

REVIEW ARTICLE

Insect Allergens on the Dining Table

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Abstract: Edible insects are important sources of nutrition, particularly in Africa, Asia, and Latin America. Recently, edible insects have gained considerable interest as a possible solution to global exhaustion of the food supply with population growth. However, little attention has been given to the adverse reactions caused by insect consumption. Here, we provide an overview of the food allergens in edible insects and offer insights for further studies. Most of the edible insect allergens identified to date are highly cross-reactive invertebrate pan-allergens such as tropomyosin and arginine kinase. Allergic reactions to these allergens may be cross-reactions resulting from sensitization to shellfish and/or house dust mites. No unique insect allergen specifically eliciting a food allergy has been described. Many of the edible insect allergens described thus far have counterpart allergens in cockroaches, which are an important cause of respiratory allergies, but it is questionable whether inhalant allergens can cause food allergies. Greater effort is needed to characterize the allergens that are unique to edible insects so that safe edible insects can be developed. The changes in insect proteins upon food processing or cooking should also be examined to enhance our understanding of edible insect food allergies.

Keywords: Food allergen, cross-reactivity, edible insects.

1. INTRODUCTION

The Food and Agricultural Organization (FAO) of the United Nations proposed promoting insects as a viable option for feeding both humans and animals to overcome food shortages associated with population growth [1, 2]. The global market for the edible insect industry was estimated to be about 33 million USD in 2015, and is expected to exceed 522 million USD by 2023 (Global Market Insight Inc. 2016). The global edible insect market was valued at 143 million USD in 2015, and the Korean government has estimated that it will be 457 million USD by 2020 [3]. However, the significant potential of food allergies to edible insects has been underestimated, especially in developing countries [4]. Silk-worm pupa allergies are recognized as a frequent cause of anaphylaxis in East Asia. With the growing interest in edible insects as an alternative source of raw materials, studies are needed to determine the risks and safety of using insects in production of foods and food ingredients [5].

Insects and their bioactive substances are important not only for food and textile production, but also for medicinal purposes in humans and animals [6, 7]. Certain insects are known to be useful in traditional oriental medicine and apitherapy (acupuncture or bee sting therapy). Approximately 300 insect species are included in an estimated 1,700 traditional oriental medicines [8].

The molecular identities of the allergens that cause allergic reactions after insect consumption have not been investigated in detail. Cockroaches are an important cause of asthma and are the only insects for which the allergen characteristics have been well studied [9, 10]. Allergens trigger the human immune system after entering the body by one of the four routes: inhalation, stinging, biting, and ingestion. Sensitization to cockroaches via inhalation or to shellfish allergens via ingestion may also induce cross-reactions to homologous proteins ingested from edible insects. Therefore, the cross-reactivity of edible insect allergens with allergens from cockroaches, house dust mites, and shellfish may be an important cause of food allergies to edible insects.

Non-allergic damage can also be elicited by the presence or even absence of insects. For example, skin contact with some caterpillars or moths can cause a form of irritant contact dermatitis called 'lepidopterism' [11]. In addition, Ek-bom syndrome is a delusory parasitosis involving the belief that one's body is infested by invisible bugs [12].

In this review, we summarized studies on the molecular properties of edible insect allergens and their possible cross-reactivity in an attempt to provide insights for future research.

2. CONSUMPTION OF INSECTS

The US Food and Drug Administration (FDA) maintains inspection regulations on the adulteration of vegetables with fruit fly eggs and maggots (CPG Sec. 585.890 Tomato Products – Adulteration with *Drosophila* fly eggs and maggots)

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(Table 1). Paradoxically, this regulation indicates the presence of insect eggs and larvae on vegetables eaten. The labeling of food merchandise with allergen sources is an important measure to prevent possible adverse reactions to unwanted food consumption. Therefore, most developed countries legally require labeling to indicate common food allergen sources, reflecting the recommendations of the Codex Alimentarius Commission, although the detailed labeling laws vary among countries [13].

