11*(3), e0151275. https://doi.org/10.1371/journal.pone.0151275

Alves, A. V., Sanjinez Argandoña, E. J., Linzmeier, A. M., Cardoso, C. A. L., & Macedo, M. L. R. (2016). Chemical Composition and Food Potential of Pachymerus nucleorum Larvae Parasitizing Acrocomia aculeata Kernels. *PLOS ONE*, *11*(3), e0152125. https://doi.org/10.1371/journal.pone.0152125

Arlian, L. G. (2002). Arthropod allergens and human health. *Annual Review of Entomology*, *47*, 395–433. https://doi.org/10.1146/annurev.ento.47.091201.145224

Arshad, S. H. (2010). Does exposure to indoor allergens contribute to the development of asthma and allergy? *Current Allergy and Asthma Reports*, *10*(1), 49–55. https://doi.org/10.1007/s11882-009-0082-6

Asokananthan, N., Graham, P. T., Stewart, D. J., Bakker, A. J., Eidne, K. A., Thompson, P. J., & Stewart, G. A. (2002). House dust mite allergens induce proinflammatory cytokines from respiratory epithelial cells: the cysteine protease allergen, Der p 1, activates protease-activated receptor (PAR)-2 and inactivates PAR-1.

Journal of Immunology (Baltimore, Md. : 1950), *169*(8), 4572–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12370395

Barennes, H., Phimmasane, M., & Rajaonarivo, C. (2015). Insect consumption to address undernutrition, a national survey on the prevalence of insect consumption among adults and vendors in Laos. *PLoS ONE*, *10*(8). https://doi.org/10.1371/journal.pone.0136458

Barros, M. P., Poppe, S. C., & Bondan, E. F. (2014). Neuroprotective properties of the marine carotenoid astaxanthin and omega-3 fatty acids, and perspectives for the natural combination of both in krill oil. *Nutrients*, *6*(3), 1293–317. https://doi.org/10.3390/nu6031293

Bodenheimer, F. S. (1951). Australia. In *Insects as Human Food* (pp. 70–136). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-6159-8_3

Bosch, G., Zhang, S., Oonincx, D. G. A. B., & Hendriks, W. H. (2014). Protein quality of insects as potential ingredients for dog and cat foods. *Journal of Nutritional Science*, *3*, e29. https://doi.org/10.1017/jns.2014.23

Campos, G. S., Bandeira, A. C., & Sardi, S. I. (2015). Zika Virus Outbreak, Bahia, Brazil. *Emerging Infectious Diseases*, *21*(10), 1885–6. https://doi.org/10.3201/eid2110.150847

Caparros Megido, R., Gierts, C., Blecker, C., Brostaux, Y., Haubruge, É., Alabi, T., & Francis, F. (2016). Consumer acceptance of insect-based alternative meat products in Western countries. *Food Quality and Preference*, *52*, 237–243. https://doi.org/10.1016/j.foodqual.2016.05.004

Césard, N., Komatsu, S., & Iwata, A. (2015). Processing insect abundance: trading and fishing of zazamushi in Central Japan (Nagano Prefecture, Honshū Island). *Journal of Ethnobiology and Ethnomedicine*, *11*, 78. https://doi.org/10.1186/s13002-015-0066-7

Chakravorty, J., Ghosh, S., Megu, K., Jung, C., & Meyer-Rochow, V. B. (2016). Nutritional and anti-nutritional composition of Oecophylla smaragdina (Hymenoptera: Formicidae) and Odontotermes sp. (Isoptera: Termitidae): Two preferred edible insects of Arunachal Pradesh, India. *Journal of Asia-Pacific Entomology*, *19*(3), 711–720. https://doi.org/10.1016/j.aspen.2016.07.001

Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. (2011). Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (North-East India). *Journal of Ethnobiology and Ethnomedicine*, *7*(1), 5. https://doi.org/10.1186/1746-4269-7-5

Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. B. (2013). Comparative survey of entomophagy and entomotherapeutic practices in six tribes of eastern Arunachal Pradesh (India). *Journal of Ethnobiology and Ethnomedicine*, *9*, 50. https://doi.org/10.1186/1746-4269-9-50

Chapman, M. D., Wünschmann, S., & Pomés, A. (2007). Proteases as Th2 adjuvants. *Current Allergy and Asthma Reports*, *7*(5), 363–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17697645

Chen, X., Feng, Y., & Chen, Z. (2009). Common edible insects and their utilization in China: INVITED REVIEW. *Entomological Research*. https://doi.org/10.1111/j.1748-5967.2009.00237.x

Chmelar, J., Calvo, E., Pedra, J. H. F., Francischetti, I. M. B., & Kotsyfakis, M. (2012). Tick salivary secretion as a source of antihemostatics. *Journal of Proteomics*, *75*(13), 3842–54. https://doi.org/10.1016/j.jprot.2012.04.026

