DRAFT SCIENTIFIC OPINION

Scientific Opinion on the evaluation of allergenic foods and food ingredients for labelling purposes[1]

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA)[2, 3]

European Food Safety Authority (EFSA), Parma, Italy

ABSTRACT

Following a request from the Food Safety Authority of Ireland, the EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) was asked to deliver a scientific opinion on the evaluation of allergenic foods and food ingredients for labelling purposes. In view of the request, the NDA Panel decided to update its previous opinions relative to food ingredients or substances with known allergenic potential listed in Annex IIIa of 2003/89/EC, as amended. These include cereals containing gluten, milk and dairy products, eggs, nuts, peanuts, soy, fish, crustaceans, molluscs, celery, lupin, sesame, mustard and sulphites. The Opinion relates to IgE- and non IgE-mediated food allergy, to coeliac disease, and to adverse reactions to sulphites in food, and does not address non-immune mediated adverse reactions to food. It includes information on the prevalence of food allergy in unselected populations, on proteins identified as food allergens, on cross-reactivities, on the effects of food processing on allergenicity of foods and ingredients, on methods for the detection of allergens and allergenic foods, on doses observed to trigger adverse reactions in sensitive individuals, and on the approaches which have been used to derive individual and population thresholds for selected allergenic foods.

KEY WORDS

food allergy, prevalence, allergens, methods of detection, eliciting dose, thresholds, food labelling

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SUMMARY

Following a request from the Food Safety Authority of Ireland, the EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) was asked to deliver a scientific opinion on the evaluation of allergenic foods and food ingredients for labelling purposes.

In view of the request, the NDA Panel decided to update its previous opinions relative to food ingredients or substances with known allergenic potential listed in Annex IIIa of Dir 2003/89/EC, as amended, which include cereals containing gluten, milk and dairy products, eggs, nuts, peanuts, soy, fish, crustaceans, molluscs, celery, lupin, sesame, mustard and sulphites. In this context, EFSA launched a procurement project (CT/EFSA/NDA/2012/02) to review published data on the prevalence of food allergy in Europe and to gather prevalence data on food allergy in the general (unselected) population. Prevalence data on allergies to foods not included in Annex IIIa will be reported whenever available.

The present Opinion relates to IgE- and non IgE-mediated food allergy, to coeliac disease, and to adverse reactions to sulphites in food, and does not address non-immune mediated adverse reactions to food. For each food ingredient or substance listed in Annex IIIa, it includes information on the prevalence of food allergy in unselected populations, on proteins identified as food allergens, on cross-reactivities, on the effects of food processing on allergenicity of foods and ingredients, on methods for the detection of allergens and allergenic foods, and on doses observed to trigger adverse reactions in sensitive individuals.

Immune-mediated adverse reactions to foods manifest with clinical signs and symptoms of variable severity and duration, which may affect different organs and systems. Anaphylactic reactions to food are IgE-mediated and may occur at any age. Non IgE-mediated food allergy includes a wide range of diseases, including atopic dermatitis, protein-induced enterocolitis and eosinophilic esophagitis.

A careful family and clinical history are the basis for diagnosis of food allergy. Food diaries, skin prick tests (SPT), allergen specific IgE measurements, food elimination diets and food challenges are part of the standard protocol for the diagnosis of food allergy. A positive SPT indicates sensitisation to the tested food, but it is not diagnostic of food allergy. Allergen-specific serum IgE antibodies similarly denote sensitisation to a particular food, but are not diagnostic without a clinical history or food challenge. The use of atopy patch tests for the diagnosis of food allergy is controversial. Other available tests have no current role in the diagnosis of food allergy. Diagnosis is confirmed by exclusion of the suspected food and the subsequent amelioration of symptoms, and by the recurrence of symptoms on re-introduction of the offending food, ideally in double-blind placebo-controlled food challenges, provided that the initial symptoms were not life threatening. Dietary avoidance of specific allergenic foods in combination with nutritional advice is the mainstay of management in IgE- and non IgE-mediated food allergy. Food allergic individuals may occasionally outgrow their allergy later in life.

There is a need for standardisation of allergenic foods and preparations for diagnostic use including oral challenge studies, and of derived allergens for SPT, as well as for standard testing protocols in order to facilitate epidemiological and other multicentre studies on allergic reactions to foods.

The prevalence of food allergy in Europe is uncertain. Using food challenges as a criterion for diagnosis, the prevalence of food allergy in Europe has been estimated to be between 3 and 4 %, both in children and adults. There are insufficient objective data to conclude on time trends with respect to the prevalence of food allergy in Europe. About 75 % of allergic reactions among children are due to egg, peanut, cows' milk, fish and various nuts. About 50 % of allergic reactions among adults are due to fruits of the latex group and of the *Rosaceae* family, vegetables of the Apiaceae family, and various nuts and peanuts. Anaphylactic reactions have been reported to foods not included in Annex IIIa.

Geographical variation in the prevalence of food allergy is due to differences in genetic regional and local factors, like pollen exposure or differences in food habits. Extrapolations of prevalence data on specific food allergies from a single European country to the entire European population are of limited accuracy due to differences in exposure to the offending foods and eating habits.

Owing to the development of proteomics, spectroscopic methods and gene cloning, allergenic proteins can be well characterised. They have been classified into families based on their sequence and three-dimensional (3D) structure. However, although common structural features of proteins and their biological activity have been tentatively related to their antigenicity, it is not possible to predict the allergenicity of a protein based on these two parameters only. Immunological and clinical data are also required to classify a protein as a food allergen.

Cross-reactivity occurs when IgE antibodies originally triggered against one antigen also bind a different antigen. Not all cross-reactivities identified *in vitro* are of clinical significance, and although most clinical cross-reactions are mediated by IgE antibodies, T cells may also be involved. However, *in vitro* cross-reactivity testing can help understanding allergenicity to multiple foods, as well as improving diagnosis and management of food allergy.

The allergenic activity of a food may decrease, remain unchanged, or even increase by food processing. Considering the multiplicity of the allergenic proteins contained in a whole food and that different proteins may be differently affected by the same treatment, the impact of food processing on the structural and allergenic properties of allergenic foods/ingredients is difficult to predict. In addition, the extent to which allergenic proteins are modified during food processing depends on the type of process and its conditions, the structure of the proteins, and the composition of the matrix. Although the effects of different (technological and cooking) treatments on the IgE-binding capacity of several allergens have been investigated, less information is available on the effects of processing on clinical reactivity.

The majority of kits commercially available for routine food allergen analysis rely on immunological methods. ELISA methods are the most widely used because they are sensitive and specific for the detection of allergenic proteins, and easy to use. However, commercial kits for quantitative analyses use different extraction buffers and calibration procedures, differ in the quality of the antibodies used, and the results vary among commercial brands and batches. Major limitations include matrix effects, insufficient extraction of the protein, insufficient specificity due to cross-reactions, and insufficient reproducibility of results. The use of incurred samples may help to improve the reliability of the method when analysing processed foods.

Mass spectrometry, in combination with techniques such as 2D-SDS-PAGE or chromatography for the preliminary separation of proteins and with allergen databases for their subsequent identification, is a reliable tool for the detection of known allergens and for the identification of new immunoreactive proteins. MS methods for quantitative analysis based on specific standard peptides or stable isotope labelling are not yet suitable for analyses of large numbers of samples, but can confirm results obtained otherwise.

DNA methods allow detection of the allergenic food rather than of the allergenic protein and are complementary to immunological assays. DNA is generally more stable than proteins and thus suitable for analysis of processed foods. The extraction and amplification procedures are well established. Both end-point and real-time PCR allow simultaneous multiple analyses. Whenever ELISA kits are not available or not specific for the analysis of a specific allergenic food/ingredient (e.g. celery), DNA analysis becomes the method of choice. Real-time PCR may provide quantitative results and allows multiplexed analysis. Commercial kits are available.

The main problem for the quantification of allergens by immunological or DNA based methods is the unavailability of certified reference materials (CRM). Reference materials developed by different producers are commercially available for the most important food allergens, but the results obtained

may not be comparable. To the Panel's knowledge, a CRM for the detection of food allergens by immunological methods has only been developed for peanuts. For milk and egg, two reference materials are commonly used.

Current clinical, epidemiological and experimental data do not allow determining safe allergen threshold levels that would not trigger adverse reactions in a sensitised consumer. Different threshold probability distributions and eliciting doses (usually ED_{01}, ED_{05} or ED_{10}, at which 1 %, 5 % or 10 % of the allergic population is likely to react when exposed to that level of allergenic ingredient) have been estimated for few allergenic foods/ingredients, which vary among publications depending on the decisions made by expert committees regarding the amount and characteristics of the challenge studies used, the distribution models applied, and the approach followed to derive population thresholds. Considering that most clinicians exclude from the challenge studies those patients having the most severe reactions and that the reliability of these thresholds has not been tested prospectively in real life conditions yet, the Panel considers that thresholds derived for populations and risk management purposes cannot be used by individuals to manage their allergy, unless they are aware of their own (individual) threshold levels under various conditions.

Coeliac disease is a life-long autoimmune systemic disorder triggered by gluten and similar cereal storage proteins present in wheat, rye and barley. Its prevalence is estimated to be 0.5-1 %. A gluten-free diet is the conventional treatment. The limit values of 20 and 100 mg/kg of gluten in "gluten-free" and "very low gluten" foods, respectively, help managing the diet of most coeliac patients efficiently.

Labelling of foods containing sulphiting agents in concentrations > 10 mg/kg or 10 mg/L is mandatory in the EU, which was based on the limit of detection (LOD) of the analytical methods available at the time. Many very sensitive and reliable methods are now available for analysis of sulphites in foods, with LODs well below 10 mg/kg. However, minimal doses eliciting adverse reactions to sulphites have not been systematically assessed and the lowest concentration of sulphites able to trigger a reaction in a sensitive person is unknown.

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BACKGROUND AS PROVIDED BY THE FOOD SAFETY AUTHORITY OF IRELAND

A certain proportion of the population (1-3 % of adults and 4-6 % of children)[4] suffer adverse health consequences as a result of the consumption of particular foods or food ingredients. Such hypersensitive responses can manifest themselves in various ways, and can be broadly categorised as immune-mediated food allergies or non-immune-mediated food intolerances. The classical food allergy results in a hyper-immune response that is mediated by IgE antibodies, the best known, and potentially most serious of which is peanut allergy. Food intolerances are often more difficult to characterise as they can be caused by non-proteinaceous food components (lactose for example), unlike true allergies which are generally the result of a reaction to one or more individual protein components.

EU food law[5] stipulates that the inclusion of certain allergenic food ingredients in a foodstuff must be indicated on the packaging so that vulnerable consumers are protected from inadvertent consumption. Regulatory authorities across the EU expend considerable resources in sampling and testing foodstuffs to ensure the integrity of food allergen labelling within their jurisdiction. However, effective risk management is hampered by a lack of information on the clinical thresholds applicable to the various allergens as well as variation in risk assessment and management strategies adopted across the EU.

The 2004 opinion of the EFSA Scientific Panel on Dietetic Products, Nutrition and Allergies relating to the evaluation of allergenic foods for labelling purposes[6] is a substantial scientific report that provides details about the main foods and food ingredients that cause allergic or intolerance reactions among EU consumers. The report was the first compiled by EFSA dealing specifically with food allergy and intolerance, and the first at EU level since the Scientific Committee on Food report of 1995.

Though the information within those reports remains valid, a number of developments have occurred, and further information has become available that could be of benefit to risk assessors and risk managers dealing with food allergies and intolerances in the EU. EU-funded research on a multidisciplinary project called EuroPrevall was completed in 2009, and examined "The prevalence cost and basis of food allergy in Europe". Many EU Member States have developed methods and procedures for the assessment and management of food allergies and intolerances within their own jurisdiction. DNA-based testing methods have been used successfully in the detection of misleading food labelling and food fraud. While the use of DNA-based analytical methods in food allergy testing could bring increased sensitivity and reliability compared to immunological methods such as ELISA, the risk of disproportionate regulatory activity could result in a greater use of precautionary "May Contain…." labels, which would not benefit allergy sufferers.

In conclusion, the EFSA report of 2004 remains a valuable scientific document, but could be enhanced by a review of the scientific and other information that has been generated in the seven years since it was adopted. A considered assessment by EFSA of new scientific information could assist in developing a harmonised approach to protecting vulnerable consumers in the EU.

TERMS OF REFERENCE AS PROVIDED BY THE FOOD SAFETY AUTHORITY OF IRELAND

With the benefit of experience gained since 2004 and based on the allergens listed in the annex of Commission Directive 2007/68/EC except for lactose, as the specific issue of lactose thresholds in

[4] Opinion of the Scientific Panel on Dietetic Products, Nutrition and Allergies on a request from the Commission relating to the evaluation of allergenic foods for labelling purposes (Request N°EFSA-Q-2003-016) (adopted on 19 February 2004).

[5] Directive 2003/89/EC of the European Parliament and of the Council of 10 November 2003 amending Directive 2000/13/EC as regards indication of the ingredients present in foodstuffs. OJ L 308, 25.11.2003, p. 15-18.

[5] Directive 2003/89/EC of the European Parliament and of the Council of 10 November 2003 amending Directive 2000/13/EC as regards indication of the ingredients present in foodstuffs. OJ L 308, 25.11.2003, p. 15-18.

[6] Opinion of the Scientific Panel on Dietetic Products, Nutrition and Allergies on a request from the Commission relating to the evaluation of allergenic foods for labelling purposes (Request N°EFSA-Q-2003-016) (adopted on 19 February 2004).

606 lactose intolerance and galactosaemia has been already assessed in a recent opinion of EFSA[7], the
607 Food Safety Authority of Ireland requests that EFSA provides a scientific opinion on:

608 • The prevalence of each allergy in the European Union.

609 • Recommendations for threshold concentrations of each allergen in food that would provide an
610 acceptable level of protection for at-risk consumers;

611 • The suitability, or otherwise, of qualitative and quantitative DNA-based tests (PCR) for the
612 detection and quantification of food allergens in comparison with immunological (e.g. ELISA)
613 or other methods.

614

[7] EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA); Scientific Opinion on lactose thresholds in lactose intolerance and galactosaemia. EFSA Journal 2010;8(9):1777. [29 pp.]. doi:10.2903/j.efsa.2010.1777. Available online: www.efsa.europa.eu/efsajournal.htm

ASSESSMENT

1. Introduction

In view of the request from the Food Safety Authority of Ireland, the NDA Panel decided to update its previous opinions (EFSA, 2004, 2005a, 2005b) relative to food ingredients or substances with known allergenic potential listed in Annex IIIa of 2003/89/EC, as amended. In this context, EFSA launched a procurement project (CT/EFSA/NDA/2012/02) on literature searches and reviews related to the prevalence of food allergy in Europe to gather prevalence data on food allergy in the general (unselected) population (University of Portsmouth, 2013). EFSA is aware of the EU-funded multidisciplinary Integrated Project EuroPrevall, launched in June 2005, which was designed to estimate the prevalence of food allergy and exposure to known or suspected risk factors for food allergy across Europe in adults and children. However, prevalence data from that project have not been published yet and are not available to EFSA.

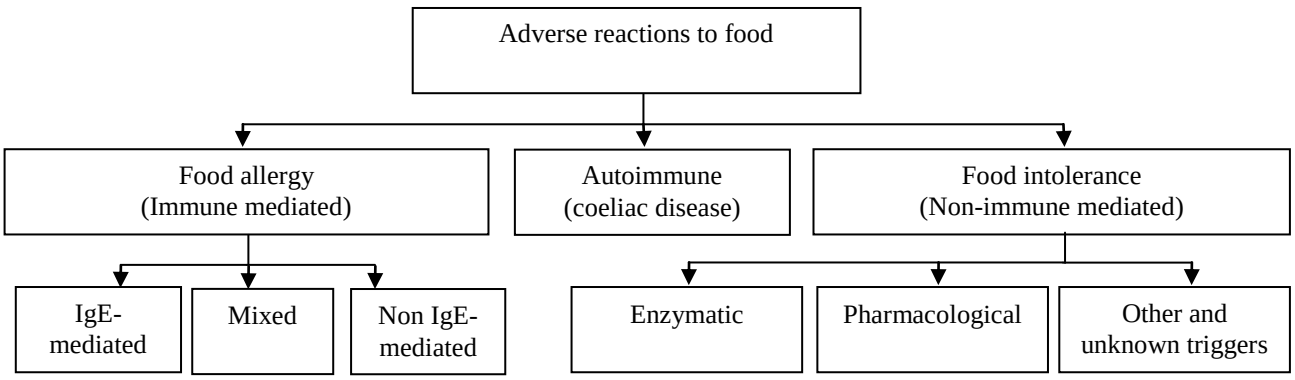
2. Classification of adverse reactions to foods and definition of terms

In this Opinion, the terms **allergenic food** and **allergenic ingredient** will be used for substances listed under Annex IIIa depending on whether they are considered as such or as part of complex foodstuffs, being aware that lactose and sulphites are not food allergens and that gluten may induce both food allergy and coeliac disease. The term **allergen** will be restricted to proteins or peptides responsible for the allergenicity of allergenic foods/ingredients, whereas **total protein** refers to the amount of protein within an allergenic food/ingredient, regardless of whether it is allergenic or not, and not to the amount of a specific allergen.

Adverse reactions to food have been classified into different groups on the basis of the pathogenetic mechanism (Figure 1). They include immunologically mediated reactions, which may be mediated either by IgE antibodies or other immunological pathways (non IgE-mediated), and non-immunological responses (food intolerance), which are dependent on enzyme deficiencies, pharmacological reactions or, in the majority of cases, arise by unknown mechanisms (Ortolani, 1995; Dupont, 2011; Sicherer and Leung, 2011; Vickery et al., 2011; Waserman and Watson, 2011).

Hypersensitivity describes an adverse clinical response where the exact nature of the underlying pathophysiology is unknown. Occasionally this term is used more broadly to describe all adverse reactions to food, including immunologically-mediated diseases and food intolerances. In this Opinion, the term 'food hypersensitivity' will not be used due to its ambiguity.

Figure 1: Classification of adverse reactions to food



Food allergy is defined as an adverse health effect arising from a specific immune-mediated response that occurs reproducibly on oral exposure to a given food (Boyce et al., 2011), which can be mediated by food-specific immunoglobulin class E (IgE) antibodies or not.

Immune, IgE-mediated food allergies may result in rapid-onset of severe reactions (usually < 2 hours) and may manifest with a variety of signs and symptoms that can involve the digestive, respiratory, cardiovascular or cutaneous organ systems (Boyce et al., 2011). The severity of reactions varies from mild (e.g. hives) to severe (e.g. anaphylaxis).

Atopy is a familial tendency to produce IgE antibodies in response to allergens, usually proteins, and to develop typical symptoms such as asthma, rhinoconjunctivitis, or eczema/dermatitis (Johansson et al., 2001). The term "atopic march" has been used to describe the natural history and sequential progression to these atopic disorders.

Immune, non IgE-mediated food allergies more commonly affect only the gastrointestinal tract in a subacute or chronic way. They are typically delayed in onset and occur two to 48 hours after ingestion of the offending food(s). The primary disorders in this category include food protein-induced enterocolitis, food protein-induced proctitis/proctocolitis and enteropathy, which in a majority of cases resolve before adolescence. Enteropathy resulting from cows' milk is one of the better-understood non IgE-mediated food allergies. Although eosinophilic gastrointestinal disorders (including eosinophilic esophagitis and eosinophilic gastroenteropathy) are typically listed under this category, a high number of cases are caused by IgE-mediated responses (Guandalini and Newland, 2011).

Coeliac disease is an autoimmune adverse reaction to food triggered by the ingestion of gluten and related to prolamins found in wheat, barley and rye.

Non-immune mediated adverse reactions to food (also called food intolerances) encompass disorders such as lactose intolerance (due to lactase non-persistence), other disorders of digestive-absorptive processes, toxic (food poisoning) and pharmacologic reactions (also called pseudo-allergic reactions) due to the release of histamine or tyramine after consumption of specific foods (Guandalini and Newland, 2011).

The present Opinion relates to IgE- and non IgE-mediated food allergy, to coeliac disease, and to adverse reactions to sulphites in food, and does not address non-immune mediated adverse reactions to food.

3. Clinical symptoms of food allergy

Immune-mediated adverse reactions to foods manifest with clinical signs and symptoms of variable severity and duration, which may affect different organs and systems (Table 1).