Cochineal, a scale insect (*Dactylopius coccus*) of the order Homoptera that produces bright red pigment (carmine), is a commonly consumed insect. Cochineal extract is routinely added as a coloring for a variety of products, including yogurt, candy, cookies, juice, milk, other beverages, and ice cream. It is also added to certain cosmetics and medications. Allergies to carmine have been reported, although they are rare [14]. The US FDA has stated that there is no evidence that carmine poses a significant hazard to the general population, and the European Food Safety Authority (EFSA) allows the use of carmine for pharmaceutical products, although a synthetic version of the food colorant has replaced insect-derived carmine.

The intake of foods containing mites and their allergens can cause severe allergic symptoms in what is known as oral mite anaphylaxis or pancake syndrome [15]. Pancake syndrome may indicate that food allergies can be elicited not only by allergens sensitized by consumption of the culprit allergen (genuine sensitization), but also by allergens sensitized by inhalation of cross-reactive allergens. For instance, the IgE reaction to shrimp allergens in Orthodox Jews who do not consume shellfish appears to be due to sensitization to tropomyosin from house dust mites or cockroaches [16].

The addition of fruit flies, scale insects, and mites to various food materials, whether intentionally or by contamination, indicates that even vegetarians cannot avoid consuming insects.

3. EDIBLE INSECTS IN KOREA

A recent study indicated that more than 2,000 insect species are consumed by 3,071 ethnic groups in 130 countries, primarily in Africa and South America [17], and most humans can be classified as entomophagous, even if unintentionally. Currently, the Korea FDA permits seven types of edible insects: rice grasshoppers (*Oxya chinensis sinuosa*), silkworm pupae (*Bombyx mori*), white silkworms, mealworm larvae (*Tenebrio molitor*), rhinoceros beetle larvae (*Allomyrina dichotoma*), white-spotted flower chafer (*Protaetia brevitarsis seulensis* (Kolbe)), and two-spotted crickets (*Gryllus bimaculatus*). White silkworms are larvae infected with cordyceps (also called vegetable worms), an insect parasitic fungus (*Cordyceps* spp.). Therefore, six insect species are allowed in the food industry (Fig. 1).

The present Korean insect market mainly consists of animal feed and medicinal products. However, various human foods using edible insect species are under development [3]. Most of the research on edible insects is focused on the identification of bioactive substances and establishment of mass production techniques to reduce production costs. However, greater attention should be given to possible ad-

verse reactions resulting from insect consumption, and further studies should be conducted to develop methods of reducing probable allergic reactions to edible insects.

4. CHARACTERIZATION OF EDIBLE INSECT ALLERGENS

4.1. Identification of Silkworm Pupa Allergens

Moths can elicit respiratory allergies. The frequency of silkworm-specific IgE among patients with respiratory allergy symptoms was 49.1% in Guangzhou, China [18] and 52.5% in Brazil [19]. These studies demonstrate that the inhalation route may be important for sensitization and provocation of adult moth allergies. However, the sensitization rate in food allergy patients has not been investigated. Silkworm pupae are among the most commonly consumed insects in East Asia, and some studies have characterized their allergens. Interestingly, several patients have had anaphylactic reactions when consuming silkworm pupae for the first time [20, 21]. Recently, silkworm pupae (chrysalis) have been reported to be the most frequent sensitizers in Korean adults suspected of having food allergies [22].

Arginine kinase (Plo i 1) was first characterized as a cross-reactive pan-allergen from the Indianmeal moth *Plodia interpunctella*, a ubiquitous food pest [23]. Thioredoxin (Plo i 2) from Indianmeal moth was also described as a potential allergen [24]. Arginine kinase was the first allergen identified from silkworm larvae and was designated as Bomb m 1 [25]. However, silkworm pupae (not larvae, which are a by-product of silk textile industry) are commonly consumed in Korea. A 27-kDa glycoprotein was identified as a heat-stable allergen from silkworm pupae, and a recombinant form of this protein was recognized by the serum IgE antibodies of 33.3% of patients with silkworm pupa allergies [26]. In addition, a 27-kDa glycoprotein was described as an allergen from the bee moth (*Galleria mellonella*), a fish bait, in a mono-sensitized allergy patient [27]. Furthermore, a 27-kDa hemolymph protein, along with apolipoprotein III, was detected as an allergen from *Galleria mellonella* in a patient with rhinoconjunctivitis due to the manipulation of the moth as fish bait [28]. Interestingly, tropomyosin, a well-known invertebrate pan-allergen [29], does not play an important role in silkworm pupa allergies [30]. Chitinase and paramyosin were also described as IgE-reactive components of silkworm pupae, although further characterization of these proteins is needed [31].