Christensen, D. L., Orech, F. O., Mungai, M. N., Larsen, T., Friis, H., & Aagaard-Hansen, J. (2006). Entomophagy among the Luo of Kenya: a potential mineral source? *International Journal of Food Sciences and Nutrition*, *57*(3–4), 198–203. https://doi.org/10.1080/09637480600738252

Costa-Neto, E. M., & Dunkel, F. V. (2016). Chapter 2 – Insects as Food: History, Culture, and Modern Use around the World. In *Insects as Sustainable Food Ingredients* (pp. 29–60). https://doi.org/10.1016/B978-0-12-802856-8.00002-8

Da Silva, C. A., Pochard, P., Lee, C. G., & Elias, J. A. (2010). Chitin particles are multifaceted immune adjuvants. *American Journal of Respiratory and Critical Care Medicine*, *182*(12), 1482–91. https://doi.org/10.1164/rccm.200912-1877OC

De León-Rodríguez, A., González-Hernández, L., Barba de la Rosa, A. P., Escalante-Minakata, P., & López, M. G. (2006). Characterization of Volatile Compounds of Mezcal, an Ethnic Alcoholic Beverage Obtained from *Agave salmiana*. *Journal of Agricultural and Food Chemistry*, *54*(4), 1337–1341. https://doi.org/10.1021/jf052154+

Demattè, M. L., Endrizzi, I., & Gasperi, F. (2014). Food neophobia and its relation with olfaction. *Frontiers in Psychology*, *5*, 127. https://doi.org/10.3389/fpsyg.2014.00127

Devaraja, S., Nagaraju, S., Mahadeswaraswamy, Y. H., Girish, K. S., & Kemparaju, K. (2008). A low molecular weight serine protease: Purification and characterization from Hippasa agelenoides (funnel web) spider venom gland extract. *Toxicon : Official Journal of the International Society on Toxinology*, *52*(1), 130–8. https://doi.org/10.1016/j.toxicon.2008.04.168

Dumez, M.-E., Herman, J., Campizi, V., Galleni, M., Jacquet, A., & Chevigné, A. (2014). Orchestration of an uncommon maturation cascade of the house dust mite protease allergen quartet. *Frontiers in Immunology*, *5*, 138. https://doi.org/10.3389/fimmu.2014.00138

Elemo, B. O., Elemo, G. N., Makinde, M., & Erukainure, O. L. (2011). Chemical Evaluation of African Palm Weevil, *Rhychophorus phoenicis* , Larvae as a Food Source. *Journal of Insect Science*, *11*(146), 1–6. https://doi.org/10.1673/031.011.14601

Ermakova, E. A., Faizullin, D. A., Idiyatullin, B. Z., Khairutdinov, B. I., Mukhamedova, L. N., Tarasova, N. B., … Nesmelova, I. V. (2016). Structure of Scots pine defensin 1 by spectroscopic methods and computational modeling. *International Journal of Biological Macromolecules*, *84*, 142–52. https://doi.org/10.1016/j.ijbiomac.2015.12.011

Fischer, J. (2008). Religion, science and markets. *EMBO Reports*, *9*(9), 828–31. https://doi.org/10.1038/embor.2008.156

Gerchman, Y., & Inbar, M. (2011). Distinct antimicrobial activities in aphid galls on Pistacia atlantica. *Plant Signaling & Behavior*, *6*(12), 2008–12. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3337195&tool=pmcentrez&rendertype=abstract

Gibbs, E. P. J., & Anderson, T. C. (n.d.). One World - One Health' and the global challenge of epidemic diseases of viral aetiology. *Veterinaria Italiana*, *45*(1), 35–44. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20391388

Gmuer, A., Nuessli Guth, J., Hartmann, C., & Siegrist, M. (2016). Effects of the degree of processing of insect ingredients in snacks on expected emotional experiences and willingness to eat. *Food Quality and Preference*, *54*, 117–127. https://doi.org/10.1016/j.foodqual.2016.07.003

Grabowski, N. T., & Klein, G. (2016). *Microbiology of processed edible insect products – Results of a preliminary survey*. *International Journal of Food Microbiology*. https://doi.org/10.1016/j.ijfoodmicro.2016.11.005

Gracy, J., Le-Nguyen, D., Gelly, J.-C., Kaas, Q., Heitz, A., & Chiche, L. (2008). KNOTTIN: the knottin or inhibitor cystine knot scaffold in 2007. *Nucleic Acids Research*, *36*(Database issue), D314-9. https://doi.org/10.1093/nar/gkm939

Hadley, C. (2006). Food allergies on the rise? Determining the prevalence of food allergies, and how quickly it is increasing, is the first step in tackling the problem. *EMBO Reports*, *7*(11), 1080–3. https://doi.org/10.1038/sj.embor.7400846

Hager, A. J., Bolton, D. L., Pelletier, M. R., Brittnacher, M. J., Gallagher, L. A., Kaul, R., … Guina, T. (2006). Type IV pili-mediated secretion modulates Francisella virulence. *Molecular Microbiology*, *62*(1), 227–37. https://doi.org/10.1111/j.1365-2958.2006.05365.x

Hamerman, E. J. (2016). Cooking and disgust sensitivity influence preference for attending insect-based food events. *Appetite*, *96*, 319–326. https://doi.org/10.1016/j.appet.2015.09.029

Hanboonsong, Y., Jamjanya, T., & Durst, P. B. (2013). *Six-legged livestock : edible insect farming , collecting and marketing in Thailand*. *Office*.