Table 1: Common clinical features of food allergy

Organ system	Clinical features
Skin	Atopic dermatitis
	Urticaria
	Angioedema
	Pruritus
	Erythema
Gastrointestinal tract	Oral allergy syndrome
	Vomiting
	Gastro-oesophageal reflux disease
	Abdominal pain
	Diarrhoea
	Enteropathies
	Infantile colic
	Constipation

	Failure to thrive
Respiratory tract	Asthma
	Rhinitis
	Cough
Eyes	Conjunctivitis
Generalised (systemic)	Anaphylaxis (with all its complications, including cardiovascular symptoms and generalised collapse)

686

687 IgE-mediated allergic reactions to food are represented by well-defined clinical features. For an
688 allergic reaction to take place, a two-step process is required. First, the capacity to respond with an
689 allergic reaction when exposed to the particular allergen must be established. This requires an immune
690 response to take place, in which the immune system responds with IgE antibody production against the
691 allergen. This phase is called the induction phase, or sensitisation. Once an individual has become
692 sensitised to a particular allergen, the individual may develop a symptomatic allergic reaction when
693 exposed again to the allergen in question. This is called the provocation or triggering phase.

694 The food allergic nature of some clinical syndromes such as migraine, attention deficit hyperactivity
695 disorder, and irritable bowel syndrome is still controversial. There is some published evidence that, in
696 a small proportion of individuals, exposure to certain foods or preservatives may be the underlying
697 trigger (Carter et al., 1993; McCann et al., 2007).

698 ## 3.1. Skin

699 ### 3.1.1. Urticaria and angioedema

700 Urticaria is an intensely itchy rash, which results from inflammation and leakage of fluid from the
701 blood into superficial layers of the skin in response to various mediators. Synonyms are “hives” or
702 “nettle rash”. Angioedema is the presence of fluid in subcutaneous tissues, particularly in the face, and
703 in the sub mucosa of eyes, lips, and sometimes tongue and throat. Urticaria can be acute (lasting for
704 less than six weeks) or chronic. In childhood, urticaria is more commonly of the acute type. Chronic
705 urticaria seems to be only rarely associated with food allergy (Zuberbier et al., 2004).

706 Urticaria due to food ingestion generally occurs within hours of ingestion, and often fades within three
707 hours. Initial localised symptoms of itching and burning progress to erythema and urticaria. Immune
708 (IgE)-mediated contact urticaria to foods is common and may progress to more widespread urticaria,
709 angioedema, and eventually anaphylaxis. Rarely, urticaria and angioedema can be induced by exercise
710 soon after eating a food, such as wheat, shellfish, nuts, or celery, whereas neither the food nor the
711 exercise alone causes any reaction.

712 ### 3.1.2. Atopic dermatitis

713 Atopic dermatitis is an extremely pruritic form of chronic inflammatory skin disease usually
714 presenting in early infancy and sometimes persisting in adulthood. Atopic dermatitis represents the
715 first clinical allergic manifestation in children who later develop asthma and, subsequently, allergic
716 rhinitis. This progression is often named atopic march (Spergel and Paller, 2003). Patients with atopic
717 dermatitis have usually high specific IgE levels and positive skin prick test (SPT) for several allergens,
718 and a genetic predisposition (i.e. if one parent is atopic there is a 20-40 % probability of a child
719 developing this condition and, if both parents are atopic, a 50-80 % probability). Epidemiological
720 studies are beginning to identify genes involved in atopic predisposition (Walley et al., 2001;
721 Weidinger et al., 2008; Genuneit et al., 2009). For example, filaggrin gene defects have recently been
722 identified as a major risk factor for the development of atopic dermatitis. These skin barrier defects
723 increase the risk of early onset, severe and persistent forms of atopic dermatitis and concomitant
724 asthma (Marenholz et al., 2006; Worth and Sheikh, 2010).

Other characteristic features of atopic dermatitis are ichthyosis, keratosis pilaris, white dermographism, atopic folds, orbital darkening, anterior sub-capsular cataracts and keratoconus. Acute atopic dermatitis is an acute rash represented by an erythematous, papulovesicular eruption. Chronic dermatitis is characterised by lichenification, excoriation and dyschromic lesions.

In infants, atopic dermatitis may be difficult to distinguish from seborrhoeic dermatitis. The acute rash is typical of the first (infantile) stage up to two years of age. This eczematous lesion is highly pruritic and usually involves both cheeks and the extensor part of the extremities. Lesion of the scalp and wheal formation may also be associated. The second (childhood) stage, from two to 12 years, is characterised by papular lesions and rash that occur in the flexural areas, such as the antecubital and popliteal ones, hands and feet (Rudikoff and Lebwohl, 1998). The third (adult) stage is characterised by diffuse lichenification in facial areas such as the periorbital and perioral areas. Chronic lesions and remission periods may characterise the life of older atopic patients. Atopic dermatitis can be divided into two distinct variants: the extrinsic, allergic form, which occurs with sensitisation towards foods or aeroallergens and high levels of total IgE antibodies; and the intrinsic, non-allergic variant, with low levels of IgE antibodies, in which no sensitisation to foods or aeroallergens can be detected.

The diagnosis of atopic dermatitis is based on well-accepted international criteria, and takes into consideration different clinical and laboratory parameters, such as the kind of skin manifestation and distribution, age of onset, frequency of relapses, association with other atopic diseases, total serum IgE, specific IgE, and blood eosinophilia, among others. On this basis, it is also possible to distinguish between the intrinsic and the extrinsic forms of atopic dermatitis. The standard for diagnosis of immune-mediated reactions to food in chronic atopic dermatitis is a double-blind placebo-controlled food challenge (DBPCFC) (Fleischer, 2008) complemented by a reliable scoring system such as SCORAD (Hanifin and Rajka, 1980; Dermatitis, 1993).

Several clinical studies have addressed the role of food allergy in atopic dermatitis demonstrating the significant effect of food elimination on the improvement of the lesions (Niggemann et al., 1999; Burks, 2003; Greenhawt, 2010). Egg allergy is the most frequent trigger of severe atopic dermatitis in children (Sampson, 1997; Heine, 2006), and egg, together with milk, peanut, soy and wheat, account for about 90 % of food allergy in children with atopic dermatitis. The underlying role of food allergy in the development of atopic dermatitis is more evident in young patients with severe disease. Patients who are allergic to peanuts, tree nuts, fish and shellfish are less likely to outgrow their food-related atopic dermatitis (Skolnick et al., 2001).

3.2. Gastrointestinal tract

Adverse reactions affecting the gastrointestinal tract range from mild oral discomfort after allergen exposure to severe diarrhoea and failure to thrive. Any part of the gastrointestinal tract can be involved and the clinical features may occur alone or together as part of a syndrome. Whereas the oral allergy syndrome is the consequence of IgE-mediated immune reactions, the remaining gastrointestinal symptoms described in this section are mostly non IgE-mediated or mixed.

3.2.1. Oral allergy syndrome

Oral allergy syndrome (OAS) is an IgE-mediated immediate type allergic reaction characterised by symptoms within several minutes after contact with food, involving the mouth and the pharynx (Amlot et al., 1987; Ortolani et al., 1988). The direct contact of the offending food triggers oral and pharyngeal itching, oral papule or blisters, lip irritation and swelling, labial angioedema, and glottis oedema. In some instances, these symptoms are followed by a more complex clinical picture involving several organs, and may lead to life-threatening reactions like anaphylactic shock (Ortolani et al., 1993). Indeed, OAS can be classified into four grades depending on the extent to which other organs are involved and on whether systemic reactions occur. Local oral symptoms are most commonly experienced, while the more severe forms are rare (Ballmer-Weber et al., 2000; Rodríguez et al., 2000; Ballmer-Weber et al., 2001). OAS-induced reactions may rarely spread to cause extra-intestinal symptoms or anaphylaxis (Webber and England, 2010).

OAS's underlying pathophysiology may play a role in the clinical presentation and outcome, depending on whether the cross-reactive protein is a heat-labile pathogenesis-related protein 10 (PR-10), a partially labile profilin, or a relatively heat-stable lipid transfer protein (LTP). OAS is frequently associated to selectively labile allergens contained in fresh fruits and vegetables, so that standard diagnostic procedures must include exposure to fresh fruits and raw vegetables. Oral symptoms are less frequent in patients allergic to foods of animal origin such as milk, eggs, fish, and shrimp (Amlot et al., 1987; Helbling et al., 1999; Schafer et al., 2001; Sugita et al., 2007).

3.2.2. Vomiting and gastro-oesophageal reflux disease

Vomiting is a common feature of allergic reactions to food (Hill et al., 1984; Heine, 2006). It may result from dysmotility induced by inflammation of the oesophagus and stomach mucosa. The inflammatory response may cause bleeding, with blood in the vomit. Gastro-oesophageal reflux disease can occur as an adverse reaction to food, particularly in children, with or without development of eosinophilic esophagitis (Moon and Kleinman, 1995; Ireland-Jenkin et al., 2008; Dalby et al., 2010).

3.2.3. Diarrhoea and enteropathies

The passage of frequent loose stools can result from impaired absorption of nutrients and water, from intestinal secretion of fluid as part of an inflammatory response, or from a combination of both. Food protein induced enterocolitis syndrome (FPIES) is a severe systemic reaction to food proteins, typically occurring within four hours after food ingestion mainly in young infants, but can also occur in older children and adults (Nowak-Wegrzyn and Muraro, 2009).

In infancy and childhood, adverse reactions to food proteins may cause severe diarrhoea ultimately leading to failure to thrive (Savilahti, 2000; Walker-Smith and Walker, 2003).

The major feature of enteropathies is a loss of the normal structure of the intestinal mucosa, which reduces its mucosal digestive and absorptive function (Kuitunen et al., 1975; Walker-Smith, 1992; Vighi et al., 2008). In young children, transient enteropathies to cows' milk, soya, eggs, and other foods may occur. Enteropathy in the context of celiac disease is discussed in section 13.

Allergic eosinophilic gastroenteropathy is a rare disease, which comprises a spectrum of conditions characterised by eosinophilic inflammation of the gastrointestinal wall. They predominantly affect infants and young children, but may occur at any age (Kelly, 2000). Any part of the gastrointestinal tract can be affected and the symptoms and signs reflect the site and extent of the damage. Loss of blood and exudation of serum into the intestinal lumen may result. Involvement of the stomach or oesophagus may present with vomiting. Damage to the small intestine and colon can cause significant loss of endogenous protein and nutrients as well as impaired digestion and absorption (Maloney and Nowak-Wegrzyn, 2007; Oh and Chetty, 2008).

The causes and mechanisms of these conditions are not well understood (Lieberman and Chehade, 2012). Some cases are associated with atopic clinical features and food specific IgE and skin prick tests to milk allergens, but others do not have these features (Moon and Kleinman, 1995; Bischoff, 2010).

3.2.4. Infantile colic

Infantile colic affects approximately 7 %-20 % of babies (Lucassen et al., 2001). Its aetiology is unknown and is likely to be multifactorial. Some cases could be attributed to adverse reactions to foods, such as cows' milk or proteins excreted in maternal breast milk (Drug and Therapeutics Bulletin, 2013)

3.2.5. Constipation

Up to 10 % of children with cows' milk allergy may suffer from constipation. Constipation due to other food items has been described (Kiefte-de Jong et al., 2010). The underlying mechanisms and exact diagnostic criteria of allergy-related gastrointestinal motility disorders have not been established (Iacono et al., 1998; Heine, 2008; El-Hodhod et al., 2010).

3.3. Respiratory tract

3.3.1. Asthma

Asthma is a reversible obstruction of the small airways associated with constriction of the airways, mucus production and inflammation. Asthma may occur as a manifestation of a food allergic reaction. It may sometimes be the dominating symptom, but is often associated with eczema, urticaria, pollen-food allergy syndrome, or gastrointestinal symptoms. Asthmatic symptoms may constitute an important part of a generalised anaphylactic reaction. Deaths from anaphylactic reactions are more often caused by respiratory problems than by hypotension and circulatory failure. Further, asthmatics who are also food allergic are at a higher risk of developing the most severe anaphylactic reactions to food.

Heiner syndrome is a rare pulmonary hypersensitivity syndrome, likely to be cows' milk sensitive, which affects primarily young children and is characterised by pulmonary hemosiderosis, diarrhoea, anaemia and poor growth (Moissidis et al., 2005).

The foods triggering allergic asthma are similar to the general allergic prevalence pattern observed in the community. Comorbidities related to environmental allergens need to be considered when evaluating individuals with a history of food related asthma (Rancé and Dutau, 2002). Most reactions to sulphites are characterised by bronchospasm, occasionally severe, which can occur within minutes after ingestion of sulphite-containing foods.

3.3.2. Laryngeal oedema

Laryngeal oedema, swelling of the mucosa of the larynx, is often seen as part of an anaphylactic reaction to food, and may lead to airways obstruction and, in the worst case, to respiratory arrest (Summers et al., 2008).

3.3.3. Rhinitis

Rhinitis is manifested as an inflammation of the nasal mucosa, which gets swollen and itchy. The condition is often accompanied by clear watery nasal secretion, and by nasal obstruction. Allergic rhinitis has also been reported as a symptom of food allergy, although less frequently than asthmatic symptoms (Oehling et al., 1992). Symptoms suggestive of rhinitis were reported in a number of pollen allergic infants with cows' milk and egg allergy (Balatsouras et al., 2011). Symptoms of rhinitis have also been reported to occur in response to food challenges (Pelikan and Pelikan-Filipek, 1987).

3.4. Eyes

The main form of allergic reaction in the eyes is conjunctivitis, where the surface of the eyes and the inner side of the eyelids get red, swollen and itchy. Conjunctivitis and rhinitis often, but not always, accompany each other, and conjunctivitis tends to occur less frequently than rhinitis. Conjunctivitis in pollen-sensitised individuals has been reported in connection with the intake of specific food items, although less frequently than asthmatic symptoms (Oehling et al., 1992; Kurosaka et al., 2011).

3.5. Generalised symptoms – anaphylaxis

Anaphylaxis is an acute, potentially life-threatening and sometimes fatal condition, which involves the cardiovascular system, the respiratory tract, the mouth, the pharynx and the skin, singly or in combination (Yunginger et al., 1988; Bock and Atkins, 1990; Sampson, 2006). Major cell types

involved through the secretion of vasoactive mediators are eosinophils, mast cells and basophils. Reactions can be triggered both by IgE and IgG (IgG1 > IgG4) antibodies, depending on the cell type involved (Tsujimura et al., 2008).

The initial symptoms often involve the skin or the oropharynx. Symptoms in the mouth region include oedema, tingling and pruritus of the lips, oral mucosa and pharynx. Skin symptoms may be urticaria or more diffuse erythema, angioedema and pruritus. Respiratory symptoms include bronchospasm, cough, stridor, dyspnoea and wheezing, and may be mistaken as worsening of pre-existing asthma. Oedema of the larynx induces cough, and difficulties with talking, breathing and swallowing. Respiratory function may be severely compromised. Anaphylactic shock may consist of cardiovascular collapse and severe fall of the blood pressure, cardiac arrhythmia and, in the worst case, cardiac arrest. In some cases, the initial manifestation of an anaphylactic reaction may be loss of consciousness. The symptoms, their sequence and their severity may vary from one episode to the other and from one individual to another. In fatal food-induced anaphylaxis, initial symptoms commonly develop within 3 to 30 minutes and severe respiratory symptoms within 20 to 150 minutes of exposure (Sampson and James, 1992; Pumphrey and Gowland, 2007). Some reactions may, however, show a bi-phasic course and be mild at their start (Stewart and Ewan, 1996). Exercise-triggered food-induced anaphylactic reactions may occur several hours after food intake. Asthmatic subjects who are also food allergic are at a higher risk of developing the most severe anaphylactic reactions to food (Gonzalez-Perez et al., 2010; Calvani et al., 2011).

The diagnosis of anaphylaxis in retrospective studies has been difficult due to the wide spectrum of clinical presentations. The criteria proposed by the US National Institute of Allergy and Infectious Diseases and the Food Allergy and Anaphylaxis Network are useful for the diagnosis of anaphylaxis in the emergency department (Sampson, 2006; Campbell et al., 2012).

Anaphylactic reactions to food are IgE-mediated. Peanut, tree nuts, fish and crustaceans (in adults) and milk and egg (in children) are the most common foodstuffs reported to induce anaphylaxis in Europe (Hourihane et al., 1996; Sampson, 2000; Jarvinen, 2011; Silva et al., 2012). In addition, a quite unusually high frequency of food-dependent exercise-induced anaphylaxis has been reported in relation to allergic reactions to cereal products (Dohi et al., 1991; Palosuo et al., 1999). However, a number of other food allergens may also cause anaphylactic reactions.

3.6. Conclusion

Immune-mediated adverse reactions to foods manifest with clinical signs and symptoms of variable severity and duration, which may affect different organs and systems. Anaphylactic reactions to food are IgE-mediated and may occur at any age. Non IgE-mediated food allergy includes a wide range of diseases, including atopic dermatitis, protein-induced enterocolitis and eosinophilic esophagitis.

4. Diagnosis of food allergy

4.1. Clinical diagnosis

The diagnosis of immunological adverse reactions to food and food ingredients depends on clinical insight, suspicion, and acumen in interpreting the history and clinical examination of the patient. Diagnosis of food allergy is often difficult because of the variable and subjective nature of the symptoms and the lack of objective clinical signs (Boyce et al., 2011; Dupont, 2011; National Institute for Health and Clinical Excellence, 2011). Guidelines and protocols for the clinical diagnosis of food allergy have been published (Boyce et al., 2011; Dupont, 2011; National Institute for Health and Clinical Excellence, 2011).

The patient's history, and particularly the temporal relationship between exposure and reaction, is key for diagnosis. A family history of atopy will increase the suspicion of immune-mediated adverse reactions to food. However, the lack of a family history does not exclude the diagnosis or an allergic cause of clinical symptoms. Investigation of any patient with clinical suspicion of anaphylaxis of

unknown cause for possible underlying food allergy has been recommended. Important information in relation to the causal role of a foodstuff in the development of symptoms can be derived from the resolution of such symptoms when the offending foodstuff is eliminated from the diet.

4.2. Specific diagnostic tests

Diagnostic procedures for allergic disease of the gastrointestinal tract in childhood have been detailed by several professional bodies and expert reports (Wershil et al., 2002; Bachert and van Cauwenberge, 2003; Lieberman and Sicherer, 2010; Burks et al., 2011; National Institute for Health and Clinical Excellence, 2011; Caubet and Sampson, 2012).

Tests commonly used for the diagnosis of food allergies are described below.

4.2.1. Food challenges

The diagnosis of IgE-mediated and other immunologically mediated adverse reactions to food can only be confirmed by exclusion of the suspected food and the subsequent amelioration of symptoms, and by the recurrence of symptoms on re-introduction of the offending food.

The offending food can be given in open challenges (subjects are aware of being challenged with the offending food, no use of placebo), in single-blind placebo controlled challenges (SBPCFC; subjects are unaware of whether the offending food or a placebo are given), or in double blind placebo controlled food challenges (DBPCFC; both subjects and investigators are unaware of whether the offending food or a placebo are given). Results from open label food challenges (OFC) are more difficult to interpret than results from SBPCFC (i.e. difficult to attribute delayed or subjective symptoms to the ingestion of the offending food in the absence of placebo). DBPCFCs are costly, time-consuming and difficult to perform. Oral food challenges are sometimes rejected by patients or their parents and by health professionals, as there is a risk of severe reactions in highly sensitised individuals unless appropriate measures are taken. However, DBPCFCs are the gold standard because all subjective bias are removed.

4.2.2. Measurement of specific serum IgE antibodies

Allergen-specific serum IgE antibodies denote sensitisation to a particular food, but do not provide information about the occurrence or the severity of allergic reactions following oral exposure to that food. The radioallergosorbent test (RAST) is being increasingly replaced by quantitative immunochemical tests for the determination of food-specific serum IgE antibodies. The clinical sensitivity and specificity of these tests for the diagnosis of food allergy vary according to the conditions in which they are used. Depending on the incriminated food, high levels of specific IgE antibodies are a good indication as to prevent oral provocation tests in highly sensitised patients (Rancé et al., 2002; Bernard et al., 2003; Caubet and Sampson, 2012). However, up to 40 % of individuals with significant allergen specific IgE levels may not experience any clinical symptoms when challenged with this allergen (Boyce et al., 2011).

In order to confirm the specificity of the binding of serum IgE to the test food allergen, RAST tests are sometimes complemented by inhibition studies where the IgE-binding capacity is inhibited by various competitors that are related to the incriminated food. The lack of standardisation of RAST tests for the determination of antibodies to dietary antigens and the lack of discrimination between high and low affinity antibodies have made the quantitative evaluation and the comparison of different studies difficult.

The Panel notes that there is a need for optimisation of antibody-based diagnostic tests to facilitate both the interpretation of published studies and patient management.

4.2.3. Skin prick test

In cases of suspected IgE-mediated immunological reactions to food, a skin prick tests (SPT) may be performed. A small amount of an allergen in solution is placed on the skin and then introduced into the epidermis by gently pricking the skin surface. A positive reaction is manifested as the development of a wheal, the diameter of which can be measured to grade the reaction. The diagnostic accuracy and sensitivity of a SPT in suspected food allergies varies according to the possible offending food and is slightly higher than measuring allergen-specific IgE. A positive SPT indicates sensitisation to the tested food, but it is not diagnostic of food allergy. Negative reactions have a 95 % predictive value to exclude IgE-mediated reactions. However, positive tests have only a 50-60 % positive predictive value (Costa et al., 2011), although strong reactions to certain allergens indicate a higher likelihood of an allergic reaction. SPTs are usually performed on the upper back or volar surface of the forearm. Skin locations may vary in their reactivity and eczematous areas should be avoided (Cox et al., 2008).