4.2. Identification of Mealworm Allergens

Occupational allergies may be induced by mealworms, which are used in the grain and poultry industries [32]. Anaphylaxis in response to mealworms has been described [33]. However, most of the studies on mealworm allergens have employed sera from patients with allergies to house dust mites and/or shellfish. Therefore, cross-reactive allergens have been described. Tropomyosin and arginine kinase in mealworms are reported to be major cross-reactive components among patients with house dust mite and shellfish allergies [34]. Proteome analysis combined with IgE immunoblotting revealed that tropomyosin, α -amylase, hexamerin, and myosin from mealworm species were recognized by IgE from patients with shellfish or house dust mite

Table 1. US Food and Drug Administration Criteria of fruit fly adulteration for direct seizure to the Division of Compliance Management and Operations (HFC-210) on tomato products.

Product type	Eggs only	Eggs and maggots*	Maggots only
Canned Tomatoes	>10 eggs/500 g	>5 eggs and >1 maggots/500 g	>2 maggots/500 g
Tomato Juice	>10 eggs/100 g	>5 eggs and >1 maggot/100 g	>2 maggots/100 g
Tomato Puree	>20 eggs/100 g	>10 eggs and >1 maggot/100 g	>2 maggots/100 g
Paste, Pizza and other sauces	>30 eggs/100 g	>15 eggs and >1 maggot/100 g	>2 maggots/100 g

*Maggots 2 mm or less in length shall be considered equivalent to fly eggs.