Handley, M. A., Hall, C., Sanford, E., Diaz, E., Gonzalez-Mendez, E., Drace, K., … Croughan, M. (2007). Globalization, binational communities, and imported food risks: results of an outbreak investigation of lead poisoning in Monterey County, California. *American Journal of Public Health*, *97*(5), 900–6. https://doi.org/10.2105/AJPH.2005.074138

Hartmann, C., Shi, J., Giusto, A., & Siegrist, M. (2015). The psychology of eating insects: A cross-cultural comparison between Germany and China. *Food Quality and Preference*, *44*, 148–156. https://doi.org/10.1016/j.foodqual.2015.04.013

HINDLEY, J., WUNSCHMANN, S., SATINOVER, S., WOODFOLK, J., CHEW, F., CHAPMAN, M., & POMES, A. (2006). Bla g 6: A troponin C allergen from Blattella germanica with IgE binding calcium dependence. *Journal of Allergy and Clinical Immunology*, *117*(6), 1389–1395. https://doi.org/10.1016/j.jaci.2006.02.017

Hoffman, A. (2014). Inside The Edible Insect Industrial Complex. Retrieved from https://www.fastcompany.com/3037716/inside-the-edible-insect-industrial-complex

House, J. (2016). Consumer acceptance of insect-based foods in the Netherlands: Academic and commercial implications. *Appetite*, *107*, 47–58. https://doi.org/10.1016/j.appet.2016.07.023

Ichikawa, S., Takai, T., Yashiki, T., Takahashi, S., Okumura, K., Ogawa, H., … Hatanaka, H. (2009). Lipopolysaccharide binding of the mite allergen Der f 2. *Genes to Cells : Devoted to Molecular & Cellular Mechanisms*, *14*(9), 1055–65. https://doi.org/10.1111/j.1365-2443.2009.01334.x

Jeong, K. Y., Hong, C.-S., & Yong, T.-S. (2006). Allergenic tropomyosins and their cross-reactivities. *Protein and Peptide Letters*, *13*(8), 835–45. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17073731

Kempkes, C., Buddenkotte, J., Cevikbas, F., Buhl, T., & Steinhoff, M. (2014). Role of PAR-2 in Neuroimmune Communication and Itch. CRC Press. Retrieved from http://www.ncbi.nlm.nih.gov/books/NBK200911/

Kim, C.-W., & Hong, C.-S. (2007). Allergy to miscellaneous household arthropods. *Protein and Peptide Letters*, *14*(10), 982–91. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18220996

Liu, H., Chen, J., Wang, X., Yan, S., Xu, Y., San, M., … Chen, Z. (2015). Functional characterization of a new non-Kunitz serine protease inhibitor from the scorpion Lychas mucronatus. *International Journal of Biological Macromolecules*, *72*, 158–62. https://doi.org/10.1016/j.ijbiomac.2014.08.010

Louati, H., Zouari, N., Miled, N., & Gargouri, Y. (2011). A new chymotrypsin-like serine protease involved in dietary protein digestion in a primitive animal, Scorpio maurus: purification and biochemical characterization. *Lipids in Health and Disease*, *10*(1), 121. https://doi.org/10.1186/1476-511X-10-121

Ludman, S. W., & Boyle, R. J. (2015). Stinging insect allergy: current perspectives on venom immunotherapy. *Journal of Asthma and Allergy*, *8*, 75–86. https://doi.org/10.2147/JAA.S62288

Macan, J., Plavec, D., Kanceljak, B., & Milkovic-Kraus, S. (2003). Exposure levels and skin reactivity to German cockroach (Blattella germanica) in Croatia. *Croatian Medical Journal*, *44*(6), 756–60. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14652891

Maki, K. C., Reeves, M. S., Farmer, M., Griinari, M., Berge, K., Vik, H., … Rains, T. M. (2009). Krill oil supplementation increases plasma concentrations of eicosapentaenoic and docosahexaenoic acids in overweight and obese men and women. *Nutrition Research*, *29*(9), 609–615. https://doi.org/10.1016/j.nutres.2009.09.004

Manca, G., Porcu, A., Ru, A., Salaris, M., Franco, M. A., & De Santis, E. P. L. (2015). Comparison of γ-aminobutyric acid and biogenic amine content of different types of ewe’s milk cheese produced in Sardinia, Italy. *Italian Journal of Food Safety*, *4*(2), 4700. https://doi.org/10.4081/ijfs.2015.4700

Maradini Filho, A. M., Pirozi, M. R., Da Silva Borges, J. T., Pinheiro Sant’Ana, H. M., Paes Chaves, J. B., & Dos Reis Coimbra, J. S. (2015). Quinoa: Nutritional, Functional and Antinutritional Aspects. *Critical Reviews in Food Science and Nutrition*. https://doi.org/10.1080/10408398.2014.1001811