In subjects with suspected OAS's, fresh food SPTs typically have the highest sensitivity (Fernandez-Rivas et al., 2008; Webber and England, 2010). The presentation of allergens within the food matrix during a SPT challenge has to be carefully considered, since it may have a marked effect on the reactions experienced after allergen ingestion (Grimshaw et al., 2003).

4.2.4. Labial and conjunctival challenges

Labial and conjunctival food allergen challenges for diagnostic purposes have been performed mostly in children (Rancé and Dutau, 1997; Krane Kvenshagen et al., 2010). However, these tests have not been included into the routine diagnostic work-up owing to lack of standardisation, varying clinical readouts, and absence of validation against prospective DBPCFC studies.

4.2.5. Atopy patch test

The atopy patch test identifies allergens, which may induce a non IgE-mediated (delayed hypersensitivity) reaction. There are published guidelines for the performance of atopy patch test (Turjanmaa et al., 2006). It involves the application of the allergen under an occlusive dressing for 48 hours onto a non-affected part of the patients' skin, and the results are read 20 min and 24 h after removal of the occlusive dressing. The test has been proposed for patients affected by atopic dermatitis and gastrointestinal food allergy (Liacouras et al., 2011). Confirmation of the result by food elimination and subsequent food challenge is needed. However, the specificity and sensitivity of atopy patch tests are still a matter of debate.

4.2.6. Tests of respiratory function

Tests of respiratory function are useful where respiratory signs and symptoms are present in immunologically mediated adverse reactions to food. Such tests may include those for assessing narrowing of the airways and/or inflammation (bronchopulmonary provocation) (Pierce et al., 2005; Beydon et al., 2007), but are not specific of food allergy.

4.2.7. Other tests in immune-mediated adverse reactions to food

Measurements of IgG and IgG subclass antibodies against food antigens in serum have no role in the routine diagnosis of food allergy and should not be the basis for exclusion of particular foods from the diet (Hamilton, 2010).

Flow cytometric studies of peripheral blood mononuclear cells and IgE in faecal extracts may be used as screening tools to identify groups of potentially food allergic patients, but their usefulness in the diagnosis of food allergy in the individual remains to be demonstrated (Beyer and Teuber, 2005; Lock and Unsworth, 2011). The cellular basophil activation test (BAT) (e.g. expression of basophil activation markers such as CD63 and CD203c detected by flow cytometry) has also been proposed for screening, although available technologies may be optimised and better standardised (Sicherer and Sampson, 2013).

The measurement of IgE against specific components of allergens, named components-resolved allergy diagnosis (Vieira et al., 2012) is not yet able to discriminate between sensitisation and clinically relevant food allergy (Ebo et al., 2010b).

ImmunocapISAC is a blood test based on microchip technology to detect specific IgE antibodies to food and airborne allergens. It allows simultaneous measurement of specific antibodies to multiple allergen components in a single test and may allow analysis of sensitisation patterns more likely to be associated with recovery or persistence of allergic sensitisation. There is, however, the risk of over-diagnosis and misinterpretation of the complex results of such tests (Skamstrup Hansen and Poulsen, 2010; Melioli et al., 2011).

4.3. Conclusion

A careful family and clinical history are the basis for diagnosis of food allergy. Food diaries, skin prick tests (SPTs), allergen specific IgE measurements, food elimination diets and food challenges are part of the standard protocol for the diagnosis of food allergy. A positive SPT indicates sensitisation to the tested food, but it is not diagnostic of food allergy. Allergen-specific serum IgE antibodies denote sensitisation to a particular food, but are not diagnostic without a clinical history or food challenge. The use of atopy patch tests for the diagnosis of food allergy is controversial. Other available tests have no current role in the diagnosis of food allergy. Diagnosis is confirmed by exclusion of the suspected food and the subsequent amelioration of symptoms, and by the recurrence of symptoms on re-introduction of the offending food, ideally in double-blind placebo-controlled food challenges, provided that the initial symptoms were not life threatening. The Panel notes that there is a need for standardisation of allergenic foods and preparations for diagnostic use, including oral challenge studies, and of derived allergens for SPT, as well as for standard testing protocols in order to facilitate epidemiological and other multicentre studies on allergic reactions to foods.

5. Management of food allergy

5.1. Allergen avoidance

The mainstay of dietary management of food allergies is the exclusion of the offending allergenic food from the diet and the avoidance of inadvertent exposure under uncontrolled conditions of intake, i.e. travel, restaurant menus, unlabelled food sources (Eigenmann et al., 2008; Lack, 2008; Boyce et al., 2011; Burks et al., 2011). Mothers of exclusively breastfed food allergic infants (i.e. with clinical diagnosis of food allergy) are also advised to eliminate the offending foods from their diet, since breast milk may contain the allergen in amounts able to trigger an adverse reaction in their infants and maintain the underlying disease process (Machtinger and Moss, 1986).

5.2. Immunological approaches for the management of food allergies

5.2.1. Specific oral tolerance induction

Systemic oral tolerance induction (SOTI) to proteins has been recognised for a long time and frequently demonstrated in biological experiments (Niggemann et al., 2006). The underlying mechanisms relating to oral tolerance induction and desensitisation procedures are still a matter of scientific investigation (Eigenmann et al., 2008). Advantages of SOTI could be an increased individual threshold dose for the offending food and thus a reduction of the risk of experiencing severe allergic reactions after inadvertent ingestion of the allergenic food.

SOTI studies with the objective of increasing the minimal dose of an allergenic food eliciting an allergic reaction or even allowing a normal intake of that food have been performed in children allergic to peanut, milk or egg (Staden et al., 2007; Jones et al., 2009; Burks et al., 2012a). A number of study participants were able to increase their minimum eliciting dose after completing the DBPCFC protocol. Since it is unclear whether these therapies lead to immunological tolerance induction with continued allergen exposure or are a variation on (rush) desensitisation protocols, children were advised to continue the intake of the allergenic food at different time intervals. In one of these studies

(Staden et al., 2007), 64 % of the treatment group had a good or at least partial response to SOTI while on treatment. Food challenges performed two months off treatment revealed that only 36 % continued to be tolerant to the allergenic food, a percentage comparable to that achieved in untreated control subjects.

Desensitisation strategies involve rush desensitisation (Itoh et al., 2010) and administration of the food allergens after heating or denaturation. In individuals with egg allergy, egg allergens have been administered in cake, as boiled or scrambled eggs, egg powder, or separated in egg white and yolk (Burks et al., 2012a). The long-term efficacy, safety and cost-effectiveness of SOTI require further assessment (Fisher et al., 2011).

The Panel notes that SOTI are not yet recommended in routine practice as means to induce tolerance in children with IgE-mediated food allergy.

5.2.2. Sublingual immunotherapy

Sublingual immunotherapy (SLIT) has been mainly applied to the treatment of allergic diseases triggered by environmental allergens (Larenas-Linnemann, 2009), and only rarely to food allergy (de Boissieu and Dupont, 2006). A combination of SOTI and sublingual immunotherapy in egg allergic children has been reported (Keet et al., 2012). This study suggests that SOTI is more effective in the treatment of egg allergy than SLIT but has potentially more serious side effects.

5.2.3. Immunological approaches under clinical development

A number of allergen specific and of allergen non specific immunotherapeutic approaches have reached the clinical trial stages (Nowak-Wegrzyn and Sampson, 2011). These include epicutaneous immunotherapy (Dupont et al., 2010) on the allergen specific side and anti-IgE therapy (Wang et al., 2010), Chinese herbal therapy (Srivastava et al., 2009), and anti-cytokine therapy (Straumann et al., 2010).

5.3. Conclusion

Dietary avoidance of specific allergenic foods in combination with nutritional advice is the mainstay of management in IgE- and non IgE-mediated food allergy. Close monitoring of growth of infants and children with food allergy is advised, as well as re-evaluation of food allergy at regular intervals to avoid unnecessary dietary restrictions. Regular pharmacological treatment of food allergic conditions is generally not recommended.

6. Epidemiology of food allergy

6.1. Methodological considerations

Numerous publications reporting on the prevalence of food allergy are available. However, the reliability of the estimates and how these reflect the true prevalence of food allergy in the general population depend on the criteria used for the diagnosis of food allergy and on the selection of the study population. Differences in sample selection and diagnostic criteria may hamper the comparability of results among studies, as well as conclusions on time trends.

The majority of studies rely on self-reported adverse reactions to food to calculate the prevalence of food allergy (Rona et al., 2007). They are easy to perform (generally based on questionnaires) and may include high numbers of subjects from the general (unselected) population. Such studies overestimate the prevalence of food allergy and do not differentiate between food allergy and non-immune reactions to food. However, they give an indication about the proportion of subjects who may follow dietary restrictions to avoid (and experience anxiety towards) the consumption of the "offending" food, regardless of whether they have food allergy or not (Soller et al., 2012).

Positive SPTs and/or IgE-binding (sensitisation) to the offending food in subjects with self-reported adverse reactions may strengthen the suspicion of food allergy, particularly if combined with a convincing history of food allergy and diagnosis by a physician. Still, owing to poor positive predictive value of these tests, studies using these diagnostic criteria only overestimate the prevalence of food allergy and are usually conducted in selected population subgroups (subjects with self-reported food allergy or clinical diagnosis of food allergy), in which the prevalence of food allergy is expected to be higher than in the general population.

Positive DBPCFCs are highly reliable for the diagnosis of food allergy. Nonetheless, studies using DBPCFC for diagnosis have been generally conducted in selected subjects with high suspicion of food allergy, exclude highly sensitised subjects, are difficult to perform, and are generally of small sample size. Open food challenges (OFC) are easier to perform, but the link between food ingestion and delayed or subjective symptoms is difficult to demonstrate in the absence of placebo.

An accurate estimation of the incidence and prevalence of immune-mediated adverse reactions to foods and their time trends has also been hampered by serious discrepancies in the way the International Classification of Diseases (ICD) coding has been used to characterise and classify food allergic reactions across Europe (WHO (World Health Organisation), 1975), WHO, 2011[8]), and by the transition from ICD-9 to ICD-10.

The Panel considers that population-based studies with a step-wise diagnostic approach and confirmation of food allergy using DBPCFC would be required to assess the prevalence of food allergies, but such studies have not been regularly conducted so far.

In this Opinion, only prevalence data for the general population or for age-specific subgroups within the general (unselected) population, rather than data obtained in subjects selected based on their disease risk or disease condition, will be considered whenever available. Data obtained in European countries will be presented first. Prevalence data in Western countries like the US, Canada, and Australia-New Zealand are considered more relevant for Europe than data obtained in Asian or African countries, and only data from the former will be considered for time trends.

6.2. Prevalence

The prevalence of food allergies in developed and developing countries is uncertain. Between 2 % and 35 % of subjects in different populations report a diagnosis of food allergy (Rona et al., 2007), and the prevalence of perceived food allergy is even higher (Roehr et al., 2004). For example, in the US, 5.3 % of adults report a physician-diagnosed food allergy, whereas about 10 % claim perceived food allergy (Vierk et al., 2007). Prevalence of food allergy in studies assessing clinical diagnosis is much lower (Penard-Morand et al., 2005).

The discrepancy between prevalence of perceived and confirmed food allergy among children and adults has been reported in several studies (Zuberbier et al., 2004; Osterballe et al., 2005; Pereira et al., 2005; Venter et al., 2008; Pyrhonen et al., 2009) and a meta-analysis (Rona et al., 2007). When the diagnosis of food allergy is confirmed by a food challenge in unselected populations, the prevalence of food allergy in Europe has been estimated to be between 3 and 4 %, both in children and adults (Table 2).

Several studies indicate that 75 % of allergic reactions among children are due to a limited number of foods, namely egg, peanut, cows' milk, fish and various nuts. Among adults, fruits of the latex group (e.g. kiwi, banana), fruits of the *Rosaceae* family (e.g. apples, pears, prunes), vegetables of the *Apiaceae* family (e.g. carrot, celery), and various nuts and peanuts (Kanny et al., 2001; Sastre, 2010; Dupont, 2011; Gadermaier et al., 2011b) are responsible for 50 % of allergic reactions.

[8] http://www.who.int/classifications/icd/en/

1131 **Table 2:** Reported prevalence of food allergy in European countries[1].

Country	Sample size	Age (years)	Diagnosis	Prevalence (%)	Reference
Denmark	486	3	OFC	2.3	(Osterballe et al., 2005)
	301	> 3		1	
	936	21-59		3.2	
Denmark	562	≤ 6	OFC or DBPCFC	3.6	(Eller et al., 2009)
Denmark	843	22	OFC	1.7	(Osterballe et al., 2009)
Germany	4093	All	DBPCFC	3.6	(Zuberbier et al., 2004)
		0-19		3.3	
		20-39		4.3	
		40-59		2.0	
		> 60		0.5	
Germany	284	0-17	DBPCFC	3.5	(Roehr et al., 2004)
UK	775	11	SPT + history + DBPCFC	1.4	(Pereira et al., 2005)
			SPT + history + OFC	2.3	
			SPT + history + DBPCFC	2.1	
	757	15	SPT + history + OFC	2.2	
UK	798	6	OFC and/or suggestive history + SPT	2.5	(Venter et al., 2006a)
			DBPCFC, clinical diagnosis or suggestive history + positive SPT	1.6	
UK	969	1	Clear history and positive OFC/DBPCFC	2.7 (DBPCFC)-3.0 (OFC)	(Venter et al., 2006b)
UK	891	3	DBPCFC + clear history	2.9	(Venter et al., 2008)
			OFC + clear history	3.0	

1132 [1] Diagnosis of food allergy based on food challenges in unselected populations;
1133 DBPCFC = double-blind placebo-controlled food challenge; OFC = oral food challenge; SPT = skin prick test
1134

1135 ### 6.3. Time trends

1136 There is evidence that the prevalence of atopy has increased over the last decades (Linneberg et al.,
1137 2000; Strannegard and Strannegard, 2001; Kosunen et al., 2002). With respect to food allergy, hospital
1138 admissions in the UK rose from 5 to 26 per million in adults from 1991 to 2004 and from 16 to 107
1139 per million in children during the same period (Gupta et al., 2003; Gupta et al., 2007). However, at the
1140 beginning of the 90's, awareness to food allergy in the medical community was not as widespread as
1141 in the 2000's, and these trends can be explained by changes in perception and diagnostic practices
1142 over time. Increase in public awareness of food allergy with broader media attention should also be
1143 considered when interpreting these results.

1144 Due to the lack of repeated cross-sectional studies over time conducted with comparable
1145 methodologies, there are no objective data to conclude on time trends with respect to the prevalence of
1146 food allergy in Europe.

1147 ### 6.4. Severe reactions/anaphylaxis

1148 Data on the prevalence of food anaphylaxis are to be taken with caution due to the lack of a
1149 universally accepted definition and the risk of misclassification, mostly due to selection bias based on
1150 hospital presentation.

From national mortality registers, anaphylaxis fatalities from all causes were estimated to be 0.33 deaths per year per million in the UK between 1992 and 2003 (n = 202). The cause of fatal episodes of anaphylaxis was reported to be "food or possible food" in 31 % of cases (n = 63), which corresponds to approximately 0.1 deaths per year and per million (Pumphrey, 2004). Tree nuts and peanuts contributed to 50 % of fatal food anaphylaxis in this study. A registry kept in the US recorded 31 individuals who died of food-induced anaphylaxis between 2001 and 2006. Subjects ranged from 5 to 50 years of age. Peanut accounted for 17 deaths, tree nuts for 8, milk for 4 and shrimp for 2. All subjects for whom there are data had asthma (Bock et al., 2007).

The prevalence of asthma in Europe varies from about 10 % to 20 % according to the International Study of Asthma and Allergies in Childhood (ISAAC) (Pearce et al., 2007). Some studies suggest that about 2 % of adults (Ozol and Mete, 2008) and about 6-8 % of children (Oehling and Cagnani, 1980; Novembre et al., 1988) with asthma may show an asthmatic reaction on food challenge. Food allergy has been found to be a major risk factor for severe asthma and life-threatening asthma episodes (Liu et al., 2010a). Asthma is also present in nearly all people who have fatal anaphylactic reactions, and severe asthma is a common manifestation of food allergy (Pumphrey, 2004; Bock et al., 2007).

6.5. Prevalence of allergy to foods not listed in Annex IIIa

Numerous foods have been reported to cause adverse reactions in sensitive individuals, but the majority of prevalence studies rely on self-reported reactions (University of Portsmouth, 2013). The relevance of prevalence data on food allergy from self-reported diagnosis is very limited for some foods (e.g. strawberry, tomato) because food allergy (IgE- and non IgE-mediated) and food intolerance due to the release of biogenic amines (e.g. histamine) have similar symptoms and clinical presentation, and thus the differential diagnosis may be difficult.

6.5.1. Vegetables

Vegetables are often part of the category "other foods" in prevalence studies that rely on questionnaire-based methods. Allergies to vegetables reported in Europe include, but are not limited to, peas, spinach, eggplant and carrot.

SPT plus clinical history was used by only two studies reporting prevalence of allergy < 1 % to carrot and carrageen in adults in Germany (Zuberbier et al., 2004), and of 0 % to pea in 18 month Icelandic children (Kristjansson et al., 1999). Seven studies used food challenges to confirm food allergy (Zuberbier et al., 2004; Osterballe et al., 2005; Venter et al., 2006a; Gelincik et al., 2008; Venter et al., 2008; Orhan et al., 2009; Mustafayev et al., 2012). With the exception of Zuberbier et al. (2004), who reported a 1.8 % prevalence of challenge proven allergy to "vegetables" (n = 3156), prevalence rates were < 0.5 %. In a study of 741 subjects (age range 5-60 years) randomly selected from rural and urban areas, the prevalence of IgE-mediated eggplant (*Solanum melongena*) allergy based on SPT and clinical history has been estimated to 0.8 % in India (Harish Babu et al., 2008). About 9.2 % of subjects reported adverse reactions to ingestion of eggplant, but some of the adverse reactions reported could be due to the pharmacological action of histamine and other non-protein components (tyramine, serotonin) rather than to specific protein allergens.

6.5.2. Fruits

Fourteen studies reported on fruit allergies in unselected populations. The data were published from 1982 to 2012 and the age of the participants ranged from birth to 97 years (University of Portsmouth, 2013).

6.5.2.1. Citrus fruit

The highest rate of citrus fruit allergy, 11 %, was reported using a self-report method in a sample of 3 year old children in Finland (Kajosaari, 1982). Only two studies used food challenges, reporting a prevalence of 2 % in 6 year olds in Finland (Kajosaari, 1982) and under 0.1 % of adults in Turkey (Gelincik et al., 2008). Allergy to citrus fruits often results in mild symptoms (OAS), although reports

of severe reactions including anaphylaxis are also available (Ebo et al., 2007; Tsiougkos and Vovolis, 2013).

6.5.2.2. Strawberry

Strawberry allergy has been addressed in six studies. Similar to the pattern for citrus fruits, the highest rates were found in young Finnish children: 7 % at age 1, 4 % at age 2 and 7 % at age 3 years, however all were estimated using self-report methods (Kajosaari, 1982). Lower rates of self-reported strawberry allergy were found in adults in Turkey (0.7%), which translated to near 0 % prevalence when diagnosis was made using DBPCFC (Gelincik et al., 2008; Orhan et al., 2009).

6.5.2.3. Kiwi

Self-reported prevalence of allergy to kiwi fruit was 0.8 % in a sample of French children (Rancé et al., 2005). The prevalence of self-reported kiwi allergy in Turkey was 0.3 % in children, decreasing to 0.1 % when a DBPCFC method was employed for diagnosis (Orhan et al., 2009). The same prevalence was found three years later in a similar population of children using OFC (Mustafayev et al., 2012).

6.5.2.4. Tomato

Tomato is consumed worldwide and notably in the Mediterranean countries. Consumption of raw tomatoes in Europe ranges between 5.9 g/day in the Netherlands to 112.5 g/day in Greece (Jenab et al., 2005). Clinical reactions to tomatoes are mostly local and mild (OAS), although severe reactions to tomato have also been reported (Zacharisen et al., 2002). The majority of tomato allergic patients develop symptoms after eating fresh tomato fruits and often tolerate consumption of processed tomato products (Pravettoni et al., 2009).