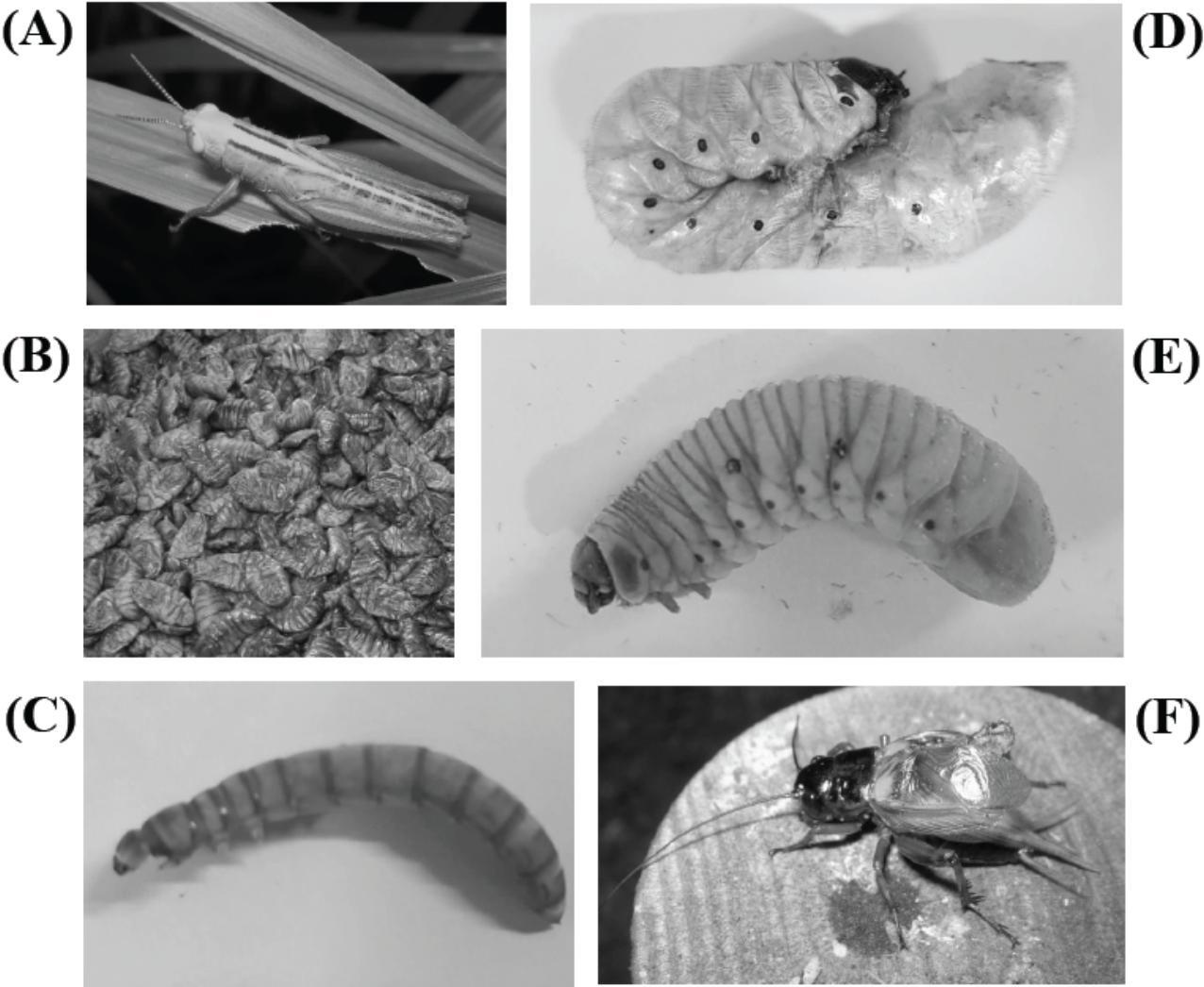


Fig. (1). Edible insects allowed in the food industry by the Korea Food and Drug Administration. Rice grasshopper nymph (*Oxya chinensis sinuosa*) (A); cooked silkworm pupa (*Bombyx mori*) (B); mealworm larva (*Tenebrio molitor*) (C); rhinoceros beetle larva (*Allomyrina dichotoma*) (D); white-spotted flower chafer larva (*Protaetia brevitarsis seulensis* (Kolbe)) (E); two-spotted cricket (*Gryllus bimaculatus*) (F).

allergies [35]. Patients with shrimp allergies are thought to be at greatest risk for edible insect food allergies, especially to mealworms [36].

4.3. Identification of Locust and Cricket Allergens

Locusts and crickets are members of the insect order Orthoptera. Allergy symptoms such as occupational asthma

have been recognized in locust breeders [37-40]. Caution is necessary because reptile pets are mostly fed potentially allergenic locusts [41]. However, studies on locusts as a cause of food allergies have not been conducted.

Expectedly, respiratory allergies to crickets have been reported [42, 43]. Arginine kinase and hexamerin (hemo-cyanin) were identified as allergens with cross-reactivity to

shrimp (*Macrobrachium* spp.) counterparts [44]. Arginine kinase was also described as an IgE-reactive component from the house cricket *Acheta domesticus*, although it was identified from the serum of a patient with respiratory allergic symptoms [43]. Tropomyosin is the allergen suspected of cross-reactivity between shellfish and various species of insects [36]. Enzymatic hydrolysis of crickets was reported to reduce IgE reaction to tropomyosin [45].