Menozzi, D., Sogari, G., Veneziani, M., Simoni, E., & Mora, C. (2017). Eating novel foods: An application of the Theory of Planned Behaviour to predict the consumption of an insect-based product. *Food Quality and Preference*, *59*, 27–34. https://doi.org/10.1016/j.foodqual.2017.02.001

Nadeau, L., Nadeau, I., Franklin, F., & Dunkel, F. (2015). The Potential for Entomophagy to Address Undernutrition. *Ecology of Food and Nutrition*, *54*(3), 200–208.

https://doi.org/10.1080/03670244.2014.930032

Navarro-Garcia, F., Sonnested, M., & Teter, K. (2010). Host-Toxin Interactions Involving EspC and Pet, Two Serine Protease Autotransporters of the Enterobacteriaceae. *Toxins*, *2*(5), 1134–1147. https://doi.org/10.3390/toxins2051134

Navarro, J. C. A., Prado, S. M. C., Cárdenas, P. A., Santos, R. D., & Caramelli, B. (2010). Pre-historic eating patterns in Latin America and protective effects of plant-based diets on cardiovascular risk factors. *Clinics (Sao Paulo, Brazil)*, *65*(10), 1049–54. https://doi.org/10.1590/s1807-59322010001000022

Negulescu, H., Guo, Y., Garner, T. P., Goodwin, O. Y., Henderson, G., Laine, R. A., & Macnaughtan, M. A. (2015). A Kazal-Type Serine Protease Inhibitor from the Defense Gland Secretion of the Subterranean Termite Coptotermes formosanus Shiraki. *PloS One*, *10*(5), e0125376. https://doi.org/10.1371/journal.pone.0125376

Nguyen, P. Q. T., Ooi, J. S. G., Nguyen, N. T. K., Wang, S., Huang, M., Liu, D. X., & Tam, J. P. (2015). Antiviral Cystine Knot α-Amylase Inhibitors from Alstonia scholaris. *The Journal of Biological Chemistry*, *290*(52), 31138–50. https://doi.org/10.1074/jbc.M115.654855

Nowak, V., Persijn, D., Rittenschober, D., & Charrondiere, U. R. (2016). Review of food composition data for edible insects. *Food Chemistry*, *193*, 39–46. https://doi.org/10.1016/j.foodchem.2014.10.114

Ogawa, H., Shinoda, T., Cornelius, F., & Toyoshima, C. (2009). Crystal structure of the sodium-potassium pump (Na+,K+-ATPase) with bound potassium and ouabain. *Proceedings of the National Academy of Sciences*, *106*(33), 13742–13747. https://doi.org/10.1073/pnas.0907054106

Ohmuraya, M., & Yamamura, K. (2011). Roles of serine protease inhibitor Kazal type 1 (SPINK1) in pancreatic diseases. *Experimental Animals / Japanese Association for Laboratory Animal Science*, *60*(5), 433–44. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22041280

Okezie, O. A., Kgomotso, K. K., & Letswiti, M. M. (2010). Mopane worm allergy in a 36-year-old woman: a case report. *Journal of Medical Case Reports*, *4*, 42. https://doi.org/10.1186/1752-1947-4-42

Patel, S. (2012a). Food , Health and Agricultural Importance of Truffles : A, *6*(January), 15–27.

Patel, S. (2012b). Therapeutic importance of sulfated polysaccharides from seaweeds: updating the recent findings. *3 Biotech*, *2*(3), 171–185. https://doi.org/10.1007/s13205-012-0061-9

Patel, S. (2016a). Emerging Adjuvant Therapy for Cancer: Propolis and its Constituents. *Journal of Dietary Supplements*, *13*(3), 245–268. https://doi.org/10.3109/19390211.2015.1008614

Patel, S. (2016b). In silico analysis of Hepatitis C virus (HCV) polyprotein domains and their comparison with other pathogens and allergens to gain insight on pathogenicity mechanisms. *Computational Biology and Chemistry*, *65*, 91–102. https://doi.org/10.1016/j.compbiolchem.2016.10.006

Patel, S. (2016c). Nutrition, safety, market status quo appraisal of emerging functional food corn smut (huitlacoche). *Trends in Food Science & Technology*, *57*, 93–102. https://doi.org/10.1016/j.tifs.2016.09.006

Petschenka, G., & Agrawal, A. A. (2015). Milkweed butterfly resistance to plant toxins is linked to sequestration, not coping with a toxic diet. *Proceedings. Biological Sciences*, *282*(1818), 20151865. https://doi.org/10.1098/rspb.2015.1865

Ponting, C. P., Schultz, J., Milpetz, F., & Bork, P. (1999). SMART: identification and annotation of domains from signalling and extracellular protein sequences. *Nucleic Acids Research*, *27*(1), 229–232. https://doi.org/10.1093/nar/27.1.229