Studies that evaluate the prevalence of tomato allergy in general population are scarce. Self-reported diagnosis of tomato allergy in children ranges between 0.01 % in Israel (Dalal et al., 2002) to 13.7 % in Sweden (Kristjansson et al., 1999). Lower rates were reported in Iceland within the same age group (3.1 %) (Kristjansson et al., 1999). Prevalence of self-reported allergy to tomato in adolescents and young adults in Sweden was 3.5 % (Marklund et al., 2004), similar to the prevalence found in Denmark in the same age category among patients sensitised to pollen (Osterballe et al., 2009). In adults, the prevalence of self-reported tomato allergy is between 0.1 % in Portugal (Falcao et al., 2004) and 0.4 % (Woods et al., 2001) including data from Europe, United States, Australia and New Zealand combined.

The prevalence of sensitisation to tomato assessed by SPT has been estimated to be 0.01 % in children aged up to two years in Israel (Dalal et al., 2002), and 0.4 % in 2-14 years old in France (Rancé et al., 2005).

The only study based on challenge tests was conducted in Denmark (Osterballe et al., 2005), where the prevalence of tomato allergy was estimated to be 1.2 % in an unselected population of children and adults and 5 % among pollen-sensitised participants.

6.5.3. Other foods

6.5.3.1. Cocoa

There are few reports in the literature regarding allergic reactions to cocoa and no reports on anaphylaxis. IgE-mediated and non IgE-mediated reactions have been documented. In Turkey (Orhan et al., 2009), the prevalence of allergy to cocoa in children 6-9 years of age differed depending on the assessment method used. Prevalence of self-reported allergy was 3 %, decreasing to 0.5 % when assessed by SPT and history and down to 0.1 % when allergy was confirmed by DBPCFC. Similar prevalence rates have been reported for adults in the same country (Gelincik et al., 2008) and for the general population in Germany (Zuberbier et al., 2004).

6.5.3.2. Buckwheat

Buckwheat (*Fagopyrum esculentum*) is a common food triggering potentially fatal anaphylaxis in Asia, especially in Japan and Korea (Takahashi et al., 1998; Oh et al., 2004). Labelling of buckwheat is mandatory in Japan, possibly reflecting the higher prevalence of this allergy in Asia. Buckwheat is used in several types of Japanese noodles. In Europe, buckwheat flour is used in pancakes and crepes, but it is also a common ingredient in gluten-free products, to which coeliac patients are particularly exposed. Twenty-two documented cases of severe anaphylaxis associated with buckwheat were declared by the French Allergy Vigilance Network between 2002 and 2006 (Beaudoin, 2007). No prevalence data on buckwheat allergy in unselected European populations or in coeliac patients is available in the literature.

6.5.3.3. Rice

Rice (*Oryza sativa*) is a cereal widely consumed in the EU. Many studies describe immediate hypersensitivity reactions to rice. Rice ingestion may cause urticaria, bronchial asthma, rhinoconjunctivitis, food protein-induced enterocolitis syndrome and, occasionally, anaphylaxis (Goliáš et al., 2013). Several rice allergens have been described, but only two, Ory s 1 (β-expansin) and Ory s 12 (profilin A), both isolated from rice pollen, have been well characterised and included in the International Union of Immunological Societies (IUIS) allergen database. The LTP Ory s 14 is relatively resistant to heat and acid and may be the cause of symptoms and cross-reactivity between rice and various plant foods, such as corn and peach (Asero et al., 2007). No prevalence data on rice allergy in unselected European populations is available in the literature.

6.6. Conclusion

The prevalence of food allergy in Europe is uncertain. Using food challenges as a criterion for diagnosis, the prevalence of food allergy in Europe has been estimated to be between 3 and 4 %, both in children and adults. There are insufficient objective data to conclude on time trends with respect to the prevalence of food allergy in Europe. About 75 % of allergic reactions among children are due to egg, peanut, cows' milk, fish and various nuts. About 50 % of allergic reactions among adults are due to fruits of the latex group and of the *Rosaceae* family, vegetables of the *Apiaceae* family, and various nuts and peanuts. Anaphylactic reactions have been reported to foods not included in Annex IIIa.

7. Influence of environmental and individual factors in the distribution of food allergies

The occurrence of allergies in general, and of food allergies in particular, requires the susceptibility of the host and the exposure to the allergen. Geographical variations in the prevalence of food allergy are driven by genetic factors and further modified by regional or local factors, like pollen exposure or differences in food habits. Although little is known about the variability of genetic susceptibility among populations or the factors, which may modify allergic responses, extrapolation of prevalence data on specific food allergies from a single European country to the entire European population may be limited by differences in exposure to the offending foods and eating habits. Inter-country differences in reporting adverse reactions to foods have also been noted and likely attributed to cultural differences (Woods et al., 2001).

7.1. Environmental factors

7.1.1. Food consumption

Some foods are more allergenic than others, i.e. they have a greater intrinsic capacity to induce allergic sensitisation and elicit allergic reactions in the general population. Examples of highly allergenic foods are milk, egg, fish and other seafood, peanuts and other nuts, soy, sesame seeds and celery. Other foods e.g. potatoes induce allergy more rarely, in spite of high levels of consumption. The amount of allergen consumed is considered an important determinant of food allergy, which in turn depends on the amount of a given allergenic food that is consumed on a regular basis (eating habits).

7.1.1.1. Allergenic proteins in foods

Common proteins that are present in large quantities in a food will have a greater probability of becoming allergens than proteins that are present in small quantities. Storage proteins of many nuts and seeds are an example. These proteins may account for half the weight of the seed or nut. The amount of some allergens in a food will depend on plant variety and growing conditions, and this may contribute to geographical variation of some food allergies, and to variation in the allergenicity of a given plant product (Codina et al., 2003).

7.1.1.2. Eating habits

In a geographic area where a certain food is commonly consumed, the risk of allergy to that food will generally be larger than in areas where that particular food is more rarely eaten. If a food is commonly eaten, not only will the induction of allergy to that food be more likely, but also allergic reactions will be more frequently triggered. The individual dose-response relationship between the consumption of a specific food and the development of sensitisation/allergy to that food is unknown. The individual dose-response relationship appears to be dependent on genetic and other individual factors.

Despite uniformisation of diets notably in Western countries, regional differences in the type and amount of food allergies are clear. For example, prevalence rates of peanut allergy are higher in North America and UK than in Mediterranean countries. This is illustrated by the fact that the prevalence of peanut allergy is 10-fold higher in Jewish children living in the UK than in Jewish children living in Israel (Du Toit et al., 2008). Such differences in prevalence may be due to differences in the level of allergen exposure or food processing rather than to differences in genetic background (Lack, 2012).

7.1.1.3. Introduction of food and breastfeeding

Best practices in relation to maternal diet, breastfeeding, and time of introduction of solid foods in order to decrease the risk of atopic diseases in infants at risk (i.e. with at least one (in Europe) or at least two (in the US) first degree family member being allergic) have been a matter of debate (Greer et al., 2008).

There is no evidence that maternal dietary restrictions during pregnancy play a significant role in preventing atopic disease (asthma, allergic rhinitis, food allergies or eczema) in infants (Kramer and Kakuma, 2012). Exclusive breastfeeding for at least four months decreases the incidence of eczema and cow's milk allergy in the first two years of life compared to intact cow's milk-based formulas in at risk infants (Zeiger, 2003; Greer et al., 2008; Boyce et al., 2011).

In infants at risk who are not breastfed, early dietary intervention in the first four months of life with cow’s milk protein hydrolysates (extensively hydrolysed casein or partially hydrolysed whey formulas) appear to reduce allergic manifestations significantly (Osborn and Sinn, 2006; Szajewska and Horvath, 2010). Most studies showing a preventive effect were mainly on atopic dermatitis (Szajewska and Horvath, 2010), but also on food allergy and early wheezing (Zeiger, 2003). A 10-year follow-up of the German Infant Nutritional Intervention (GINI) Study showed that feeding with a partially whey hydrolysed or an extensively hydrolysed casein formula may decrease the cumulative incidence of eczema but not asthma, allergic rhinitis, or sensitisation to common food allergens or aeroallergens in children at risk up to age of 10 years, compared to an intact cow's milk-based or an extensively hydrolysed whey formulas (von Berg et al., 2013). In this context, it is to note that no regulatory definition of the level of protein hydrolysation in formulas is available and that the extent to which a formula is declared to be hydrolysed does not imply an effect on the risk of developing allergy. The Panel considers that clinical studies are necessary to demonstrate the potential of each particular hydrolysed formula to prevent the occurrence of short and long-term clinical manifestations of food allergy in infants at risk who are not breastfed.

Current evidence does not support feeding with a hydrolysed formula for the prevention of allergy compared with exclusive breastfeeding (Osborn and Sinn, 2006). Amino acid-based formulas, and

intact or hydrolysed soy or rice formulas, have not been shown to prevent allergic diseases in intervention studies.

It has been suggested that early complementary feeding (before four months) may reduce allergic sensitisation in children with a parental history of asthma or allergy (Joseph et al., 2011), and that dietary manipulation might affect the risk of developing food allergy and atopic manifestations such as asthma or eczema in infants at risk (Kumar et al., 2010). However, the evidence is insufficient to recommend the introduction of complementary feeding before four months for that purpose. In addition, there is no convincing scientific evidence that avoidance or delayed introduction of foods beyond 4-6 months reduces the risk of allergies in infants at risk (Greer et al., 2008). Concerns have been raised by the National Institute for Allergy and Infectious Diseases (NIAID) in relation to delaying the introduction of certain foods, which could result in inadequate nutritional intake, growth deficits and feeding problems (Boyce et al., 2011).

7.1.2. Food processing and preparation

Processing and preparing food may increase or decrease its allergenicity. The same raw product may be processed and prepared in different ways according to local traditions and socio-economical setting. Also, the food matrix may influence the likelihood of inducing an allergic reaction, its severity, and/or the time of the reaction after food ingestion (food matrix effect).

7.1.3. Other environmental factors modulating allergic reactions to food

The "hygiene hypothesis" suggests that the lack of early exposure to microorganisms increases the susceptibility to atopic diseases by modulating the development of the immune system (Prescott et al., 2010; Gourbeyre et al., 2011). However, while certain infections are suggested to be protective, other studies do not support this hypothesis, and some parasites (e.g. *Ascaris suum*) and respiratory viral infections have been associated with an increased risk of developing food allergy (Ben-Shoshan et al., 2012).

7.2. Individual factors

7.2.1. Genetic background

A family history of food allergy is a major risk factor for the development of food allergy. For example, having a sibling with peanut allergy increases the risk of developing peanut allergy by five (Hourihane et al., 1996). A limited number of reports describe a significant association between specific food allergies and specific HLA types. Since some HLA types show distinct geographical variation, such variation could, in principle, contribute to the geographical variation of food allergy. However, the extent to which HLA types determine clinical allergic reactions to particular foods is uncertain. For example, HLA-DRB1, DQB1 and DPB1 have been associated with an increased frequency of peanut allergy (Boehncke et al., 1998; Howell et al., 1998). However, none of such associations were statistically significant after adjustment for multiple testing (Hong et al., 2009) and a genotypic association between the HLA class II alleles and peanut allergy in a cohort of sibling pairs discordant for peanut allergy could not be established (Shreffler et al., 2006).

7.2.2. Age and sex

The overall occurrence of food allergy changes with age (Osterballe et al., 2005; Pereira et al., 2005; Venter et al., 2006a; Venter et al., 2006b; Venter et al., 2008; Zuidmeer et al., 2008; Osterballe et al., 2009), and so do the specific allergies (Kagan et al., 2003; Rona et al., 2007; Zuidmeer et al., 2008). Egg and milk allergy are quite common among infants, but are often outgrown in early childhood. Conversely, shellfish allergy is more common among adults than children, while peanut allergy is more common among children than among adults. The age dependency of food allergy is partly due to the so-called "atopic march" and could also be in part explained by exposure factors. Milk consumption is high for small children, while shellfish is consumed more commonly by schoolchildren and adults.

To which extent sex may determine the individual susceptibility to food allergy has not been systematically investigated. In adults, food allergy is somewhat more common in adult women (Schafer et al., 2001; Zuberbier et al., 2004). Of the first 250 cases reported to the Norwegian National Reporting System and Register of Severe Allergic Reactions to Food, the female to male ratio was about 3:2 (Løvik and Namork, 2004) in adults. The putative gender difference could be due to physiological differences or to differences in health-seeking behaviour. There is also little information on sex differences in food allergy in children, among which food allergy seems to be more common in males (Ben-Shoshan et al., 2012).

7.2.3. Socio-economic factors

Most (Metsala et al., 2010; Gupta et al., 2011), but not all (Victorino and Gauthier, 2009; Liu et al., 2010a) studies suggest an increased rate of food allergy in higher socio-economic populations, but evidence on the association is still controversial. The direct association between parental socioeconomic status and food allergy notably in children can be explained by the fact that mothers of high economic status consult a physician more often compared with mothers of lower socioeconomic status.

The geographic remoteness from cities (rural areas) characterised by difficulties to access to primary and specialist medical care and sometimes important cost of transportation could also explain that socio economic advantage and residence in major cities may be considered as risk factors for childhood food allergy (Mullins et al., 2010). However, it remains possible that the association of a decreased risk of food allergy with a low socioeconomic status could be explained by confounding factors, such as mode of infant feeding and environmental conditions.

7.2.4. Ethnicity

Differences in the prevalence of food allergy among ethnic groups could be due to genetic differences (e.g. in the HLA system), different food habits, and possibly different prevalence of food allergy in the country of origin for immigrants. Information on the prevalence of food allergy in different ethnic groups is scarce. It appears that immigrants from less developed countries generally present fewer atopic diseases at the time they migrate to European countries. However, they gradually adapt to the new environment and, over a decade, they become more similar to the people grown up in the country of destination (Kalyoncu and Stalenheim, 1992). In the European Community Respiratory Health Survey (Tobias et al., 2001), immigrants as a group had similar levels of atopy as non-migrant Europeans.

7.2.5. Other individual factors

Food allergic reactions may be facilitated by physical exercise, alcohol intake, antibiotics, gastric acidity inhibitors, and non-steroid anti-inflammatory drugs (NSAIDs) in some individuals (Sicherer and Sampson, 2013).

7.3. Conclusion

The occurrence of food allergies requires susceptibility of the host and exposure to the allergen. Geographical variation in the prevalence of food allergy is due to differences in genetic regional and local factors, like pollen exposure or differences in food habits. Extrapolations of prevalence data on specific food allergies from a single European country to the entire European population are of limited accuracy due to differences in exposure to the offending foods and eating habits.

8. Characterisation of food allergens

8.1. Introduction and nomenclature

Allergenicity of a given complex food might not be due to a single protein component, but to different proteins, which constitute the allergen repertoire of the food. The combination of food science and

medical science allows defining the clinically relevant food allergens contained in different foods. Several food allergens have been isolated, purified and characterised.

A systematic International Union of Immunological Societies (IUIS) Allergen Nomenclature has been established and adopted by WHO (King et al., 1994). The official site (http://www.allergen.org) lists all recognised allergens and isoforms and is regularly updated. By convention, allergens in the systematic IUIS nomenclature are designated by the first three letters of the genus, the first letter of the species name according to the Linnaean taxonomical system, and an arabic number reflecting the chronological order in which the allergen was identified and characterised (e.g. Bos d[omesticus] 4) (Chapman et al., 2007). The nomenclature defines also isoallergens and variants. Isoallergens are allergens from a single species, which share similar molecular size, identical biological function, and more than 67 % of the amino acid sequence (sequence identity). Isoallergens are denoted by the addition of two numeral suffixes to the allergen name (e.g. Ara h 1.01). A variant is an allergen which shows a limited number of amino acid substitutions in the isoallergen structure and is denoted with the addition of other two numbers to the allergen name (e.g. Ara h 1.0101). A gene encoding for a specific allergen is denoted in italics (e.g. *Ara h 1*). Natural allergens may be denoted by the prefix "n" to distinguish them from recombinant allergens, which are indicated by the prefix "r" (e.g. nPru p 3 / rPru p 3). The insertion of a synthetic peptide in an allergen structure is indicated with "s", with the particular peptide residue indicated in parentheses after the allergen name (e.g. sBet v 1.0101 (100-120)).

The WHO/IUIS Allergen Nomenclature database uses the terms "major" and "minor" for allergens depending on whether more or less than 50 % of the allergic patients tested show allergen-specific IgE-binding to this allergen in a given test system, respectively. These terms do not refer to the ability of the allergen to trigger clinical allergic reactions or to their severity, i.e. clinical reactions may be similar whether they are triggered by major or minor allergens.

A number of allergen databases which differ with respect to the number of molecules listed as allergens and to the type of information displayed have been reviewed (Brusic et al., 2003) (Gendel and Jenkins, 2006; Mari et al., 2006; Schein et al., 2007; Gendel, 2009). The Allergome database provides regular updates on allergens from publications in the scientific literature (http://www.allergome.org/). Not only allergenic molecules are reported but also allergenic sources, organisms and IgE-binding molecules, either causing clinical allergic reactions or not. The Protein family (Pfam) database (http://pfam.sanger.ac.uk) assigns sequences of clinically proven food allergens to protein families (Jenkins et al., 2005). AllFam merges the Allergome allergens database with data on the Pfam database (Radauer and Breiteneder, 2007) and contains all allergens with known sequences that can be assigned to at least one Pfam family (http://www.meduniwien.ac.at/allergens/allfam/). The Structural Database of Allergenic Proteins (SDAP) provides detailed structural data on allergens in the IUIS Nomenclature, including sequence information, Program Data Base files (PDB-files) and computational tools to analyse IgE epitopes (http://fermi.utmb.edu/). The Food Allergen Research and Resource Program (FARRP) is focused on food allergens, providing sequence similarity searches (http://www.farrp.org/), while the PROTALL, which includes only allergens derived from plants and clinical data (skin prick tests and provocation tests), has developed into the InformAll Database dedicated to all food allergens (http://foodallergens.ifr.ac.uk). The SWISS-PROT (http://www.genscript.com/) and the National Center for Biotechnology Information (NCBI) (http://ncbi.nlm.nih.gov/) databases include protein and nucleotide sequence information not restricted to allergens.

In this Opinion, only food allergens listed in the IUIS database as of December 2013 will be mentioned and discussed in the sections dedicated to specific allergenic foods, unless otherwise specified.

8.2. General considerations on the structure of food allergens

The allergenicity of a protein is due to the IgE-binding epitopes that are widespread within the protein molecule. Epitope mapping is the characterisation of all epitopes in an allergen molecule. Similar to allergens, not all epitopes in a protein are recognised by all patients allergic to that protein: some epitopes are immuno-dominant, while others are only recognised by few patients. Two types of epitopes have been described depending on their structure: conformational epitopes, which are associated to the secondary and tertiary structure of the protein, and linear/sequential epitopes, formed by a continuous sequence of amino acid residues in the protein chain. Once the protein is denatured, conformational epitopes are generally modified or destroyed, whereas linear epitopes are maintained. The clinical significance of epitopes may depend on their structure and location within the molecule. For example, short linear IgE-binding epitopes located in hydrophobic parts of allergenic proteins could be used as markers of a persistent food allergy, i.e. to milk and to peanut (Chatchatee et al., 2001).

Although there are no common structural features which allow predicting the allergenic potential of a protein, food allergens generally belong to protein families which have conserved structural features in relation to their biological activity, have a globular compact structure stabilised by hydrogen and disulphide bonds, and are often glycosylated, stable to processing, and resistant to proteolysis by digestive enzymes.

8.3. Classification of food allergens based on their structural properties

Owing to the development of proteomics, spectroscopic methods and gene cloning, proteins have been classified into families on the basis of their sequence and three dimensional (3D) structure. The structural features and potential allergenicity of the most important allergen protein families have been reviewed (Hoffmann-Sommergruber and Mills, 2009).

The biological activity of a protein is related to its structure. Some allergens bind ligands, such as metal ions, lipids and steroids. Others interact with bacterial or fungal membranes inducing a leakage, thus protecting plants from microbial pathogens. Some enzymes are allergens, such as lysozyme, cysteine proteases, transferrins, and arginine kinases. While in some cases allergenicity is strictly related to the biological activity (e.g. proteolytic activity), in other cases it is not.

The Panel notes that, although common structural features of proteins and biological activity have been tentatively related to their antigenicity, it is not possible to predict the allergenicity of a protein on the basis of these two parameters only (Breiteneder and Mills, 2005).

8.3.1. Allergens of plant origin

Both Pfam and AllFam databases classify plant allergens into four main families on the basis of sequence homology, conserved 3D structures and function: the prolamin superfamily, the cupin superfamily, profilins, and the Bet v 1 superfamily.