4.4. Identification of Allergens from Other Insects

Almost all commonly found insects can cause allergic reactions. Allergic sensitizations to caddisflies, mayflies, houseflies, midges, ants, silverfish, carpet beetles, ladybugs, and moths have been described [46-51]. These insects cause respiratory allergies, but it is not clear in many cases whether these are genuine allergies or simple cross-reactions without clinical manifestations. Studies have not been performed on the allergenic potential of rhinoceros beetle larvae (*A. dichotoma*) or white-spotted flower chafer (*P. brevitarsis seulensis* (Kolbe)), although these species are allowed in the food industry. Allergic responses have been reported after consumption of bee larvae/pupae [72], cicadas [73], mopane worms [74], pine processionary caterpillars [75], sago worms [76], scale insects (carmine) [77], and two-line velvet hawkmoths [72]. However, the culprit allergens have not been identified. Cockroaches, which are known to be strongly associated with asthma, are the insects with the best-defined allergen characteristics [78, 79].

Most of the allergenic components identified from edible insects are proteins that have been described as inhalant allergens from the other insects, demonstrating their potential cross-reactivity (Table 2). However, it is questionable whether the same allergen from an insect can cause both respiratory and food allergies. The allergens from insect stings or bites are quite different from edible insect food allergens [57, 71]; indeed, due to their intrinsic properties [80-83], the allergens responsible for food allergies generally have different properties than those responsible for respiratory allergies. Aeroallergens are buoyant and sticky antigens with small molecular weights (10-50 kDa) and thus can be carried by particulate matter and remain airborne. Excreted and secreted allergens from insects (mostly insect feces) have these properties. However, food allergens must be resistant to digestive enzymes and acid and heat processing, and allergens from insect muscle and hemolymph could have these characteristics.

5. COMPONENT-RESOLVED DIAGNOSIS AND INSECT ALLERGENS

With the progress of molecular biology, numerous allergens have been cloned, and novel diagnostics and immunotherapeutics using recombinant proteins have been developed for allergies [84-88]. Particular clinical benefits are expected from molecular diagnosis, also known as component-resolved diagnosis (CRD), for food allergies [89]. CRD helps to discriminate clinically significant sensitization from irrelevant asymptomatic sensitization by identifying specific IgEs to the relevant molecules (primary sensitizers) for allergic risk. CRD may reduce the need for oral provocation tests, which can elicit severe adverse reactions. CRD also makes it

easy to identify patients who could benefit from immunotherapy and may be useful for predicting the prognosis of food allergies.

Many of the allergens identified from edible insects to date are highly cross-reactive pan-allergens from shellfish, such as tropomyosin and arginine kinase (Table 2). Thus, it is tempting to speculate that some of the IgE reactions to tropomyosin and arginine kinase are cross-reactions rather than genuine sensitizations. The weak IgE reactivity to tropomyosin in a silkworm allergy patient may support this idea [30]. Although cross-reactivity has been reported for glutathione *S*-transferase and paramyosin among invertebrate species [91-93], a cross-reactivity study has not been conducted with edible insects. Therefore, more studies are needed to characterize edible insect allergens to improve diagnosis.

6. FOOD PROCESSING AND FOOD MATRICES

Food processing can alter the allergenic potential of food proteins. In general, heat, pressure, fermentation, and hydrolysis can reduce the allergenicity of proteins [94, 95]. Glycation during the Maillard reaction also influences the allergenicity of food proteins [96, 97]. There is some evidence that heated tropomyosin (Cra g 1) has higher IgE reactivity than the raw form due to denaturation and polymer formation [98], but most studies have demonstrated that the allergenicity of shrimp or crab tropomyosin is reduced by the Maillard reaction and conformational changes of the allergen [99, 100].

Detailed studies on the proteins in edible insects have not been conducted. Heat processing was reported to reduce but not eliminate the allergenicity of mealworm extracts [35], but that study was performed with serum samples from patients experiencing clinical allergic symptoms due to house dust mites or crustaceans, not edible insects. The 27-kDa hemolymph glycoprotein from silkworm pupae is the only edible insect allergen confirmed to be stable against heat treatment [26]. The effects of food processing on edible insects deserve attention not only from the insect food industry, but also from the medicinal insect industry. In addition, studies on carbohydrate epitopes should be performed to enhance diagnosis, since cross-reactive carbohydrate determinants (CCDs) are the main cause of false-positive reactions [101, 102].