Premalatha, M., Abbasi, T., Abbasi, T., & Abbasi, S. A. (2011). Energy-efficient food production to reduce global warming and ecodegradation: The use of edible insects. *Renewable and Sustainable Energy Reviews*, *15*(9), 4357–4360. https://doi.org/10.1016/j.rser.2011.07.115

Ramos-Elorduy, J., Moreno, J. M. P., Vázquez, A. I., Landero, I., Oliva-Rivera, H., & Camacho, V. H. M. (2011). Edible Lepidoptera in Mexico: Geographic distribution, ethnicity, economic and nutritional importance for rural people. *Journal of Ethnobiology and Ethnomedicine*, *7*, 2. https://doi.org/10.1186/1746-4269-7-2

Rand, K., Bar, E., Ben-Ari, M., Lewinsohn, E., & Inbar, M. (2014). The mono - and sesquiterpene content of aphid-induced galls on Pistacia palaestina is not a simple reflection of their composition in intact leaves. *Journal of Chemical Ecology*, *40*(6), 632–42. https://doi.org/10.1007/s10886-014-0462-9

Raubenheimer, D., & Rothman, J. M. (2013). Nutritional Ecology of Entomophagy in Humans and Other Primates. *Annual Review of Entomology*, *58*(1), 141–160. https://doi.org/10.1146/annurev-ento-120710-100713

Reese, G., Ayuso, R., & Lehrer, S. B. (1999). Tropomyosin: an invertebrate pan-allergen. *International Archives of Allergy and Immunology*, *119*(4), 247–58. https://doi.org/24201

Rippere, V. (1983). Food additives and hyperactive children: a critique of Conners. *The British Journal of Clinical Psychology / the British Psychological Society*, *22 Pt 1*, 19–32. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6831074

Robinson, N. (2015). First EU edible insect food safety guide published. *Food Manufacture*.

Rossano, R., Larocca, M., Polito, T., Perna, A. M., Padula, M. C., Martelli, G., & Riccio, P. (2012). What are the proteolytic enzymes of honey and what they do tell us? A fingerprint analysis by 2-D zymography of unifloral honeys. *PloS One*, *7*(11), e49164. https://doi.org/10.1371/journal.pone.0049164

Rumpold, B. A., & Schlüter, O. K. (2013). Potential and challenges of insects as an innovative source for food and feed production. *Innovative Food Science & Emerging Technologies*, *17*, 1–11. https://doi.org/10.1016/j.ifset.2012.11.005

Samra, S., Ghanim, M., Protasov, A., Branco, M., & Mendel, Z. (2015). Genetic diversity and host alternation of the egg parasitoid Ooencyrtus pityocampae between the pine processionary moth and the caper bug. *PloS One*, *10*(4), e0122788. https://doi.org/10.1371/journal.pone.0122788

Schouteten, J. J., De Steur, H., De Pelsmaeker, S., Lagast, S., Juvinal, J. G., De Bourdeaudhuij, I., … Gellynck, X. (2016). *Emotional and sensory profiling of insect-, plant- and meat-based burgers under blind, expected and informed conditions*. *Food Quality and Preference* (Vol. 52). https://doi.org/10.1016/j.foodqual.2016.03.011

Seabrooks, L., & Hu, L. (2017). Insects: an underrepresented resource for the discovery of biologically active natural products. *Acta Pharmaceutica Sinica B*. https://doi.org/10.1016/j.apsb.2017.05.001

Shelomi, M. (2015). Why we still don’t eat insects: Assessing entomophagy promotion through a diffusion of innovations framework. *Trends in Food Science & Technology*. https://doi.org/10.1016/j.tifs.2015.06.008

Shelomi, M. (2016). The meat of affliction: Insects and the future of food as seen in Expo 2015. *Trends in Food Science & Technology*. https://doi.org/10.1016/j.tifs.2016.08.004

Silva-Carvalho, R., Miranda-Gonçalves, V., Ferreira, A. M., Cardoso, S. M., Sobral, A. J. F. N., Almeida-Aguiar, C., & Baltazar, F. (2014). Antitumoural and antiangiogenic activity of Portuguese propolis in in vitro and in vivo models. *Journal of Functional Foods*, *11*, 160–171. https://doi.org/10.1016/j.jff.2014.09.009

Smetana, S., Palanisamy, M., Mathys, A., & Heinz, V. (2016). Sustainability of insect use for feed and food: Life Cycle Assessment perspective. *Journal of Cleaner Production*, *137*, 741–751. https://doi.org/10.1016/j.jclepro.2016.07.148

Srinroch, C., Srisomsap, C., Chokchaichamnankit, D., Punyarit, P., & Phiriyangkul, P. (2015). Identification of novel allergen in edible insect, Gryllus bimaculatus and its cross-reactivity with Macrobrachium spp. allergens. *Food Chemistry*, *184*, 160–166. https://doi.org/10.1016/j.foodchem.2015.03.094