The prolamin superfamily contains the largest number of plant food allergens: 2S seed storage albumins, cereal seed storage proteins, cereal α-amylase/trypsin inhibitors and non-specific lipid transfer proteins (nsLTPs). Prolamins were originally defined on the basis of their water/alcohol solubility and of their content of proline and glutamine. Prolamins are characterised by a high content in sulphur-containing amino acid residues and often consist of bundles of four α-helices stabilised by disulphide bonds, involving eight well-conserved cysteine residues. The major role of 2S albumins is to provide proteins to the developing seed. They also have a defensive role against pathogenic fungi. Major allergens in tree nuts, sesame and mustard seeds belong to this family. Cereal seed storage proteins are characterised by a high content in proline and glutamine. Cereal α-amylase and protease inhibitors induce a certain resistance of plant tissues to insect pests and include allergens present in wheat, barley, rice and corn (Pastorello et al., 2002b). The lipid transfer protein family comprises low molecular weight monomeric proteins (around 7-9 kDa) involved in the synthesis of cutin, and thus

have a protective role in the plant, and particularly in the fruit. They have a very compact and stable tertiary structure constituted by the association of α-helices and loops stabilised by eight disulphide bonds, which define a central cavity containing a lipid-binding site. Binding with hydrophobic ligands also contributes to the stabilisation of the molecule. Lipid transfer proteins are frequent and potentially severe allergens: they are one of the numerous defence protein families (also called pathogenesis-related proteins) that are responsible for most of the allergic reactions to fruits from the *Rosaceae* family.

The cupin superfamily includes the major globulin storage proteins, which are the cause of most allergic reactions to legumes and nuts. The name comes from their common architecture, consisting of 6-stranded β-sheets associated with α-helices which form a β-barrel cavity (Latin *cupa,* barrel) with a binding site for a hydrophobic ligand (Breiteneder and Ebner, 2000). Subgroups in the cupin superfamily have been defined depending on the number of cupin domains present in the protein. Monocupins comprise the majority of cupin proteins, can be monomeric, dimeric or oligomeric, and most are enzymes (e.g. dioxygenases). Germin and germin-like proteins (GLP) are oligomeric monocupins ubiquitarious in plants (e.g. wheat and barley). They have a disc-shape homohexameric structure organised as trimers of dimers. The globulin fractions of seed storage proteins, which can be extracted with saline solutions, are 2-domain cupins. According to their sedimentation coefficient determined by ultra centrifugation, globulins are divided in a smaller fraction, i.e. 7S/8S globulins (called vicilins), and a bigger fraction i.e. 11S globulins (called legumins). 7S/8S globulins are generally trimers with 50-60 kDa molecular weight (MW). Post-translational modifications such as glycosylation often occur. 11S globulins consist of six subunits with a MW around 60 kDa and are rarely glycosylated. Each subunit consists of a non-covalent association of two polypeptide chains. 7S and 11S globulins have a relatively low sequence identity but a common 3D conformation. Globulins are clinically relevant allergens in peanuts, soybean, lentils, walnut, hazelnut and sesame.

Profilins are cytosolic proteins of 12 to 15 kDa exclusively found in flowering plants, such as peanut (Ara h 5), apple (Mal d 4) and celery (Api g 4). They are folded in a compact globular structure of an antiparallel β-sheet enclosed by α-helices on both sides. The high sequence conservation and the even higher 3D structure similarity account for the strong serological cross-reactivity with other plant foods, pollens and *Hevea latex,* which may be of variable clinical significance.

The Bet v 1 superfamily comprises eight families, among which the "pathogenesis related proteins 10" (PR 10), major latex proteins. These allergens are homologous of the major birch pollen allergen Bet v 1 and are present in fruits of the *Rosaceae* family (e.g. apple, cherry, apricot, and pear) and *Apiaceae* vegetables (e.g. celery, carrot). They are polypeptides of 154-160 amino acids with high sequence similarity. The Bet v 1 homologous proteins contain a GXGXXG or a GXG motif, responsible for binding of the phosphate group of oligonucleotides, and share a characteristic fold formed by seven β-sheets surrounding a long C-terminal helix and two additional short helices connecting two β-sheets and forming a large y-shaped hydrophobic cavity able to bind sterols, as observed in structures obtained by X-ray crystallography. Because of their sequence and 3D similarities, the Bet v 1 related proteins cross-react with allergens present in birch pollen, in particular with Bet v 1, sometimes inducing severe allergic reactions.

8.3.2. Allergens of animal origin

Food allergens of animal origin, less numerous than allergens of plant origin, are classified in three main structurally-related families: tropomyosins, EF-hand proteins and caseins.

Tropomyosins are a family of closely related proteins present in muscle and other cells with a regulatory role in muscle contraction. They contain a 7-amino acid repeat (heptad), with most isoforms having a series of 40 continuous heptads. These proteins form a parallel α-helical coiled-coil dimeric structure, which then bind head to tail to form a cable winding around the helix. Tropomyosins, which are clinically relevant as food allergens, are present in molluscs and crustaceans.

The EF-hand proteins present a helix-loop-helix motif characterised by a sequence of usually 12 amino acid residues, which form a loop flanked on both sides by a 12-residue α-helical domain. This loop is capable of coordinating calcium or magnesium ions with different geometries. The same motif is present in a large family of calcium binding proteins, such as parvalbumins, which have three EF-hand motifs, two of which capable of binding calcium. Loss of calcium by thermal treatment induces major conformational changes in the protein, with loss of conformational epitopes. However, the remaining IgE-binding epitopes are sufficient to trigger allergic reactions in fish allergic subjects (Lewit-Bentley and Rety, 2000).

Caseins are mammalian proteins present in milk which bind calcium ions through the phosphoserine or phosphothreonine residues of αS1-, αS2- and β-casein, forming nanoclusters in which amorphous calcium phosphate is included, stabilised by κ-casein. Nanoclusters aggregate (ca. 1 000 molecules) to form macrostructures, corresponding to the milk micelles.

8.4. Stability of food allergens

An important characteristic shared by the majority of allergens is stability, defined as the capacity to maintain their native 3D structure upon thermal, chemical or enzymatic (proteases) treatment. No single structural motif can account for the stability of a protein (Breiteneder and Mills, 2005). However, structural features clearly related to stability include the β-barrel structure of cupins and the presence of intra- and intermolecular disulphide bonds, which constrain the molecule in a rigid scaffold not easily disrupted which can be eventually reformed in a different position following the treatment. This type of covalent bond is found in the prolamin superfamily and in thaumatin-like proteins (TLP).

Although a number of allergens share a compact globular shape with a well-defined 3D structure, others contain large regions of disordered structures. Such proteins are constituted by polypeptidic chains with different secondary structures in equilibrium with each other, resembling unfolded or partially unfolded proteins, and are called rheomorphic. On account of their flexibility, they are more susceptible to hydrolysis by proteases, but do not undergo conformational changes and their epitopes remain exposed even after thermal treatments. Caseins and the seed storage prolamins belong to this group.

Glycosylated allergenic proteins appear to be more resistant to proteolysis. N-glycosylation, which usually occurs on asparagine residues in a specific three amino acid sequence (asparagine-any amino acid-serine or threonine), can have a significant stabilising effect on a protein, as in the case of the 7S globulin of pea. Hydroxyproline, serine and threonine can also be O-glycosylated, contributing to the 3D structure of the protein. Glycosylation plays a role in inducing cross-reactivity between pollen and plant allergens.

Under physiological conditions or following industrial treatments, food allergens with repetitive structures form non-covalent aggregates, which are particularly stable to heat. Tropomyosin allergens from shellfish and seed storage proteins belong to this category. Protein aggregates in foods may be more allergenic than monomeric proteins due to the higher number of IgE epitopes they contain.

8.5. Resistance of food allergens to *in vitro* digestion

The digestibility of allergens *in vitro* has been studied either to provide a biochemical measure of their physico-chemical stability under non-physiological conditions or to investigate the role of digestion on their allergenic potential under simulated physiological conditions.

The *in vitro* simulated gastric fluid (SGF) pepsin resistance test shows that there is a certain correlation between resistance to proteolysis and allergenic properties of food allergens (Astwood et al., 1996) (FAO/WHO, 2001; Codex Alimentarius Commission, 2003), although a cause-effect relationship cannot be established owing to the variability of results obtained from digestibility studies performed under different testing conditions (e.g. pH, protein/enzyme ratio, purity of the protein).

Thus, resistance to proteolysis cannot be used as a parameter to predict the allergenicity of a protein, whereas the SGF test is commonly accepted to establish the chemical stability of the protein and for structure determination. A "simulated intestinal fluid" test with the use of trypsin and chymotrypsin as duodenal digestion enzymes is also available. A sequential treatment with SGF and the "simulated intestinal fluid" has been proposed to simulate the entire transit of food in the gastrointestinal tract (Mouécoucou et al., 2004).

The digestibility of a protein depends on its structure, but also on the food matrix in which it is contained, which may hamper or favour the accessibility of digestive enzymes to the protein. Thus, more sophisticated static models aiming to mimic physiological conditions as closely as possible by the addition of other substances present *in vivo* which may affect digestibility, such as biosurfactants like phosphatidyl choline and bile salts, or food ingredients such as lipids and carbohydrates, have been developed. A standardised digestion protocol with and without addition of surfactants has been tested in a multi-laboratory trial in the course of the EuroPrevall EU-funded Project (Mandalari et al., 2009), showing consistency between laboratories for two allergenic milk proteins, β-casein and β-lactoglobulin.

Dynamic *in vitro* digestion models, which take into account other factors affecting digestibility, such as mastication, gastrointestinal transit and peristalsis, have also been developed. The effects of different *in vitro* models on the stability of food allergens to digestion have been reviewed (Moreno, 2007).

The Panel notes that *in vitro* digestion tests should be combined with immunological assays in order to understand the interaction of peptides derived from proteolysis (or their aggregates) with the immune system.

8.6. Physico-chemical characterisation of food allergens

8.6.1. Extraction, isolation and purification

The first step in the structure characterisation of a food allergen is the extraction of the protein from the food matrix in suitable amounts to allow the characterisation of the structure by spectrometric and spectroscopic methods, as well as the verification of its IgE-binding capacity. Cloning techniques can be used to obtain sufficient amounts of protein, as long as the identity of the recombinant product with the native protein is confirmed. Extraction methods vary according to the nature of allergens e.g. incubation of the raw material in a buffer at different pH plus centrifugation, extraction protocols to eliminate concurrent extraction of contaminants (phenols), use of salting out methods and defatting procedures to eliminate undesired sugars and lipids.

Purification of the protein is obtained by monodimensional electrophoretic separation on Sodium Dodecyl Sulphate-PolyAcrylamide Gel-Electrophoresis (SDS-PAGE) or by chromatographic methods, using different columns according to the nature of the protein. Ion-exchange chromatography as well as preparative Reversed-Phase High Performance Liquid Chromatography (RP-HPLC) are efficiently used according to the inherent polar/apolar character of the protein. Size-Exclusion Chromatography (SEC), also called gel-filtration, allows the exclusion of contaminants and other proteins on the basis of their different size or MW relative to a porous matrix (swollen gel) with pores of a particular size (mesh). Affinity chromatography is a very specific tool for protein purification, which relies on the affinity of a ligand (e.g. specific antibody) immobilised in the column for the particular allergen, but requires previous knowledge about the nature of the allergen to be purified.

Methods for the isolation and purification of food allergens have been described in detail elsewhere (Pastorello and Trambaioli, 2001a).

8.6.2. Allergen identity and identification of epitopes

Sequencing and/or physicochemical methods are used to verify the identity of the purified allergen (Harrer et al., 2010).

The molecular characterisation of an allergen starts with the determination of its MW by Mass Spectrometry (MS). The spectrometric techniques involve two types of ionisation: Matrix Assisted Laser Desorption Ionisation (MALDI) and Electrospray Ionisation (ESI). The former involves gas-phase ionisation of the intact protein and is usually coupled to a Time Of Flight (TOF) analyser to generate protein mass fingerprinting. MALDI-TOF analysis is currently applied in the "top-down" strategy for the identification of intact proteins. ESI-MS is considered the preferred ionisation method for proteomics and is mostly coupled to ion traps (IT) and triple quadrupoles (QqQ). Tandem mass spectrometry (MS/MS), in the most commonly performed "bottom-up" direction, allows sequencing on proteolytic peptides obtained by previous digestion with enzymes. The resulting fragments can be compared with databases for unequivocal identification of the peptides and of the protein. Details on the use of Mass Spectrometry for the qualitative/quantitative analysis of food allergens are given in section 11.

The Edman degradation method allows identifying amino acid residues and their sequence starting from the N-terminal residue. The unequivocal identification of a known protein may be achieved by combining Edman degradation data on the amino acid sequence of the N-terminal region with the exact molecular mass of the entire molecule obtained by MS or High Resolution-MS (HR-MS).

Identification of epitopes is important for the characterisation of food allergens. Sequential epitopes may be identified by an ELISA system with the use of patient sera (PEP-SCAN). Conformational epitopes are best characterised by the phage display technique, in which libraries of randomised short peptides are fused to the coat proteins of filamentous phages and examined with sera of allergic patients. Another method consists of replacing each amino acid, one by one, with a different amino acid in the IgE-binding epitope or by inducing mutations in the IgE-binding epitope with amino acid substitution or deletion.

8.6.3. Three-dimensional structure

Knowledge of the 3D structure of an allergen is needed to gain information on the surface of the protein, to evidentiate the epitopes and to evaluate potential cross-reactivities. The 3D structure of an allergenic protein in the solid state may be assessed by X-rays crystallography, and in solution by Nuclear Magnetic Resonance (NMR) spectroscopy and Circular Dichroism (CD). In most cases the allergen was obtained by recombinant techniques because of the amount of protein needed to perform crystallisation trials or NMR studies (ca. 5-20 mg).

X-ray crystallography operates by diffraction of monochromatic X-rays by protein crystals. From the diffraction pattern, the electron density map of the molecule is converted by a Fourier Transform algorithm and the protein sequence is fitted into atomic coordinates. Crystal structures of some food allergens have been elucidated (e.g. peanut allergens Ara h 1, Ara h 2, Ara h 6, wheat profilin Tri a 12, peach Pru p 3, celery Api g 1, cherry Pru av 1) and can help understanding cross-reactivity.

NMR spectroscopy allows studying the structure of a protein allergen in solution (also in water) under similar conditions to those present in food matrices. The most useful magnetic nuclei for that purpose are those of ^{1}H, ^{13}C, ^{15}N and ^{31}P, which can be used alone (homonuclear NMR) or in combination (heteronuclear NMR). High Resolution spectrometers (600-1100 MHz) are required. The monodimensional homonuclear (1D) 1H-NMR provides information about structured and non-structured parts of the protein (Alessandri et al., 2012). Bidimensional (2D) NMR allows characterising the conformation and is suitable for small proteins and peptides. Tridimensional (3D) NMR can be used to determine the structure of larger proteins, but requires an isotopically (^{13}C and ^{15}N) labelled protein and a high concentration of the protein. The Nuclear Overhauser Enhancement (NOE) allows determining the inter-proton distances and provides a 3-D model. In addition, NMR can

give information on the dynamics of the protein (e.g. the flexibility of the protein in a disordered structure) by measuring the relaxation times T_1 and T_2. While protein structures obtained in the solid state are static, those obtained in solution by NMR are dynamic and also depend on the interactions with the solvent.

CD is a valuable tool to investigate the secondary and tertiary structure of proteins, which has also been used to characterise allergens. The method is based on the different absorption of the polarised light by chiral and by achiral molecules immersed in a rigid chiral environment. The chiral centre in proteins is represented by the Cα atom of the amino acid adjacent to the peptide bonds, which absorb below 240 nm (far UV) with maxima and minima related to the conformations of the angle bonds of the adjacent groups. α-Helix, β-sheet, β-turn, and random coil structures show characteristic patterns of positive and negative bands. Other chromophores such as aromatic amino acid side chains and disulphide bonds allow obtaining information on the tertiary structure of the protein.

Fourier Transform Infrared (FTIR) spectroscopy can confirm the folding of the protein and allow useful comparison with known allergens and monitor eventual conformational changes or aggregation following cooking or technological treatments. Indeed a secondary structure change can be visualised by a shift of the frequency and/or intensity of the longitudinal amide I vibration, as well as transitions from α-helices and intra- to inter-chain β-sheets can account for protein aggregation. Aggregation of the protein can be detected also by atomic force microscopy and fluorescence.

8.7. Immunological characterisation of food allergens

Characterisation of food allergens requires immunological data. Immunological tests include IgE-binding assays, such as the Enzyme Linked Immunosorbent Assay (ELISA). The CAP system, a fluorenzyme immune assay, which is completely automated, is most currently used on account of its high sensitivity and specificity, as is the SDS-PAGE followed by immunoblotting with IgE-containing human sera.

The Panel notes that the IgE-binding capacity of a protein is related to its antigenicity (i.e. the ability to induce the synthesis of specific IgE antibodies), and not necessarily to its allergenicity upon ingestion (i.e. the ability to induce immune-mediated clinical reactions).

8.8. Conclusion

Following the development of proteomics, spectroscopic methods and gene cloning, allergenic proteins can be well characterised. They have been classified into families on the basis of their sequence and three dimensional (3D) structure. However, although common structural features of proteins and their biological activity have been tentatively related to their antigenicity, it is not possible to predict the allergenicity of a protein on the basis of these two parameters only. Immunological and clinical data are required to classify a protein as a food allergen.

9. Cross-reactivities

Cross-reactivity occurs when IgE antibodies originally triggered against one antigen also bind a different antigen. Not all cross-reactivities identified *in vitro* are of clinical significance, and although most clinical cross-reactions are mediated by IgE antibodies, T cells may also be involved (Bohle et al., 2003). However, *in vitro* cross-reactivity testing can help understanding allergenicity to multiple foods, as well as improving diagnosis and management of food allergy.

Cross-reactions occur among proteins with high sequence homology and/or with similar structural features or common epitopes. Both linear and conformational epitopes may induce cross-reactivity. The Structural Database of Allergenic Proteins (SDAP) (http://www.fermi.utmb.eu/SDAP) can be used to predict the likelihood of cross-reactivity among proteins on the basis of sequence homology and the presence or absence of particular amino acids in non-contiguous positions.

In order to assess the potential IgE cross-reactivity of a protein with a known allergen, an identity > 35 % over an 80-amino acid window is currently recommended for further testing. Sequences are then compared to an allergen database using alignment tools, such as Fast All (FASTA) (Pearson and Lipman, 1988) or the Basic Local Alignment Search Algorithm (BLAST) (Altschul et al., 1990). Computational methods for assessing potential cross-reactivity among proteins have been reported and discussed in detail (EFSA, 2010).

Panallergens, usually classified as minor allergens, are homologous molecules that originate from a multitude of organisms and cause IgE cross-reactivity between evolutionary unrelated species (Hauser et al., 2010). Profilins, polcalcins (calcium binding proteins), nsLTP and Bet v 1 homologues are considered as panallergens.

Pollen allergens (e.g. birch pollen, mugwort) cross-react with LTP, ubiquitous in plants, and with profilins. Frequent cross-reactions are observed between birch pollen and hazelnut, apple, and more generally fruits of the *Rosaceae* family. Allergens belonging to the Bet v 1 superfamily present a highly conserved structure, similar surface amino acid residues and the same main chain conformations (Jenkins et al., 2005). The so called "pollen-food allergy syndrome" usually manifests as oral allergy syndrome (OAS). Cross-reactions are also observed between pollen of *Compositae* (mugwort) and celery.

Other examples of cross-reactivity include those between latex and fruits, dust mite and shrimp tropomyosin, and mold and spinach. All foods belonging to the latex group (e.g. chestnut, walnut, kiwi, banana, avocado) have defence proteins (chitinases) with a common "hevein" domain that is present in the latex prohevein and accounts for most cross-reactivities.

IgE antibodies interact *in vitro* with N-glycans, i.e. carbohydrate moieties linked to proteins (asparagine). α(1-3)-fucose and β(1-2)-xylose are considered the major cross-reactive carbohydrate determinants (CCDs) in plants (Andersson and Lidholm, 2003). N-glycans may be shared by pollen, plants and insects, but these are different from N-glycans present in mammalian proteins. There is evidence that N-glycans may contribute to the allergenic potential of some foods (e.g. celery) (Bublin et al., 2003). However, the biological role of CCDs in triggering clinical symptoms is matter of debate (Jin et al., 2008).

In vitro techniques do not allow distinguishing between dual sensitisation (i.e. synthesis of IgE against proteins in two different foods) and cross-reactivity (i.e. synthesis of IgE against proteins in one food, which also bind proteins in a second food). In cross-reactions to several foods, different allergens may be causing cross-reactivity between different pairs of foods, as observed with snail, mite and shrimp (van Ree et al., 1996a). Moreover, profilins from certain species have been shown to induce cross-reactive IgE antibodies (birch, celery and latex), whereas others induce species-specific IgE (Radauer and Breiteneder, 2006).

9.1. Conclusion

Cross-reactivity occurs when IgE antibodies originally triggered against one antigen also bind a different antigen. Not all cross-reactivities identified *in vitro* are of clinical significance, and although most clinical cross-reactions are mediated by IgE antibodies, T cells may also be involved. However, *in vitro* cross-reactivity testing can help understanding allergenicity to multiple foods, as well as improving diagnosis and management of food allergy.