7. IMMUNOLOGICAL ASPECTS OF INSECT PROTEINS

Food allergens must resist the gastric acid and digestive enzymes in the gastrointestinal tract and enter the circulatory system to affect the immune system [103]. Allergens must undergo endolysosomal degradation by antigen-presenting cells for antigen presentation to both B- and T-cells. However, glycosylation and lipidation can prevent or delay enzymatic digestion of allergens [104]. Thus, a high lipid content during cooking could influence the allergenicity of insect proteins.

The interaction between insect allergens and the gut microbiome has not been studied in detail. The human immune reaction should be affected by pathogen-associated molecu-

Table 2. Major allergens from edible insects.

Biochemical identity	Allergen source		Allergen name (IUIS)	Accession No.*	IgE reactivity	Route of exposure	References
	Common name	Scientific name					
Arginine kinase	Silkworm	<i>Bombyx mori</i>	Bom b m 1	DQ2725299	100% (10/10)	Ingestion	Liu <i>et al.</i> , 2009 [25]
	Bombay locust	<i>Patanga succincta</i>	-	NA	NA	Ingestion	Phiriyangkul <i>et al.</i> , 2015 [52]
	Grasshopper	<i>Schistocerca americana</i>	-	NA	NA	Cross-reaction	Binder <i>et al.</i> , 2001 [23]
	Cricket	<i>Gryllus bimaculatus</i>	-	NA	NA	Ingestion (cross-reaction)	Srinroch <i>et al.</i> , 2015 [44]
	German cockroach	<i>Blattella germanica</i>	Bla g 9	ABC86902	34.4% (11/32)	Inhalation	Chuang <i>et al.</i> , 2010 [53]
	American cockroach	<i>Periplaneta americana</i>	Per a 9	GU301882	80.0% (20/25)	Inhalation	Sookrung <i>et al.</i> , 2006 [54]
	Indianmeal moth	<i>Plodia interpunctella</i>	Plo i 1	AJ315030	11.1% (10/90)	Inhalation	Binder <i>et al.</i> , 2001 [23]
	Asian wasp	<i>Vespa affinis</i>	-	NA	73.3% (11/15)	Sting	Sookrung <i>et al.</i> , 2014 [55]
	Social wasp	<i>Polybia paulista</i>	-	NA	NA	Sting	dos Santos <i>et al.</i> , 2010 [56]
	Yellow fever mosquito	<i>Aedes aegypti</i>	-	NA	13.3% (2/15)	Inhalation	Cantillo <i>et al.</i> , 2017 [57]
	Mealworm	<i>Tenebrio molitor</i>	-	NA	NA	Cross-reaction	Verhoeckx <i>et al.</i> , 2014 [34]
Tropomyosin	Yellow fever mosquito	<i>Aedes aegypti</i>	Aed a 10	XP_001655954	60.0% (10/15)	Inhalation	Cantillo <i>et al.</i> , 2017 [57]
	German cockroach	<i>Blattella germanica</i>	Bla g 7	AF260897	16.2% (6/37)	Inhalation	Jeong <i>et al.</i> , 2003 [58]
	Oriental cockroach	<i>Blatta orientalis</i>	-	NA	NA	Inhalation	Asturias <i>et al.</i> , 1999 [59]
	Silkworm	<i>Bombyx mori</i>	-	NM_001110312	53.3% (8.15)	Ingestion	Jeong <i>et al.</i> , 2017 [30]
	Non-biting midge	<i>Chironomus kiiensis</i>	Chi k 10	CAA09938	80.9% (17/21)	Inhalation	Jeong <i>et al.</i> , 2004 [60]
	Formosan subterranean termite	<i>Coptotermes formosanus</i>	Copt f 7	AGM32377	31.3% (5/16)	Inhalation (cross-reaction)	Mattison <i>et al.</i> , 2017 [61]
	Silverfish	<i>Lepisma saccharina</i>	Lep s 1	CAC84590	100% (3/3)	Inhalation	Barletta <i>et al.</i> , 2005 [62]
	House fly	<i>Musca domestica</i>	-	NA	51.7% (15/29)	Inhalation	Martinez <i>et al.</i> , 1997 [63]
	American cockroach	<i>Periplaneta americana</i>	Per a 7	Y14854	41.4% (12/29)	Inhalation	Asturias <i>et al.</i> , 1999 [59]

(Table 2) contd....