Stamer, A. (2015). Insect proteins-a new source for animal feed: The use of insect larvae to recycle food waste in high-quality protein for livestock and aquaculture feeds is held back largely owing to regulatory hurdles. *EMBO Reports*, *16*(6), 676–80. https://doi.org/10.15252/embr.201540528

Sudha, V. T., Arora, N., Gaur, S. N., Pasha, S., & Singh, B. P. (2008). Identification of a serine protease as a major allergen (Per a 10) of Periplaneta americana. *Allergy*, *63*(6), 768–76. https://doi.org/10.1111/j.1398-9995.2007.01602.x

Sun-Waterhouse, D., Waterhouse, G. I. N., You, L., Zhang, J., Liu, Y., Ma, L., … Dong, Y. (2016). Transforming insect biomass into consumer wellness foods: A review. *Food Research International*, *89*, 129–151. https://doi.org/10.1016/j.foodres.2016.10.001

Takeo, S., Hisamori, D., Matsuda, S., Vinetz, J., Sattabongkot, J., & Tsuboi, T. (2009). Enzymatic characterization of the Plasmodium vivax chitinase, a potential malaria transmission-blocking target. *Parasitology International*, *58*(3), 243–8. https://doi.org/10.1016/j.parint.2009.05.002

Tan, H. S. G., Fischer, A. R. H., Tinchan, P., Stieger, M., Steenbekkers, L. P. A., & van Trijp, H. C. M. (2015). Insects as food: Exploring cultural exposure and individual experience as determinants of acceptance. *Food Quality and Preference*, *42*, 78–89. https://doi.org/10.1016/j.foodqual.2015.01.013

Tan, H. S. G., Fischer, A. R. H., van Trijp, H. C. M., & Stieger, M. (2016). Tasty but nasty? Exploring the role of sensory-liking and food appropriateness in the willingness to eat unusual novel foods like insects. *Food Quality and Preference*, *48*, 293–302. https://doi.org/10.1016/j.foodqual.2015.11.001

Tandy, S., Chung, R. W. S., Wat, E., Kamili, A., Berge, K., Griinari, M., & Cohn, J. S. (2009). Dietary Krill Oil Supplementation Reduces Hepatic Steatosis, Glycemia, and Hypercholesterolemia in High-Fat-Fed Mice. *Journal of Agricultural and Food Chemistry*, *57*(19), 9339–9345. https://doi.org/10.1021/jf9016042

Tantong, S., Pringsulaka, O., Weerawanich, K., Meeprasert, A., Rungrotmongkol, T., Sarnthima, R., … Sirikantaramas, S. (2016). Two novel antimicrobial defensins from rice identified by gene coexpression network analyses. *Peptides*, *84*, 7–16. https://doi.org/10.1016/j.peptides.2016.07.005

Taveira, G. B., Carvalho, A. O., Rodrigues, R., Trindade, F. G., Da Cunha, M., & Gomes, V. M. (2016). Thionin-like peptide from Capsicum annuum fruits: mechanism of action and synergism with fluconazole against Candida species. *BMC Microbiology*, *16*, 12. https://doi.org/10.1186/s12866-016-0626-6

Uddin, G., Rauf, A., Al-Othman, A. M., Collina, S., Arfan, M., Ali, G., & Khan, I. (2012). Pistagremic acid, a glucosidase inhibitor from Pistacia integerrima. *Fitoterapia*, *83*(8), 1648–52.

https://doi.org/10.1016/j.fitote.2012.09.017

Uddin, G., Rauf, A., Arfan, M., Waliullah, khan, I., Ali, M., … Samiullah. (2012). Pistagremic acid a new leishmanicidal triterpene isolated from Pistacia integerrima Stewart. *Journal of Enzyme Inhibition and Medicinal Chemistry*, *27*(5), 646–8. https://doi.org/10.3109/14756366.2011.604853

Ullah, H., Rauf, A., Ullah, Z., Fazl-i-Sattar, Anwar, M., Shah, A.-H. A., … Ayub, K. (2014). Density functional theory and phytochemical study of Pistagremic acid. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *118*, 210–214. https://doi.org/10.1016/j.saa.2013.08.099

van Huis, A. (2017). Cultural significance of termites in sub-Saharan Africa. *Journal of Ethnobiology and Ethnomedicine*, *13*(1), 8. https://doi.org/10.1186/s13002-017-0137-z

van Huis, A., Berry, E., Dernini, S., Burlingame, B., Meybeck, A., Conforti, P., … Drew, D. (2015). Edible insects contributing to food security? *Agriculture & Food Security*, *4*(1), 20. https://doi.org/10.1186/s40066-015-0041-5

Van Huis, A., & Dunkel, F. V. (2017). Chapter 21 – Edible Insects: A Neglected and Promising Food Source. In *Sustainable Protein Sources* (pp. 341–355). https://doi.org/10.1016/B978-0-12-802778-3.00021-4

Veiga, S. S., da Silveira, R. B., Dreyfus, J. L., Haoach, J., Pereira, A. M., Mangili, O. C., & Gremski, W. (2000). Identification of high molecular weight serine-proteases in Loxosceles intermedia (brown spider) venom. *Toxicon : Official Journal of the International Society on Toxinology*, *38*(6), 825–39. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10695968