10. Effects of food processing on allergenicity

Food and food ingredients undergo different treatments to improve their palatability, to inactivate pathogenic microorganisms and/or to destroy toxins. Food is processed at home, in restaurants and institutional settings, and by the food industry.

The structure and chemical properties of proteins are influenced by food processing techniques. Major modifications include protein unfolding and aggregation, proteolysis, glycosylation and glycation, solubility and pH effects, and networking to gel formation, which may alter its allergenic potential (Paschke, 2009). The extent to which proteins are modified during food processing depends upon the process conditions, the nature of the protein and the composition of the matrix.

The allergenic activity of a complex food may decrease, remain unchanged, or even increase by food processing. Considering the multiplicity of the allergenic structures contained in a whole food and that different proteins may be differently affected by the same treatment, the impact of food processing on the structural and allergenic properties of food allergens is difficult to predict (Mills et al., 2009). In addition, the effects of processing on the IgE-binding capacity of allergens do not necessarily predict the allergenicity of the modified food in the allergic patient population.

This section provides an overview of the most common methods of food processing and their effects on the allergenic potential of foods. Most studies available report on the IgE-binding capacity of processed foods rather than on their allergenicity, whereas systematic investigations on the effects of food processing on allergenicity under controlled conditions are scarce. The specific alterations induced by processing on foods/ingredients included in Annex IIIa of the Directive 2003/89/EC (as amended) are reported in the dedicated sections.

10.1. Thermal processing

Significant alterations in protein structure do occur during heat treatments. The nature and extent of such changes depend on the temperature and duration of the thermal processing, as well as on the intrinsic characteristics of the protein and the physicochemical conditions of its environment (e.g. pH, matrix composition). Typically, loss of tertiary structure is followed by (eventually reversible) unfolding, loss of secondary structure (55-70 °C), cleavage of disulphide bonds (70-80 °C), formation of new intra-/inter-molecular interactions, rearrangements of disulphide bonds (80-90 °C) and formation of aggregates (90-100 °C) (Davis and Williams, 1998). These modifications reflect a progressive passage to a disorganised structure with denaturation of the protein that adopt an unfolded, random-coil conformation. Other chemical modifications of the protein may also occur at high temperatures (100-125 °C and higher), e.g. formation of covalent bonds between the lysine residues and other constituents of the food matrix, leading to various adducts. In thermal treatments the conformational epitopes responsible for allergenicity are generally destroyed, whereas the linear epitopes may be maintained and others, hidden in the native conformation, may become surface exposed. In addition, thermal processing (e.g. Maillard reaction) can generate new immunologically reactive structures (neoallergens) as well as destroy existing epitopes (Davis and Williams, 1998).

The structure of the protein strongly influences its stability and hence its modification upon heating. Roasting (i.e. 140 °C for 40 min) reduces the allergenicity of Cor a 1.04 (a major hazelnut allergen) and of hazelnuts by approximately 100-fold (Hansen et al., 2003). In contrast, IgE-binding to Ara h 1 (a major peanut allergen) increases approximately by 90-fold in roasted vs. raw peanuts (Maleki et al., 2000). The explanation is that Cor a 1 belongs to the Bet v 1 superfamily of plant food allergens, which are generally thermolabile, whereas Ara h 1, a seed storage globulin, may form trimers upon roasting.

An opposite effect of wet vs. dry heating on the allergenic potential of Ara h 1 and Ara h 2 has been reported (Mondoulet et al., 2005). Whereas roasting (dry heating at high temperature) increases the allergenic potential of peanuts, boiling (wet heating at lower temperature, < 100 °C) and frying (wet heating at high temperature, 120 °C) decrease it. Dietary and cooking habits may thus explain in part the geographical differences observed in the prevalence of peanut allergy, i.e. peanut allergy seems to be rare in countries where peanuts are eaten boiled or fried (e.g. China) than in Western countries where peanuts are mostly eaten roasted (Beyer et al., 2001).

Allergens belonging to the prolamin superfamily have an inherently stable structure characterised by the presence of several cysteine residues forming three or four intramolecular disulphide bridges, which induce a constrained folded structure. These proteins are particularly stable to thermal and chemical treatments. Allergens exhibiting such stability are the Brazil nut allergen Ber e 1, the sesame allergen Ses i 1, and the non specific LTP from apple Mal d 3. Other examples of "heat stable" allergens are milk proteins and the prolamin seed storage proteins from wheat, which form gluten. The type of thermal treatment (e.g. autoclaving, blanching, microwave heating, dry roasting) does not seem to decrease the allergenicity of stable proteins, such as those present in cashew nut seeds (Venkatachalam et al., 2008).

Nevertheless, the consequences of thermal treatment on allergenicity are generally unpredictable. Some allergenic foods are described as heat stable (e.g. milk, egg, fish, peanuts and products thereof), while others are considered partially stable (e.g. soybean, cereals, celery, tree nuts and their products) or heat labile (fruits of the *Rosaceae* family and carrots) (Besler et al., 2001).

10.2. Enzymatic hydrolysis

Enzymatic hydrolysis is the most common process industrially used to reduce the allergenicity of a protein. For example, proteases to reduce the allergenic potential of soybean, actinase to reduce the allergenicity of rice, as well as trypsin and chymotrypsin, are used for producing hydrolysed formulas.

The type and degree of hydrolysis depend on the primary structure of the protein, but also on its secondary/tertiary structure and on post-translational modifications (e.g. glycosylation). The sites of hydrolysis depend on the specificity of the proteolytic enzymes utilised, whereas the degree of hydrolysis is related to the working conditions. Most proteolytic treatments generate partial hydrolysis, so that not all epitopes are destroyed (Asero et al., 2000). Moreover, proteolysis can destroy some epitopes, but it can also unmask linear epitopes that were buried into the three-dimensional native structure and/or located in hydrophobic domains of the protein, becoming available for IgE-binding. Some peptides resulting from partial hydrolysis are still allergenic because they contain the epitope and/or may form allergenic aggregates. For example, treatments of hazelnut with trypsin or elastase, of soybeans with proteases and of wheat with bromelain decrease the likelihood of triggering allergic reactions in sensitised individuals consuming these foods, whereas enzyme-mediated proteolysis does not destroy IgE-binding epitopes in peanut and peach (Paschke, 2009).

10.3. Fermentation

A decreased IgE-binding capacity of β-lactoglobulin was observed in fermented milk and yogurt (Ehn et al., 2004). In these highly pasteurised products, the protein is partially hydrolysed by the enzymatic activity of the starter culture, which may destroy some epitopes. IgE-binding may also be prevented by the protein gel structure and other aggregates. Fermentation with lactic acid bacteria (*Lactobacillus helveticus* and *Streptococcus thermophilus*) also decreased the IgE-binding capacity of α-lactalbumin and β-lactoglobulin in skim milk (Bu et al., 2010). No clinical data on the effects of milk fermentation on allergenicity are available.

Fermentation of soy and products thereof with bacteria and yeast (e.g. *Lactobacillus plantarum, Bifidobacterium lactis, Saccharomyces cerevisiae*) generally reduces the IgE-binding capacity of soy allergens (up to 89 %). All the commercial soy-containing products tested (e.g. yogurt, miso, tempeh) show very low immunoreactivity (Song et al., 2008). However, allergenicity was retained in a soy sauce, a fermented product containing both wheat and soy (Hefle et al., 2005).

10.4. High Pressure Processing

The High Hydrostatic Pressure (HHP) processing of food allows homogeneity of treatment through the food product and shows a variety of effects on food allergens depending on the protein structures, the type of epitopes involved (conformational vs. linear) and the processing conditions. HHP may reduce immunoreactivity of a protein by destroying conformational epitopes and other mechanisms. In HHP treated rice grains in distilled water, the reduced amount of allergenic proteins in rice was

attributed to the release of these proteins from the grains into the aqueous solution (Estrada-Girón et al., 2005). In soy sprouts obtained from HHP treated seeds, the reduced immunoreactivity was explained by a higher availability of the HHP treated proteins for enzymatic hydrolysis during germination (Peñas et al., 2011).

10.5. Preservation

Methods commonly used to preserve safety, nutritional value and organoleptic properties of foods include control of pH, salting, smoking, and addition of spices and antioxidants. Little is known about the effects of long storage of preserved food products on allergenicity.

10.5.1. Effect of pH

The effect of pH on immunoreactivity has been studied in protein extracts from unprocessed and processed foods, where changes in the solubility of proteins resulting from the process-induced modifications must be considered. Denaturation of the protein may induce loss of conformational epitopes, increased accessibility of previously hidden epitopes, or the burying of previously exposed epitopes by unfolding/refolding/aggregation of the protein. A combined effect of pH changes and heating can induce partial hydrolysis of the protein, eventually destroying linear epitopes and decreasing allergenicity. In such experiments, interactions between the allergen and the food matrix have not been considered.

Cashew nut allergens Ana o 1, Ana o 2 and Ana o 3 were examined in a range of pH (1-13) in relation to different processes (autoclaving, blanching, microwave heating and dry roasting, and γ-irradiation). The three allergens were stable over the tested pH range in any process, except at the extreme pHs 1 and 13 (Venkatachalam et al., 2008). The IgE-binding capacity of Ara h 1, Ara h 2 and Ara h 3 was reduced after treatment at pH 1 with acetic acid or commercial vinegar (Kim et al., 2012).

10.5.2. Other preservation treatments

Some preservation methods have been used to reduce the allergenicity of foods, but only data in relation to their effects on the IgE-binding capacity of allergens are available at present. Pulsed ultraviolet light (PUV) treatment reduced the IgE-binding capacity of peanut extracts and liquid peanut butter (Chung et al., 2008b), while γ-irradiation had no effect. Ultrasound treatments have been reported to reduce the IgE-binding capacity of shrimp proteins (Li et al., 2006). Ultrafiltration was also used to reduce the IgE-binding capacity of peach juice and nectar by partially removing the offending proteins (Brenna et al., 2000).

10.6. Multiple treatments

Whereas any single treatment is unlikely to effectively reduce or abolish the allergenicity of a food, the IgE-binding capacity of proteins could be extensively reduced by combining two or more treatments, although the effect of treatment combination on the allergenic potential of a food is again unpredictable.

The IgE-binding capacity of eggs and products thereof can be decreased about 100 times by combining enzymatic and thermal treatments (Hildebrandt et al., 2008). Also the susceptibility of ovalbumin to proteolysis by pepsin was increased by the simultaneous application of HHP and enzymatic treatments, leading to lower IgE-binding capacity of the hydrolysates (López-Exposito et al., 2008). However, despite the absence of intact protein, hydrolysates maintained IgE- and IgG-binding capacity on account of the formation of long hydrophobic peptides, which retained sequential epitopes. In contrast, the IgE-binding capacity of almond, cashew nut and walnut proteins remained stable after γ-irradiation (1-25 kGy) even when combined with common thermal processing methods, including autoclaving, dry roasting, blanching, oil roasting and microwave heating (Su et al., 2004).

10.7. Conclusion

The allergenic activity of a complex food may decrease, remain unchanged, or even increase by food processing. Considering the multiplicity of the allergenic structures contained in a whole food and that different proteins may be differently affected by the same treatment, the impact of food processing on the structural and allergenic properties of allergenic foods/ingredients is difficult to predict. In addition, the extent to which allergenic proteins are modified during food processing depends on the type of process and its conditions, the structure of the proteins, and the composition of the matrix. Although the effects of different (technological and cooking) treatments on the IgE-binding capacity of several allergens have been investigated, less information is available on the effects of processing on clinical reactivity.

11. Methods for the detection of allergens and allergenic ingredients in food

Reliable methods for the detection and quantification of food allergens are necessary in order to ensure compliance with food labelling legislation. Different approaches have been designed to detect the presence of allergenic ingredients in food products depending on the allergen to be detected, the food matrix, and the technological treatments applied, so that no single method fits all purposes.

The choice of the method requires first the identification and selection of the target analytes. Several methods target a specific allergenic protein or a number of allergenic proteins present in the food (direct analysis), whereas others target the DNA as a marker of the allergenic ingredient (indirect analysis). Several reviews on qualitative and quantitative methods for the analysis of food allergens are available (Poms et al., 2004a; van Hengel, 2007; Kirsch et al., 2009; Monaci and Visconti, 2010; Sancho and Mills, 2010).

Analysis of proteins is commonly performed by immunological (notably ELISA) and physico-chemical methods (in particular mass spectrometry). Analysis of DNA is based on the amplification of specific DNA fragments by means of the polymerase chain reaction (PCR) and on the use of specific primers, which identify the sequence of the food ingredient to be amplified. PCR methods are commonly used for detecting the presence of allergenic ingredients in foods (Table 3).

Table 3: Commonly used methods for food allergen analysis

Analysis of Proteins		Analysis of DNA
Physico-chemical methods	**Immunological methods**	**PCR-Mediated Methods**
(1DE/2DE) SDS-PAGE	ELISA	End-point PCR
HPLC	Immunoblotting	Real Time PCR
Capillary electrophoresis	RIE	PCR-ELISA
Mass spectrometry	LFD	DNA Biosensors
	Dipsticks	DNA Microarrays
	Dot-blot	
	Protein Biosensors	
	Protein Microarrays	

ELISA = enzyme linked immunosorbent assay; HPLC = high performance liquid chromatography; LFD = lateral flow devices; PCR = polymerase chain reaction; RIE = rocket immuno electrophoresis; SDS-PAGE = sodium dodecyl sulphate-polyacrylamide gel-electrophoresis.

Any given analytical method needs a well-defined reference material and a reliable method of recovery. The usual criteria of sensitivity, specificity, accuracy and precision (repeatability, reproducibility) have to be fulfilled. Cross-reactivity, matrix effects and food processing should also be considered (Poms and Anklam, 2004). When investigating the effects of food processing on allergen detection, incurred samples (i.e. to which the allergen of interest has been added before

processing) are preferred to spiked samples (i.e. to which the allergen of interest has been added after processing).

11.1. Detection of allergens without previous separation of proteins

The extraction procedure (using solvents and buffers) is a critical initial step in food allergen analysis, which strongly impacts recovery and performance of the subsequent detection system. Extractability of the proteins depends on their isoelectric point and their polar/apolar nature, the pH and the temperature of the extraction solvent, the presence of eventual interferents in the food, the food matrix and the production process, so that there is no universal solvent/buffer suitable to extract all proteins. The use of a mixture of chaotropic agents (thiourea/urea) and detergents (e.g. CHAPS), though improving solubility, may induce denaturation of the protein and hamper its detection by antibodies.

11.1.1. Immunological methods

Immunological methods utilise antibodies for the recognition of specific allergenic proteins and can be performed either directly on a protein mixture or with previous separation of the proteins. The former methods include Enzyme Linked Immunosorbent Assays (ELISA), Lateral Flow Devices (LFD), Dipsticks, Rocket Immuno Electrophoresis (RIE), Dot-immunoblotting (Dot-blot), Protein Microarrays and Protein Biosensors, which are rapid screening methods. The latter methods involve preliminary separation by mono- or bidimensional gel electrophoresis (1DE or 2DE SDS-PAGE), HPLC or capillary electrophoresis (CE) of the proteins, followed by immunoblotting.

11.1.1.1. Enzyme Linked Immunosorbent Assay

The most frequently used allergen detection technique is the Enzyme Linked Immunosorbent Assay (ELISA), which allows the detection of known allergens by using specific antibodies. "Sandwich" and "Competitive inhibition ELISA" are commercially available, with both direct and indirect detection.

In sandwich ELISA assays the antigen present in the food sample is captured by a specific antibody immobilised on a solid surface forming an Ab-Ag complex. The complex reacts with a second analyte-specific antibody which is conjugated to an enzyme, forming a "sandwich", and the enzyme reacts with a specific substrate developing a colour. The concentration of the Ab-Ag complex, measured by the absorbance of the coloured product, is directly proportional to the amount of allergen present in the sample (direct detection). A calibration curve built with proper standards provides quantitative results.

In competitive ELISA assays the antigen bound to the solid phase competes with the food antigen present in the sample for binding to an analyte-specific antibody. If no second enzyme-labelled, analyte-specific antibody is available, an enzyme-labelled species-specific antibody is used (indirect detection). The absorption of the coloured product formed after addition of the substrate is inversely proportional to the concentration of the analyte.

ELISA methods have been automated allowing high throughput and routine analysis with a limited amount of reagents. They are fast and relatively easy to handle. The recovery and selectivity depend on the protein extraction solvent, which may affect the Ag-Ab binding. The sensitivity is generally good, with a limit of detection/limit of quantification (LOD/LOQ) in the range of 0.07-1.5 mg/kg depending on the allergenic ingredient and food matrix. An overview of the most recently published ELISA methods for most allergenic foods/ingredients in Annex IIIa of Directive 2003/89/EC, as amended, is available (Monaci and Visconti, 2010). The results are reproducible for the same ELISA kit and food matrix, whereas results from different kits may diverge depending on the specificity of the antibody and the reference material. Antibodies present in the kit may cross-react with other proteins or other food matrix components, leading to false positive results. Monoclonal antibodies are directed to a single epitope of a particular allergen and are very selective. Polyclonal antibodies recognise multiple epitopes, are more tolerant to slight protein modifications, and thus preferred for testing allergens eventually modified by technological processes. Among the ELISA kits commercially available for the detection of food allergens (Schubert-Ullrich et al., 2009), only few

have been validated by the Association of Analytical Communities (AOAC) International (Mermelstein, 2008).

Very important for the quantification of allergens is the availability of certified reference materials (CRM). Reference materials developed by different producers are commercially available for most major food allergens, but the results obtained may not be comparable. To the Panel's knowledge, only a peanut test material has been produced by the Institute for Reference Materials and Measurements (IRMM) IRMM-481, containing five different varieties of peanuts. For egg detection, egg powder from the National Institute of Standards and Technology (NIST) (NIST RM-8445) and for milk the NIST fat-free milk powder (NIST RM-1549), are available though not certified.

ELISA has been combined with other techniques, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS), in order to increase the sensitivity and the precision of the assay (Careri et al., 2007b). In ELISA-ICP-MS, the secondary antibody is labelled with a stable isotope (europium), so that the Ag-Ab1-Ab2 complex can be quantified by MS. The method was able to detect low amounts of peanuts (down to approximately 2 mg/kg) in a cereal-based matrix.

11.1.1.2. Lateral Flow Devices and Dipsticks

Lateral Flow Devices (LFDs) and Dipsticks are simplified versions of ELISAs for which also sandwich and competitive formats are available. They are inexpensive, quick, portable, and do not require particular skills, but are only qualitative or semi-quantitative (LOD about 1 mg/kg). In LFD the sample flows along a polyvinylidene difluoride (PVDF) membrane by capillarity to reach a line where the antibody has been adsorbed, giving rise to a coloured Ab-Ag complex. Dipsticks are based on the same principle but do not have a mobile phase moving up the strip. A number of LFDs and Dipsticks are commercially available for most allergenic foods/ingredients in Annex IIIa of Directive 2003/89/EC (Schubert-Ullrich et al., 2009).

11.1.1.3. Rocket Immuno Electrophoresis

In Rocket Immuno Electrophoresis (RIE) antibodies are incorporated in the gel covering an electrophoresis plate. The protein extract is allowed to flow on the plate where the proteins are separated according to their electrophoretic mobility. Precipitation of the Ag-Ab complex occurs from the beginning of migration, so that the allergen detected appears as a rocket shape. The method is semi-quantitative and not suitable for routine analysis (LOD = 2.5-30 mg/kg) (Besler et al., 2002).

11.1.1.4. Dot-immunoblotting

This technique is a simplified version of the Western blotting in which proteins are not separated. The sample extract is spotted on a nitrocellulose or PVDF membrane as a dot and incubated with an enzyme-labelled allergen specific antibody. Upon binding with the target antigen, a coloured spot is observed after the enzyme-substrate interaction. Dot-blot is a qualitative/semi-quantitative test (2.5 mg/kg for peanut) suitable for preliminary screening purposes (Blais and Phillippe, 2000).

11.1.1.5. Protein Microarrays

Immunoassays for allergen testing, in particular microarrays, allow a large number of allergens to be tested simultaneously for diagnostic purposes. The most common protein microarrays for food allergens are the antibody microarrays, where antibodies raised against known allergens are immobilised by microprinting or microstructuring processes to form a patterned surface on the chip (e.g. a glass slide or a well array) allowing the recognition and quantification of allergens in food samples in the microliter to nanoliter range (Seidel and Niessner, 2008). Detection can be achieved by different techniques and data analysis is performed with software for image processing. Analytical flow-through microarray platforms for quantification of allergens by sandwich ELISA have also been developed. The platform consists of a fluidic system for sample introduction, a reagent supply, a flow cell, a microarray and a detection system.