Biochemical identity	Allergen source		Allergen name (IUIS)	Accession No.*	IgE reactivity	Route of exposure	References
	Common name	Scientific name					
-	Dusky brown cockroach	<i>Periplaneta fuliginosa</i>	Per f 7	AF106961	26.9% (7/26)	Inhalation	Jeong <i>et al.</i> , 2004 [64]
	Mealworm	<i>Tenebrio molitor</i>	-	NA	NA	Cross-reaction	Verhoeckx <i>et al.</i> , 2014 [34]
α -amylase	Mealworm	<i>Tenebrio molitor</i>	-	P56634	NA	Ingestion	Verhoeckx <i>et al.</i> , 2014 [34]
	German cockroach	<i>Blattella germanica</i>	Bla g 11	ABC68516	41.4% (12/29)	Inhalation	Jeong <i>et al.</i> , 2013 [65]
	American cockroach	<i>Periplaneta americana</i>	Per a 11	KR019685	83.0% (39/)	Inhalation	Fang <i>et al.</i> , 2015 [66]
Paramyosin	Silkworm	<i>Bombyx mori</i>	-	EU812510	NA	Ingestion	Zhao <i>et al.</i> , 2015 [31]
	Mealworm	<i>Tenebrio molitor</i>	-	XP_970719	NA	Ingestion	van Broekhoven <i>et al.</i> , 2015 [35]
Hexamerin/hemocyanin	Mealworm	<i>Tenebrio molitor</i>	-	XP_966959	NA	Ingestion	van Broekhoven <i>et al.</i> , 2015 [35]
	Bombay locust	<i>Patanga succuncta</i>	-	NA	NA	Ingestion	Phiriyangkul <i>et al.</i> , 2015 [52]
	Cricket	<i>Gryllus bimaculatus</i>	-	NA	NA	Ingestion (cross-reaction)	Srinroch <i>et al.</i> , 2015 [44]
	German cockroach	<i>Blattella germanica</i>	Bla g 3	GU086323	23.0% (14/61)	Inhalation	Khurana <i>et al.</i> , 2013 [67]
	American cockroach	<i>Periplaneta americana</i>	Per a 3	GU726839	100% (19/19)	Inhalation	Wu <i>et al.</i> , 1997 [68]
Myosin	Mealworm	<i>Tenebrio molitor</i>	-	CAA37309	NA	Ingestion	van Broekhoven <i>et al.</i> , 2015 [35]
	German cockroach	<i>Blattella germanica</i>	Bla g 8	DQ389157	NA	Inhalation	Allergen.org
Trypsin	Mealworm	<i>Tenebrio molitor</i>	-	DQ356015	NA	Ingestion	Verhoeckx <i>et al.</i> , 2014 [34]
	German cockroach	<i>Blattella germanica</i>	-	DQ149980	NA	Inhalation	Ock <i>et al.</i> , 2005 [69]
Serine protease	Mealworm	<i>Tenebrio molitor</i>	-	DQ356023	NA	Ingestion	Verhoeckx <i>et al.</i> , 2014 [34]
	American cockroach	<i>Periplaneta americana</i>	Per a 10	AY792954	82.2% (35/47)	Inhalation	Sudha <i>et al.</i> , 2008 [70]
Chitinase	Silkworm	<i>Bombyx mori</i>	-	AB104488	NA	Ingestion	Zhao <i>et al.</i> , 2015 [31]
	American cockroach	<i>Periplaneta americana</i>	Per a 12	KR019686	60.0% (9/15)	Inhalation	Fang <i>et al.</i> , 2015 [66]
	Silkworm	<i>Bombyx mori</i>	-	AB104488	NA	Ingestion	Zhao <i>et al.</i> , 2015 [31]
Enolase	Bombay locust	<i>Patanga succuncta</i>	-	NA	NA	Ingestion	Phiriyangkul <i>et al.</i> , 2015 [52]

(Table 2) contd....