Verneau, F., La Barbera, F., Kolle, S., Amato, M., Del Giudice, T., & Grunert, K. (2016). The effect of communication and implicit associations on consuming insects: An experiment in Denmark and Italy. *Appetite*, *106*, 30–36. https://doi.org/10.1016/j.appet.2016.02.006

Voltolini, S., Pellegrini, S., Contatore, M., Bignardi, D., & Minale, P. (2014). New risks from ancient food dyes: cochineal red allergy. *European Annals of Allergy and Clinical Immunology*, *46*(6), 232–3. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25398168

Wan, H., Lee, K. S., Kim, B. Y., Zou, F. M., Yoon, H. J., Je, Y. H., … Jin, B. R. (2013). A spider-derived Kunitz-type serine protease inhibitor that acts as a plasmin inhibitor and an elastase inhibitor. *PloS One*, *8*(1), e53343. https://doi.org/10.1371/journal.pone.0053343

Wan, H., Winton, H. L., Soeller, C., Taylor, G. W., Gruenert, D. C., Thompson, P. J., … Robinson, C. (2001). The transmembrane protein occludin of epithelial tight junctions is a functional target for serine peptidases from faecal pellets of Dermatophagoides pteronyssinus. *Clinical and Experimental Allergy : Journal of the British Society for Allergy and Clinical Immunology*, *31*(2), 279–94. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11251630

Wang, Y., Chang, Y., Yu, L., Zhang, C., Xu, X., Xue, Y., … Xue, C. (2013). Crystalline structure and thermal property characterization of chitin from Antarctic krill (Euphausia superba). *Carbohydrate Polymers*, *92*(1), 90–7. https://doi.org/10.1016/j.carbpol.2012.09.084

Warrant, E., Frost, B., Green, K., Mouritsen, H., Dreyer, D., Adden, A., … Heinze, S. (2016). The Australian Bogong Moth Agrotis infusa: A Long-Distance Nocturnal Navigator. *Frontiers in Behavioral Neuroscience*, *10*, 77. https://doi.org/10.3389/fnbeh.2016.00077

Yang, Q., Liu, S., Sun, J., Yu, L., Zhang, C., Bi, J., & Yang, Z. (2014). Nutritional composition and protein quality of the edible beetle Holotrichia parallela. *Journal of Insect Science (Online)*, *14*(1), 139. https://doi.org/10.1093/jisesa/ieu001

Yates-Doerr, E. (2015). The world in a box? Food security, edible insects, and “One World, One Health” collaboration. *Social Science & Medicine*, *129*, 106–112. https://doi.org/10.1016/j.socscimed.2014.06.020

Zagrobelny, M., & Møller, B. L. (2011). Cyanogenic glucosides in the biological warfare between plants and insects: The Burnet moth-Birdsfoot trefoil model system. *Phytochemistry*, *72*(13), 1585–1592. https://doi.org/10.1016/j.phytochem.2011.02.023

Zhang, H., Zeng, X., & He, S. (2014). Evaluation on potential contributions of protease activated receptors related mediators in allergic inflammation. *Mediators of Inflammation*, *2014*, 829068. https://doi.org/10.1155/2014/829068

Table 1.

Arthropod orders	**Species**
Coleoptera	Beetle larvae and pupae
Hemiptera	Giant water bugs and cicadas
Hymenoptera	Ants and bees
Isoptera	Termites
Lepidoptera	Moth and butterfly larvae and pupae
Orthoptera	Cricket, grasshoppers, and locusts