"Multiplexed" format immunoassays allow simultaneous detection of several analytes with less amount of sample and reagents and lower cost with respect to conventional single-analyte immunoassays. However, allergens present in the food sample are not separated previously and may have a different accessibility to antibodies.

11.1.1.6. Protein biosensors

Biosensors are based on an integrated receptor-transducer device able to provide semi- or quantitative signals and provide a novel approach for allergen detection. The receptor is generally an antibody raised against an allergenic protein, which is immobilised on a sensor chip surface. The recognition event is converted by a transducer into a signal, which is detected by various physico-chemical techniques, e.g. Surface Plasmon Resonance (SPR). Several SPR-platforms and kits for allergenic proteins are commercially available and have been reported to be quite sensitive (LOD in the range 1 to 10 mg/kg) (Yman et al., 2006). They require short time of analysis and may be suitable for automation.

11.1.1.7. Expression of the results on food allergens obtained by immunological methods

The European standard EN 15633-1 (CEN, 2009), relative to the research on food allergens by immunological methods, requires that results are expressed as total amount of allergenic ingredient per kg of food (mg/kg), or as total amount of protein per kg of food, using an appropriate factor which allows conversion to the amount of allergenic ingredient per kg of food. However, conversion factors are difficult to calculate when the composition of the food is not well known and the amount of protein per kilogram of food may change according to the origin of the ingredient and following technological treatments or cooking. LODs and LOQs are mostly expressed in the literature as mg of allergenic protein/kg of food or as mg/L in the case of liquid foods or as ng/mL of buffer solution.

11.1.2. Detection of allergens with previous separation of protein

Separation of proteins is a key point for the detection of allergens. The most commonly used protein separation method is the sodium dodecylsulfate polyacrylamide gel electrophoresis (SDS-PAGE) in 1- or 2-dimensional electrophoresis (1DE/2DE). 1D-SDS-PAGE separates the proteins according to their molecular mass relatively to the migration of standard protein markers (Pastorello and Trambaioli, 2001a). 2DE is the combination of two electrophoretic techniques based on isoelectric focusing (IEF), which separates the proteins according to their isoelectric point followed by SDS-PAGE (De Angelis et al., 2010).

Once the proteins of a food extract have been separated, they are transferred onto a membrane of nitrocellulose or of a hydrophobic polymer (e.g. polyvinylidene difluoride, PVDF) by blotting (or printing). The detection of the immobilised allergens is performed by incubation with an antibody solution, usually a human allergic individual serum or with antibodies raised against the allergens in animals. The antibodies specific to the immobilised allergens are then detected by incubation of the blot with an enzyme labelled second antibody, followed by the addition of the enzyme substrate. In order to confirm the identity of each immunoreactive protein, the spot obtained by 2DE is excised from the gel, digested by proteolytic enzymes (e.g. trypsin) into peptides, and subjected to mass-spectrometric (MS) analysis.

2D-SDS-PAGE is an extremely powerful tool for separating proteins with similar molecular mass, it is most important for research studies, but it suffers from significant drawbacks. Solubilisation of the proteins with chaotropic agents and detergents may modify the isoelectric point (pI) and immuno-detectability. There can be spots overlapping/too many spots (low dynamic range). A concentrated antibody solution, usually human serum (individual sera) or antibodies raised against animals, is necessary. Variations gel to gel may be relevant. There is a need for confirmation and identification of the protein off-line (by Mass Spectrometry). A skilful operator is required and it is labour intensive and time consuming. It has also some limitations for hydrophobic and alkaline proteins. It is not quantitative and not suitable for routine analysis.

Improvements in sensitivity, accuracy and precision have been obtained with the introduction of the fluorescence-based in gel electrophoresis (2D-DIGE), which eliminates gel to gel variation in protein migration, hindering computer assisted comparison of spot patterns, thus allowing resolution and identification of spots corresponding to isoforms or to process modified allergens (Chassaigne et al., 2009).

Other separation techniques are also available for the separation of proteins, such as liquid chromatography (LC) (Heick et al., 2011a), capillary electrophoresis (CE), and field-flow fractionation (FFF) (Reschiglian and Moon, 2008). LC is advantageous owing to its separation power, ease of automation and routine coupling with various detection techniques, in particular mass spectrometry (MS). In conclusion, LC techniques, despite their lower resolution power relatively to 2D-SDS-PAGE, show a higher dynamic range and are suitable to automation. In connection with Mass Spectrometry, they are becoming the methods of choice for the identification and quantification of proteins.

11.1.3. Detection of allergens by Mass Spectrometry

Mass Spectrometry (MS) methods are available for the detection and unambiguous identification of food allergens on account of their specificity and sensitivity (Monaci and Visconti, 2009). Two strategies are available for the analysis of proteins by MS: the "bottom up" and the "top down" approach.

11.1.3.1. The "bottom up" approach

In the "bottom up" approach the protein is digested with one or more proteolytic enzymes in gel, in solution or in a column, and the peptides obtained are separated by chromatography (shotgun proteomics). Protein identification may be achieved by peptide mass fingerprinting (PMF) or by peptide fragment fragmentation (PFF) of one or more peptides by tandem-MS (MS/MS or MS^2), which allows the sequencing and identification of each single peptide. In order to identify the allergen, the peptide spectra are scanned against specific protein-sequence databases using statistical tools.

Different instruments are available to perform MS/MS: quadrupoles (Q), tandem time of flight (TOF^2), ion traps (ITs) and Fourier Transform Ion-Cyclotron Resonance (FT-ICR). Quadrupole-TOF (Q-TOF) and TOF^2 are the most suitable to identify and quantify proteins, including modified allergens in processed foods. These MS instruments may be coupled to different ion sources (e.g. matrix-assisted laser desorption ionisation (MALDI) or surface-enhanced laser desorption ionisation (SELDI), which can be coupled with TOF analysers; electron spray ionisation (ESI), which is coupled to ion traps (ITs) and triple quadrupoles (QqQ)).

An advantage of the "bottom-up" approach is the low LOD because peptides are more efficiently separated than proteins and can be detected by the more sensitive MS instruments. However, a limitation is the necessity of using a preliminary enzymatic digestion process, which might be non exhaustive, thus preventing the identification and quantification of the protein. Depending on the extraction method, digestion process, separation method and MS technique used, the LODs are in the order of 1-5 mg/kg, although a LOD of 0.2 mg/kg and a LOQ of 0.5 mg/kg have been obtained in some cases.

11.1.3.2. The "top-down" approach

The "top-down" approach is an emerging strategy, which involves gas-phase ionisation of the intact protein and mass measurements of the ions obtained by fragmentation with high resolution MS. MALDI-TOF analysis is currently applied in the "top-down" strategy for the identification of intact proteins, and in particular small proteins. Lysozyme, previously extracted from cheese using immunocapture with magnetic particles covered with the specific antibody, was detected at a level of 5 mg/kg level with a method based on MALDI-TOF (Schneider et al., 2010a). However, MALDI-TOF may not be appropriate to detect small protein modifications resulting from food processing.

11.1.3.3. Quantification of allergens by Mass Spectrometry

MS is suitable for quantification of allergenic proteins provided that reference materials are available. A method based on HPLC-MS (triple quadrupole) has been developed for the detection of milk seroproteins (α-lactalbumin and β-lactoglobulin A and B) in fruit juices. The LOD and the LOQ were estimated at 1 and 4 mg/L, respectively (Monaci and van Hengel, 2008).

MS is also suitable for the quantification of allergens at the level of peptides by using isotopically labelled synthetic peptides: the simultaneous detection and quantification of allergenic proteins from five foods (cashew nut, hazelnut, almond, walnut and peanut) was obtained by monitoring five biomarker peptides by LC-LIT-MS/MS, with LODs from 5 to 50 mg/kg (Bignardi et al., 2010).

Methods involving stable isotopes can be used for quantification at the peptide level. Tagging by light (^{12}C) and heavy (^{13}C-labelled) tags and using isotopically labelled synthetic peptides allow achieving relative or absolute quantification, respectively. The so-called label-free absolute quantification (AQUA) method based on signal intensity has become available only recently. The reference peptide incorporates ^{13}C and ^{15}N isotopes in one of its amino acids, obtaining an expected mass difference with respect to the endogenous peptide. The selected peptide must be unique to the protein of interest and quantitatively obtained by complete enzymatic digestion of the native protein, since the concentration of the protein is deduced from the concentration of the peptide. The MS method most suitable for this analysis is the triple quadrupole in the Multiple Reaction Monitoring mode (MRM), for which several variants have been reported but only few dedicated to allergenic proteins (e.g. of peanut and casein). Quantitative methods for allergen analysis have been reviewed (Kirsch et al., 2009). The LODs and LOQs are generally expressed in the literature as mg/kg, but often as pg of the allergenic protein/mg of food or as ng/mL, and in few cases as absolute values (pg).

11.2. Detection of allergenic ingredients by DNA analysis

Indirect methods based on the detection of specific DNA sequences for the allergenic protein or the allergenic food of interest may be used whenever direct methods for the detection of allergenic proteins fail (e.g. foods containing low amounts of protein, processed foods with extensive modification of native proteins). DNA-methods for allergen detection (Poms et al., 2004; Monaci and Visconti, 2010) and their applicability to several allergenic foods (Demmel et al., 2008; Scaravelli et al., 2008) have been extensively reviewed.

DNA extraction from lipophilic matrices (e.g. fats and oils) with low amounts of DNA, from complex matrices containing surfactants and emulsifiers, and from matrices containing compounds, which may prevent DNA amplification (e.g. polyphenols, which are PCR inhibitors) can be particularly difficult. DNA extraction methods include precipitation (e.g. with cetyltrimethylammonium bromide (CTAB)), resin binding methods, and magnetic particles (Pafundo et al., 2011).

11.2.1. PCR

DNA methods are based on the amplification of specific DNA fragments by means of the Polymerase Chain Reaction (PCR) which, by using specific oligonucleotides serving as primers, amplifies only the DNA originating from the offending food. DNA may be amplified by end-point PCR, which is qualitative (i.e. it detects the presence of a specific DNA sequence), or by real-time PCR, which is quantitative, provided that an adequate reference material is used. The targeted DNA sequences are not necessarily located in the genes encoding for the allergenic protein, and thus the analysis detects genomic DNA of the offending ingredient but does not necessarily indicate the presence of the protein, which is responsible for the allergic response. Several PCR kits are commercially available. Restriction site analysis, DNA sequencing, or hybridisation with probes based on oligonucleotides or their peptide analogues PNA (Rossi et al., 2006) can be used to confirm the detection of the correct amplified sequence (amplicon).

In end-point-PCR, after amplification, gel electrophoresis either as slab or as CE is used for routine separation of DNA. Compared with conventional slab gel electrophoresis, CE is more sensitive and

provides correct size information with improved resolution. Instrumentation with chip-like multichannel CE is available for this purpose. HPLC analysis can also be performed (Germini et al., 2005).

Real-time PCR requires more expensive equipment, but allows amplification and detection of DNA in "real time". In the most common set up of real-time PCR, the DNA is amplified in the presence of a specific oligonucleotide probe carrying a reporter dye and a quencher dye at the two extremities of the strand. The probe hybridises to the single strand DNA in the region limited by the two primers to be amplified. Being the quencher and the reporter relatively close, the fluorescence is suppressed. During amplification, the polymerase (a 5'-exonuclease) cleaves the probe, displacing reporter and quencher from the new copy strands, so that fluorescence is switched on. The number of cycles required to increase fluorescence above a standard predefined line correlates with the amount of the PCR product.

The quantitative analysis of DNA by PCR (qPCR) depends on the availability of reference materials and on the knowledge of the genomic sequences. Standard materials are provided together with the commercially available kits or are produced "in house". No certified reference materials (CRMs) are available.

DNA methods available for the detection of several allergenic foods/ingredients and their respective LOD (0.1-100 mg/kg) have been reviewed (Monaci and Visconti, 2010). With few exceptions where the correlation between the amount of DNA and the amount of allergenic protein present in a food has been determined (Scaravelli et al., 2009), the DNA measured cannot be directly correlated to the amount of the allergenic protein but rather to the amount of allergenic ingredient in foods.

11.2.1.1. Multiplex PCR methods

Multiplex PCR methods based on different approaches have been developed for the simultaneous determination of several allergens. These systems save time and resources, but must be carefully designed and validated. In general, the amplification of a specific single sequence, both in end-point PCR and in real-time PCR, is considered more reliable on account of the higher specificity.

A duplex real-time PCR assay for the simultaneous detection of sesame and hazelnuts in spiked food down to 0.005 % of both sesame and hazelnut has been developed (Schoringhumer et al., 2009), as well as a qualitative duplex real-time PCR method for the simultaneous detection of lupin and soy mitochondrial DNA with a LOD of 2.5 mg/kg in processed food (Gomez Galan et al., 2011). The simultaneous detection of hazelnuts and peanuts down to 50 pg DNA has been obtained after PCR amplification on a peptide nucleic acid (PNA) microarray (Rossi et al., 2006).

Two tetraplex qPCR were developed for the simultaneous detection of eight allergenic foods (peanut, hazelnut, celery, soy, egg, milk, almond and sesame), with specificity and sensitivity in the range of 0.01 % (Köppel et al., 2010). Two quantitative hexaplex real-time PCR systems for the detection and quantification of 12 allergenic ingredients in foods became available thereafter. The first system simultaneously determines DNA of cashew, peanut, hazelnut, celery, soy, and mustard, whereas the second determines DNA of milk, egg, almonds, sesame, pistachio and walnut (Köppel et al., 2012). The two tests showed good specificity and a LOD of at least 0.1 % for all allergenic ingredients in mixed foods. Quantification on a weight to weight base was not possible in the absence of reference materials. However, the two multiple PCR systems are suitable as screening tool in routine analysis.

Another six-plex qPCR able to detect cashew, hazelnut, peanut, walnut, almond and sesame has been developed (Pafundo et al., 2010). The LOD of the template DNA is 5 pg for almond, peanut and hazelnut and 0.5 pg for cashew, walnut and sesame.

A multiplex ligation-dependent probe amplification (MLPA) method for the detection of different nuts (peanut, cashew, pecan, pistachio, hazelnut, macadamia nut, almond, walnut and brazil nut) and sesame has been described (Ehlert et al., 2009). The technique does not amplify the target sequences, but rather the products resulting from the ligation of bipartite hybridisation probes. Ligation-mediated

amplification offers many advantages over traditional qPCR in terms of specificity and reproducibility and may be extended to further targets of interest. The method is specific and sensitive, allowing the simultaneous detection of nuts and sesame seeds in the lower mg/kg range. The LOD for single allergenic ingredients in different food matrices was 5 mg/kg. Quantification was not possible, due to the lack of appropriate reference materials.

A quantitative 10-plex competitive MLPA method for the detection of eight allergenic ingredients (sesame, soy, hazelnut, peanut, lupin, gluten, mustard and celery) with an internal positive control (IPC) is available (Mustorp et al., 2011). Amplicons were easily separated by CE. The sensitivity is high: the LODs varied from approximately 5 to 400 gene copies depending on the allergenic ingredient. For spiked foods the LODs were of the same order of magnitude or higher than those obtained with qPCR.

Optical thin-film biochips for multiplex visible detection of eight allergenic ingredients (celery, almond, oat, sesame, mustard, lupin, walnut and hazelnut) in foods have been developed on the basis of two tetraplex PCR systems (Wang et al., 2011b). The PCR fragment targets are recognised by the biochip by enzymatic conversion of the nucleic acid hybrids to molecular thin films. The mass contributed by the thin film alters the interference pattern of light on the biochip surface, giving rise to a visible colour change on the chip surface. The absolute LOD was measured only for sesame (0.5 pg DNA); the practical LOD for sesame concentration in a blended mixture was 0.001 %, the lowest value observed so far.

A DNA microarray on a digital versatile disk (DVD) has been developed for the simultaneous detection of hazelnut, peanut and soybean in food (Tortajada-Genaro et al., 2012). The method is versatile, specific and sensitive, with a LOD of 1 µg/g, and is particularly suitable for screening.

11.2.1.2. PCR-ELISA

PCR-ELISA is a combination of the highly specific DNA-methodology and the ELISA assay. A specific DNA segment of an allergenic food is amplified and then hybridised to an oligonucleotide probe labelled with a specific protein. The protein is recognised by a specific antibody carrying an enzyme, which in the presence of a substrate develops a colour. The concentration of DNA is proportional to the absorbance of the coloured solution (Holzhauser et al., 2002). Although some kits are available on the market, this method is complex and seldom used.

11.2.2. DNA Microarrays

The main feature of the microarray technology is the simultaneous detection of multiple analytes in one sample. Microarrays based on oligonucleotides (Bettazzi et al., 2008) or their analogs complementary to the DNA of several allergens have been developed (Rossi et al., 2006), but few are commercially available. The specific probes are immobilised on a solid surface by different techniques and recognise the complementary fluorescently labelled PCR amplicons. The resulting fluorescent spots are read with a fluorescence scanner at the proper wavelength. The method is qualitative and useful for a rapid screening.

11.2.3. DNA Biosensors

DNA-based biosensors are in rapid development. An electrochemical DNA sensor was developed for peanut allergen Ara h 1 detection with a LOD of 0.35x10-15 M. A Surface Plasmon Resonance Imaging (SPRI)-based biosensor using an immobilised PNA probe as receptor was able to detect non-amplified genomic soy DNA down to $41x10^{-21}$ M (D'Agata et al., 2010). DNA biosensors are used for research rather than for routine analyses.

11.2.4. Expression of the results on allergenic ingredients obtained by DNA analysis

The European Standard EN 15634-1:2009 relative to the detection of allergenic ingredients in foodstuffs by molecular biology methods based on DNA analysis establishes that LODs must be

expressed as the number of copies of DNA equivalent to a total quantity of the allergenic ingredient per kg of food (mg/kg). The equivalence is based on reference materials certified by the EU. In most cases standard materials have been produced in different laboratories independently by means of genomic DNA purified and quantified "in situ". The more recent European Standard EN 15842 (CEN, 2010) provides general considerations on the validation of the methods of the detection (immunochemical, DNA analysis and chromatography) of allergens and allergenic ingredients in foodstuffs. LODs are expressed in the literature in different ways: as number of copies of DNA, as absolute pg of DNA detected, as pg DNA/mg of food, or as percentage of the allergenic ingredient in food (% w/w) when the value is referred to a spiked or incurred preparation. When using biosensors, the LOD is expressed as molarity (M).

11.3. Detection of allergens and allergenic ingredients in processed foods

Technological processes and cooking generally affect the structure of the proteins, whereas DNA is more resistant to technological treatments (i.e. DNA is cleaved only at high temperatures or at acidic pH). Food processing also modifies the food matrix (e.g. disruption of structure and cells, gelification, generation of new intermolecular interactions among the components, aggregated/disaggregated assemblies and other supramolecular structures). Thus the extractability of the protein/DNA from processed food may be either easier or more difficult than from raw materials.

As for proteins, reduced detection of allergens from processed foods can be due to either poor extraction efficiency or to reduced accessibility to the epitopes in the immunological assay. Several buffers and extraction modes have been considered depending on the nature of the protein (hydrophilic/lipophilic) and of the matrix (Chassaigne et al., 2007). Ultrasonic and microwave extraction increased protein homogenisation and allergen extractability from a soybean meal and from roasted almonds (Albillos et al., 2011). The performance of available extraction kits for DNA analysis strongly depends on the food matrix (Pafundo et al., 2011).

Food processing may hamper the detectability of food allergens by immunological analysis. For example, the milk protein β-lactoglobulin is a globular compact protein, which is thermo-labile and resistant to degradation by digestive proteases. Heat treatments induce denaturation of the protein (i.e. loss of its 3D and 2D structure), which becomes undetectable by antibodies raised against the native form and thus by immunological methods. However, the denatured β-lactoglobulin keeps most of its allergenic potential because linear epitopes are recognised by IgE of allergic patients (Negroni et al., 1998). Moreover, heat treatment followed by sharp cooling (i.e. tempering) decreased the detectability of casein and β-lactoglobulin by commercial ELISA kits in a dark chocolate matrix, whereas it did not affect the detectability of peanut and egg (Khuda et al., 2012a).

The effect of heat treatment on the detection of peanut was investigated by using three real-time PCR methods and two ELISA kits (Scaravelli et al., 2009). A comparison was made between the two methods on both peanut kernels and peanut containing cookies baked under different conditions. A detrimental effect of the processing temperature/time on the detection of peanut was observed with either method. The performance of both methods was similar. The same trend was observed with roasted peanuts. In this case, the variability was higher between the two ELISA kits, which targeted two different proteins (Ara h 1/Ara h 2), than among the three PCR methods.

The use of incurred samples is preferable to the use of spiked samples to assess the effects of food processing on food allergens (Monaci and Visconti, 2010).

11.4. Conclusion

Screening (qualitative), quantitative and confirmatory methods are available for the detection of food allergens.