Biochemical identity	Allergen source		Allergen name (IUIS)	Accession No.*	IgE reactivity	Route of exposure	References
	Common name	Scientific name					
-	German cockroach	<i>Blattella germanica</i>	-	ABC96322	25.0% (8/32)	Inhalation	Chuang <i>et al.</i> , 2010 [53]
27 kDa hemo-lymph glycoprotein	Silkworm	<i>Bombyx mori</i>	-	AB062103	33.3% (5/15)	Ingestion	Jeong <i>et al.</i> , 2016 [26]
	Wax moth/bee moth	<i>Galleria mellonella</i>	-	NA	NA	Inhalation	Antico <i>et al.</i> , 2017 [27]
GAPDH	Bombay locust	<i>Patanga succuncta</i>	-	NA	NA	Ingestion	Phiriyangkul <i>et al.</i> , 2015 [52]
Pyruvate kinase	Bombay locust	<i>Patanga succuncta</i>	-	NA	NA	Ingestion	Phiriyangkul <i>et al.</i> , 2015 [52]

*Accessions No. of some allergens identified by MS/MS analyses or antibodies are not available (NA).

Table 3. Allergenic glutathione S-transferases from insects.

Organism		Allergen name (subtype)	Accession No.	IgE reactivity	Route of exposure	References
Common name	Scientific name					
German cockroach	<i>Blattella germanica</i>	Bla g 5 (sigma class)	U92412	72.5% (29/40)	Inhalation	Arruda <i>et al.</i> , 1997
German cockroach	<i>Blattella germanica</i>	BgGSTD1 (delta class)	EU266076	17.9% (7/39)	Inhalation	Jeong <i>et al.</i> , 2009
American cockroach	<i>Periplaneta americana</i>	Per a 5	AY92949	39.1% (25/64)	Inhalation	Lee <i>et al.</i> , 2012

lar patterns not only from the human gut microbiome, but also from the insect microbiome.

Chitin, a major component of insect exoskeletons, could play an important role in induction of allergic inflammation [105, 106]. Chitin may at least partly explain why shellfish (shrimp) allergies are common and may also be related to edible insect allergies. However, it is interesting to note that the homologous proteins of major shrimp allergens are not major allergens in silkworm pupae. Further studies are needed to address these phenomena.

CONCLUDING REMARKS

Insects are important sources of allergenic molecules, and there is increasing interest in edible insects as dietary supplements and medicinal components [107]. Insect allergens can be introduced into the human body by inhalation, ingestion, stings, and bites. Insect sting (Hymenopteran insects) allergens that frequently cause anaphylaxis are relatively well characterized, as are the allergens from insect bites [57, 71]. Cockroaches have long been recognized as an important cause of asthma, and some cockroach allergens have been characterized [79]. However, less attention has been given to the characterization of edible insect allergens, and most published studies have employed sera from patients with allergies to house dust mites or crustaceans. Further studies using specimens from patients with edible insect allergies are urgently required so that genuine edible insect allergens can be identified.

The production of recombinant allergens may enhance the development of diagnostics and therapeutics. The labeling of allergen sources in food merchandise is an important measure to prevent possible adverse reactions to unwanted food consumption. Therefore, most developed countries legally require the labeling of common food allergen sources, reflecting the recommendations of the Codex Alimentarius Commission, although the detailed labeling laws vary among countries [13]. The development of a quantification system for edible insect allergens along with an allergen labeling system may reduce the number of patients suffering from food allergies to edible insects.

LIST OF ABBREVIATIONS

CCD = Cross-reactive carbohydrate determinant

CRD = Component-resolved diagnosis

CONSENT FOR PUBLICATION

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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