Fig. 1

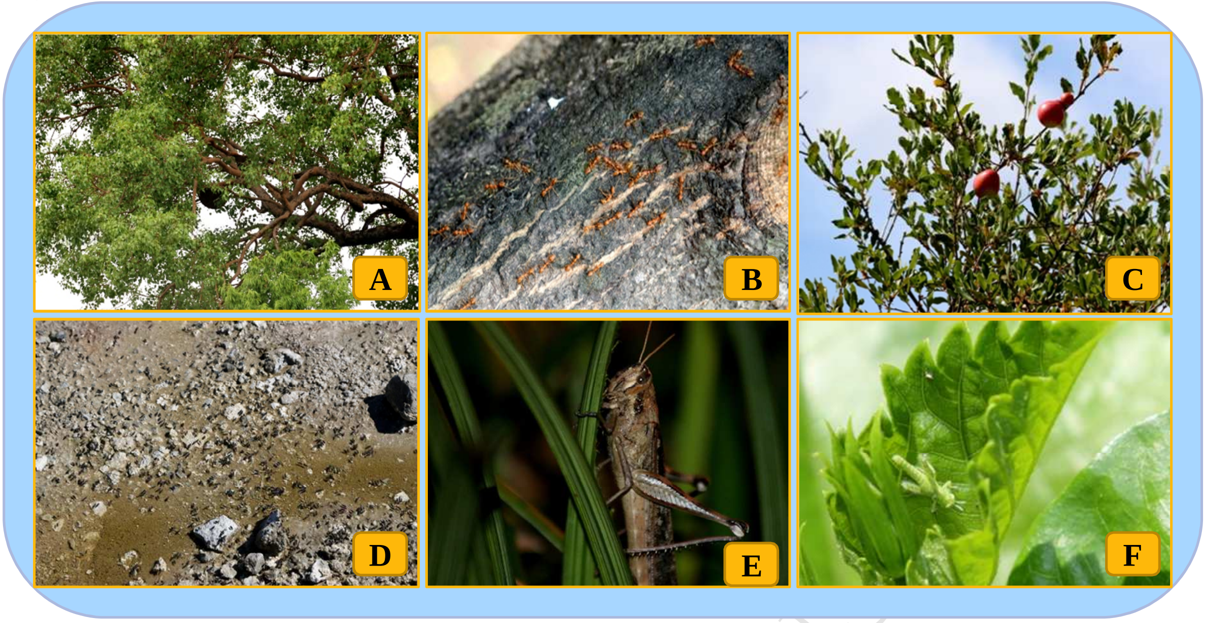
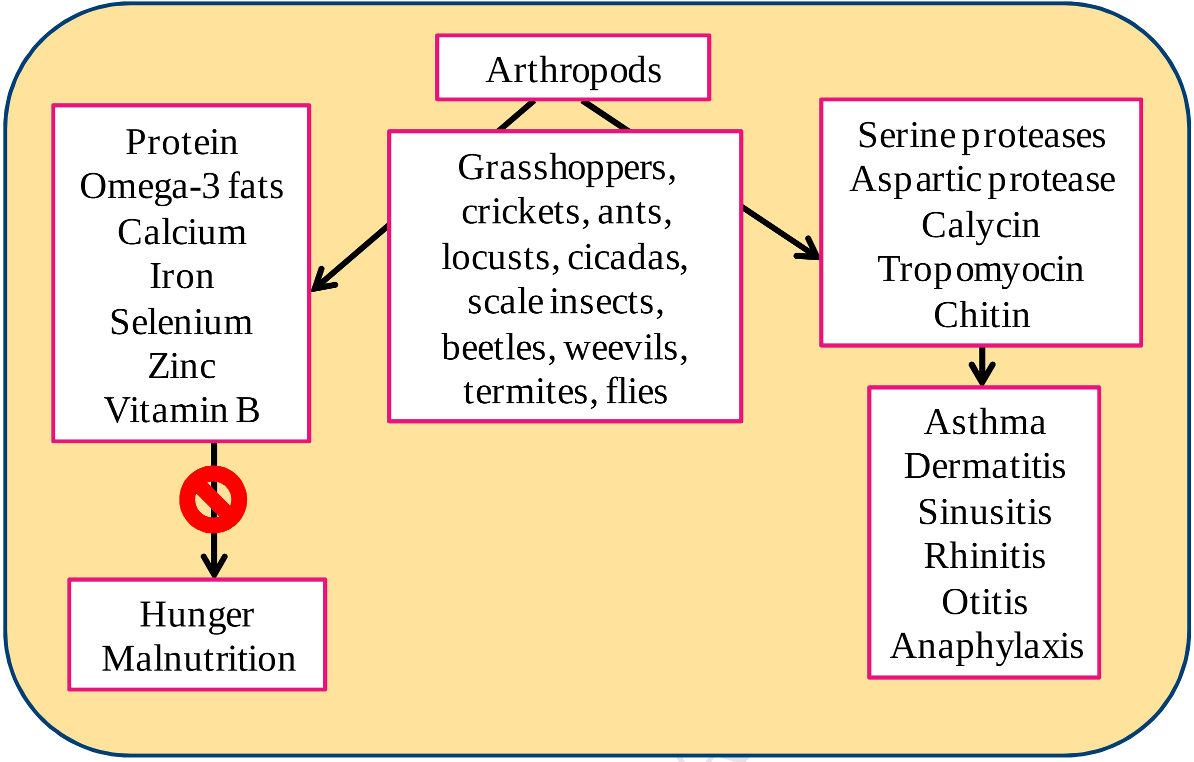


Fig. 2


Arthropods
Grasshoppers, crickets, ants, locusts, cicadas, scale insects, beetles, weevils, termites, flies
Protein
Omega-3 fats
Calcium
Iron
Selenium
Zinc
Vitamin B
Hunger
Malnutrition
Serine proteases
Aspartic protease
Calycin
Tropomyocin
Chitin
Asthma
Dermatitis
Sinusitis
Rhinitis
Otitis
Anaphylaxis

- The World is facing food insecurity and it requires prospecting of underutilized nutritious foods.
- Arthropods, with abundance of proteins, unsaturated fats and minerals are potent candidates.
- However, the allergens, status as pathogen vectors and ‘disgust factors’ undermine their food candidature.
- This review analyzes the pros, cons and scopes of entomophagy.