The majority of kits commercially available for routine food allergen analysis rely on immunological methods. ELISA methods are the most widely used because they are sensitive and specific for the

detection of allergenic proteins and easy to use. However, commercial kits for quantitative analyses use different extraction buffers and calibration procedures, differ in the quality of the antibodies used, and the results vary among commercial brands and batches. Major limitations include matrix effects, insufficient extraction of the proteins, insufficient specificity owing to cross-reactions, and insufficient reproducibility of results. The use of incurred samples may help to improve the reliability of the method when analysing processed foods.

Mass spectrometry, in combination with techniques such as 2D-SDS-PAGE or chromatography for the preliminary separation of the proteins and with allergen databases for their subsequent identification, is a reliable tool for the detection of known allergens and for the identification of new immunoreactive proteins. MS methods for quantitative analysis based on specific standard peptides or stable isotope labelling are not yet suitable for analyses of large numbers of samples, but can confirm results obtained otherwise.

DNA methods allow detection of the allergenic food rather than of the allergenic protein and are complementary to immunological assays. DNA is generally more stable than proteins and thus suitable for analysis of processed foods. The extraction and amplification procedures are well established. Both end-point and real-time PCR allow simultaneous multiple analyses. Whenever ELISA kits are not available or not specific (e.g. celery), DNA analysis becomes the method of choice. Real-time PCR may provide quantitative results and allows multiplexed analysis. Commercial kits are available.

The main problem for the quantification of allergens by immunological or DNA based methods is the unavailability of CRMs. Reference materials developed by different producers are commercially available for most major food allergens, but the results obtained with different kits may not be comparable. To the Panel's knowledge, a CRM for the detection of food allergens by immunological methods has only been developed for peanuts (IRMM-481). For milk and egg, two reference materials are commonly used, NIST RM-1549 and NIST RM-8445, respectively.

12. Determination of thresholds for allergenic foods/ingredients

12.1. Introduction and terminology

The notion of determining threshold levels for allergenic foods below which sensitised consumers are not at risk of developing allergic reactions has attracted much attention from regulatory bodies, consumer associations and industry throughout Europe.

The no-observed adverse-effect level (NOAEL) is the highest tested dose of an allergenic food, which does not trigger an adverse reaction in an allergic individual. The terms individual threshold, lowest observed adverse effect level (LOAEL) and minimal observed eliciting dose (MOED) or minimum eliciting dose (MED) have been used to describe individual allergen exposure levels below which an allergic individual is unlikely to react. The MOED/MED used for allergenic foods are similar to the LOAEL used for chemicals (Spanjersberg et al., 2007; Blom et al., 2013). However, the terms individual threshold and MOED/MED, which are occasionally used interchangeably, have different meanings.

A MOED is defined as an individual's lowest level of exposure at which an 'objective' allergic reaction has occurred and below which an objective adverse effect is not expected in that individual, although 'subjective' allergic symptoms, such as abdominal pain, headaches, tingling sensation in the throat and similar could occur at lower dose levels (FDA (Food and Drug Administration), 2006; Taylor et al., 2009a). MED is the lowest tested dose of an allergen triggering allergic symptoms in an individual, whether "objective" or "subjective". In this context, the term allergic reaction is restricted to IgE-mediated adverse effects occurring usually within two hours after administration of the offending allergenic food. The true (rather than tested) individual minimum eliciting dose for an allergenic food, which is the individual threshold, lies between the NOAEL and the MED by definition.

Both MOED and MED are often combined in statistical models to derive population threshold curves (Blom et al., 2013) and calculate population-based eliciting doses (ED) at which a specified percent of the allergic population is likely to react.

12.2. Determination of thresholds for an individual

Standardised DBPCFCs are the standard for analysis of individual threshold levels of an allergenic food in food allergic patients (Sicherer et al., 2000a; Bahna, 2003). However, the selection of subjects, the doses of allergen tested and the interpretation of the results vary from investigator to investigator. Variability is particularly related to the scoring of the patient's subjective and objective symptoms and their severity. In addition, most clinicians exclude from challenge studies those patients likely to have the most severe reactions (i.e. highly sensitised individuals and those with history of anaphylaxis) based on the individual's history (Taylor et al., 2002).

Doses of the allergenic food/ingredient reported to trigger adverse reactions in controlled studies range from micrograms to milligrams, and sometimes grams (Wensing et al., 2002b). It is not always stated whether the doses reported relate to the administered allergenic protein equivalent or to the allergenic food/ingredient. In some studies, the allergenic food is not administered in the form that it is usually eaten (e.g. freeze dried, introduced as flour, or modified in other ways) (Hourihane et al., 1997). Although such food preparations are necessary to fulfil strict DBPCFC criteria, they may affect the LOAELs and MEDs for a particular allergenic food that are derived from that specific study (Grimshaw et al., 2003).

Variables affecting the determination of individual MEDs in DBPCFCs are listed in Table 4.

Table 4: Variables affecting minimal eliciting dose levels

Variables
Severity of the allergic condition
Symptoms used as the clinical read-out system (subjective vs. objective symptoms and their associated severity)
Administration protocols, challenge conditions and food preparations
Raw versus processed food
Food matrix and allergen content of challenge foods
Total amount of administered dose and time frame
Reproducibility (false positives and negatives)
Co-factors (for example exercise, alcohol, medication)
Patient population (geographical distribution of underlying sensitisation rates for cross-reacting allergens; genetic background)

Most DBPCFCs conducted in food allergic patients have been designed for diagnostic purposes rather than to establish individual thresholds for an allergen (Hourihane et al., 1997; Wensing et al., 2002a; Moneret-Vautrin and Kanny, 2004). In some cases, the gap between the NOAEL and the MED can be considerable depending on the dose intervals used, and these studies did not provide a scientific basis for setting a NOAEL or for recommending acceptable levels of intake of the allergenic food/ingredient for an individual (Morisset et al., 2003a). In some other cases, either the MED (e.g. allergic individuals not reacting to the higher tested dose) or the NOAEL (e.g. allergic individuals reacting to the first tested dose) cannot be established. A statistical methodology, the interval censoring survival analysis (ICSA), has been used to determine individual thresholds taking account of these uncertainties in order to derive population threshold curves (Taylor et al., 2009a).

12.3. Determination of thresholds for a population

Three different approaches have been proposed to derive thresholds for allergenic food/ingredients at a population level (Madsen et al., 2009): (i) the traditional risk assessment using the NOAEL and

uncertainty factors, (ii) the Bench Mark Dose (BMD) and Margin of Exposure (MoE) approach, and (iii) probabilistic models.

In traditional toxicological risk assessment, experimental studies testing different doses of a substance are generally used to determine the NOAEL, and then uncertainty factors (often between 100-1000) are applied to account for extrapolation from animals to humans and to account for inter-individual human variation in order to derive threshold levels for populations (Calabrese and Baldwin, 1994; Pelekis et al., 2003; Madsen et al., 2009). Such values are then compared to exposure levels in the population to characterise the risk of adverse health effects associated to the consumption of that substance. The ensuing risk is generally a point estimate resulting from the worst-case value for each variable (NOAEL, health outcome and exposure levels). In food allergy, the level of exposure to allergenic foods/ingredients, which may trigger adverse allergic reactions in susceptible individuals, is extremely variable, so that setting population thresholds for allergenic foods/ingredient using a traditional toxicological risk assessment approach is not appropriate.

The BMD approach has also been used in toxicology safety assessment. Rather than using a single data point from a single study, all experimental data as available are fitted in a distribution curve to calculate the BMD lower limit (BMDL), which is divided by the estimated intake in a population to derive a Margin of Exposure (MoE). Different margins of exposure can be calculated using the same BMD distribution for different exposure scenarios. However, the MoE does not describe the likelihood that an adverse reaction will occur in the allergic population.

A probabilistic approach for food allergy risk assessment has been proposed (Spanjersberg et al., 2007; Madsen et al., 2009) and tested for some allergenic foods (van Bilsen et al., 2011; Allen et al., 2013; Blom et al., 2013; Remington, 2013; Taylor et al., 2013). This approach estimates the distribution of intake of an allergenic food in a given population (from food consumption and the concentration of the allergenic ingredient in foodstuffs) and the threshold probability distribution for that allergenic food in the same population (from individual MEDs and LOAELs reported in, or calculated from, DBPCFCs). By comparing the threshold distribution to the distribution of consumption of the allergenic food, the probability of an allergic reaction occurring upon exposure to an allergenic food expressed as mg of total protein is calculated. Factors to convert mg of total protein into mg of allergenic food/ingredient are available (Remington, 2013; Taylor et al., 2013). The graphic statistical display allows the definition of the eliciting dose (usually ED_{01}, ED_{05} or ED_{10}) at which a particular percentage (1 %, 5 % or 10 %) of the allergic population is likely to react when exposed to that level of allergenic ingredient (Madsen et al., 2009). The reliability of the estimates depends on the type, quality, and amount of data used, particularly to describe the lower end of the distribution; on the extent to which the sample used to derive the MED distribution is representative of the overall allergic population; and on whether food consumption data from dietary surveys reflects consumption patterns in the allergic consumer.

Different threshold probability distributions and eliciting doses have been estimated for few allergenic foods depending on the amount and characteristics of the challenge studies used (e.g. age and gender of subjects, challenge materials, geographical region, discrete versus cumulative trigger doses), on the distribution models applied (e.g. log-logistic, log-normal or Weibull), and on the approach followed to derive population thresholds (BMD versus probabilistic models) (Eller et al., 2012; Allen et al., 2013; Remington, 2013; Taylor et al., 2013). Estimated EDs for each allergenic food/ingredient as mg of total protein are depicted in Appendix A. For example, the type of challenge studies included in the distribution (e.g. food challenges for immunotherapy, threshold-finding or diagnostic purposes) had an impact on the ED_{01} and ED_{05} estimated for milk (Allen et al., 2013). The challenge material used significantly affected population threshold doses for egg (cooked or raw whole egg vs. raw egg white), whereas the age of the sample population used to calculate the individual threshold curves significantly affected population threshold doses for hazelnut (Allen et al., 2013; Taylor et al., 2013). The scarcity of data available did not allow an independent assessment of the effect of geographical region on estimated eliciting doses for populations for any allergenic food/ingredient. Moreover, to offset the lack of data from oral food challenges for some allergenic foods/ingredients, data were

sometimes extracted from both published and unpublished studies (Allen et al., 2013; Taylor et al., 2013). Threshold doses estimated for the same allergenic food/ingredient and expressed as mg of total protein notably varied from one group of investigators (Eller et al., 2012) to another (Allen et al., 2013; Remington, 2013; Taylor et al., 2013).

The lowest reference doses (mg of protein) which have been proposed by others for labelling purposes based on estimated ED_{01} for objective symptoms, 95 % lower CIs of the ED_{05}, or both, depending on the allergenic ingredient, are for mustard (0.05 mg) and egg (0.03 mg), followed by milk and hazelnut (0.1 mg) and by peanuts and sesame seeds (0.2 mg). Higher reference doses have been proposed for soy and wheat (1 mg), cashew (2 mg), lupin (4 mg), and the highest for shrimp (10 mg) (Allen et al., 2013; Taylor et al., 2013).

The Panel notes that, at present, there is no standard method to calculate population thresholds across allergenic food/ingredients, and that decisions on the sources of data (occurrence and intake data, studies used to derive individual thresholds) and that the distribution models and approaches chosen to derive population thresholds have been based on expert judgement, the underlying basis of which are not fully transparent (e.g. use of unpublished data) and therefore not reproducible. The Panel also notes the high variability among various population thresholds estimated for a same allergenic food/ingredient, and that the accuracy of these thresholds has not been tested yet prospectively in real life conditions (i.e. percentage of the allergic population actually reacting to a given dose of the allergic ingredient when consumed in different food matrices and eating occasions relative to the percentage of the allergic population estimated to react from population threshold curves).

12.4. Prediction of individual sensitivity

Specific IgE levels and results of skin prick tests are only loosely related to the likelihood and severity of allergic reactions. In addition, several attempts to use these tests for the prediction of individual thresholds and/or the severity of allergic reactions in allergic individuals have yielded conflicting results (Eigenmann and Sampson, 1998; Boyano Martinez et al., 2001; Niggemann et al., 2001; Sampson, 2001; Morisset et al., 2003a; Osterballe and Bindslev-Jensen, 2003).

Thresholds derived for populations and risk management purposes (e.g. which assume a particular risk, margin of safety, or a percentage of the population reacting to a particular dose of allergenic food/ingredient) cannot be used by individuals to manage their food allergy, unless they are aware of their own (individual) threshold levels under various conditions, e.g. food matrix, ingestion in combination with exercise or medications.

12.5. Conclusion

Current clinical, epidemiological and experimental data do not allow determining safe allergen threshold levels that would not trigger adverse reactions in a sensitised consumer. Different threshold probability distributions and eliciting doses (usually ED_{01}, ED_{05} or ED_{10}, at which 1 %, 5 % or 10 % of the allergic population is likely to react when exposed to that level of allergenic ingredient) have been estimated for few allergenic foods/ingredients, which vary among publications depending on the decisions made by expert committees regarding the amount and characteristics of the challenge studies used, the distribution models applied, and the approach followed. Considering that most clinicians exclude from the challenge studies those patients having the most severe reactions and that the reliability of these thresholds has not been tested prospectively in real life conditions yet, the Panel considers that thresholds derived for populations and risk management purposes cannot be used by individuals to manage their allergy, unless they are aware of their own (individual) threshold levels under various conditions.

In the remaining sections of this Opinion dedicated to specific allergenic foods/ingredients, minimal (observed) eliciting doses for individuals reported in challenge studies, rather than estimated thresholds for populations, will be considered.

13. Coeliac disease

13.1. Background

Coeliac disease is an autoimmune systemic disorder triggered by gluten in genetically susceptible individuals. It is a life-long disease with permanent gluten intolerance and is characterised by the presence of a variable combination of gluten-dependent clinical manifestations, coeliac disease-specific antibodies, HLA-DQ2 or HLA-DQ8 haplotype, and a small intestinal mucosal lesion (enteropathy) (Marsh, 1992; Collin et al., 1994; Fasano and Catassi, 2001; Tack et al., 2010; Husby et al., 2012; Ludvigsson et al., 2013).

Coeliac disease is strongly associated with HLA-DQ2 and DQ8 (Marsh, 1992; Sollid, 2002; Schuppan et al., 2009). Gluten peptides are presented by DQ2- and DQ8- positive antigen-presenting cells to immunocompetent cells of small intestinal lamina propria. Tissue transglutaminase, which has also been identified as the important autoantigen in coeliac disease, is released and it may potentiate antigen presentation by deamidating or cross-linking gluten peptides (Schuppan et al., 2009). As a result, T cell activation, cytokine production, mucosal inflammation and destruction evolve. As a secondary event, production of humoral antibodies to the autoantigen transglutaminase and to gluten/gliadin peptides occurs. Immune pathophysiology of coeliac disease involves innate and adaptive immunity. The mechanisms are different from IgE-mediated food allergy. As a consequence, time course and clinical manifestations of the reactions are different.

Coeliac disease has a wide range of clinical presentations in all age groups. The most severe cases may present with diarrhoea and cachexia; less severely affected patients may present with malabsorption resulting in weight loss and, in children, with failure to thrive. However, the disease may present with more insidious symptoms. In some childhood cases, impaired weight or height gain, or delayed puberty may be the only clinical evidence of illness. In adults, infertility, osteoporosis, iron deficiency or other deficiency syndromes may be the only clinical manifestation. Clinical manifestations and enteropathy are responsive to elimination of the trigger by a gluten-free diet except for a few cases of refractory coeliac disease (Meresse et al., 2009; Tack et al., 2010).

The diagnosis of coeliac disease relies on a combination of typical symptoms and a small intestinal biopsy indicating enteropathy which responds to a gluten-free diet, on the demonstration of autoantibodies against endomysium and tissue transglutaminase as well as against deamidated gliadin peptides, and on the demonstration of the DQ2/DQ8 haplotype (Volta and Villanacci, 2011; Husby et al., 2012). Coeliac disease can also be diagnosed in the absence of symptoms.

Coeliac disease can be associated with other autoimmune diseases, with type 1 diabetes mellitus and with IgA deficiency. First degree relatives of coeliac patients have a 10 % risk to develop coeliac disease themselves. Underestimation and unawareness of the diagnosis is still common.

In some patients where coeliac disease had been excluded, non-coeliac gluten sensitivity has been suggested (Biesiekierski et al., 2011). However, this entity has not been well defined, and there are no reliable and accepted diagnostic criteria.

13.2. Epidemiology

13.2.1. Prevalence

World-wide, the prevalence of coeliac disease based on the clinical diagnosis, classical gastrointestinal symptoms and enteropathy formerly appeared to be about 1:3 000 (Fasano and Catassi, 2001). However, this classical picture with abdominal distension, steatorrhea and deficient growth has become rare. Oligosymptomatic forms (patients with anaemia, retarded puberty, dental anomalies, oral ulcers, infertility, abdominal pain, constipation, short stature, arthritis, neurological and psychiatric complaints) have become more predominant (Collin et al., 1999; Husby et al., 2012; Ludvigsson et al., 2013). Considering the classical picture, oligosymptomatic and even asymptomatic forms together, the

overall prevalence is estimated to be as high as 0.5-1 % in Europe and the Western World (Fasano and Catassi, 2001; Rubio-Tapia et al., 2009; Virta et al., 2009).

13.3. Proteins identified to trigger coeliac disease

Gluten is defined as the rubbery dough forming protein that remains when wheat flour is washed to remove starch (Stern et al., 2001; Wieser and Koehler, 2008). Gluten is characterised by a unique high content of glutamin and proline. It consists of glutenin and gliadin, two seed storage proteins, which have been shown to trigger the pathophysiological and clinical features of coeliac disease. Glutenin is a high-molecular protein fraction insoluble in alcohol. The alcohol-soluble gliadins contain mainly monomeric low-molecular proteins. Gliadins belong to a group of plant storage proteins rich in proline (prolamins). Gliadins contain repetitive peptide units such as QPQPFPPQQPYP and PQQPFPQ. These repetitive peptide units are contained in α, γ, ω subtypes of gliadin, which have all been shown to elicit the disease. A 33-mer peptide (LQLQPSTQPQLPYPQPQLPYPQPQLPYPQPQPF) was the first primary initiator of the inflammatory response in coeliac disease identified (Shan et al., 2002).

Wheat, rye and barley contain coeliac-active prolamins, whereas maize, rice, millet and sorghum do not. Oats contains low amounts of the prolamin type avenin. Wheat, rye and barley have been established to trigger coeliac disease, whereas maize, rice and buckwheat were found not to be harmful. Toxicity of oats has been questioned. Uncontaminated oats seem to be safe in the vast majority of patients of all ages (Janatuinen et al., 2002; Lundin et al., 2003; Holm et al., 2006; Kemppainen et al., 2007), although oat cultivars may show variable toxicity depending on the presence of specific peptide sequences with higher or lower immunogenicity (Comino et al., 2011; Real et al., 2012). Yet, oats is commonly contaminated with other cereals containing gluten (mostly barley).

Different gluten peptides have been shown to elicit coeliac effects, both at the intestinal epithelia and immunocompetent cells level (van de Wal et al., 1998; Anderson et al., 2000; Shan et al., 2002; Vader et al., 2002; Koning et al., 2005; Bodd et al., 2012). At the level of T cell reactivity, stimulatory gluten peptides have been identified up to the molecular level. There is a diverse repertoire of gluten peptides eliciting a coeliac response, including immuno-dominant T cell stimulatory peptides rich in proline residues (Arentz-Hansen et al., 2002; Vader et al., 2002; Molberg et al., 2005).

13.4. Possible effects of food processing on coeliac "toxicity" of gluten

Food processing generally does not affect coeliac "toxicity" of gluten. For example, partial hydrolysis and enzymatic peptic-tryptic degradation of gluten do not affect coeliac-triggering properties since the important peptide units are unaffected. Heat treatment (baked products) does not change coeliac "toxicity" either, whereas complete acid hydrolysis abolishes toxicity. All food technology processes, however, affect extractability and detectability of gluten, which are important in any attempts to measure gluten quantitatively in food (Stern et al., 2001; Hischenhuber et al., 2006).

13.5. Detection of gluten in food

The existing methods of the detection for gluten in foods have been recently reviewed (Haraszi et al., 2011; Diaz-Amigo and Popping, 2012).

13.5.1. Immunological methods

13.5.1.1. ELISA

A number of rapid and sensitive monoclonal and polyclonal sandwich ELISA kits are commercially available for gluten analysis. However, the results obtained with such kits are often non comparable, since they target different gluten components and differ in antibody specificity, extraction conditions and matrix effects (Immer and Haas Lauterbach, 2010; van Eckert et al., 2010; Diaz-Amigo and Popping, 2013).

The Association of Analytical Communities and the Codex Alimentarius Commission (Codex Alimentarius Commission, 2006, 2008) have endorsed two different sandwich ELISA for gluten analysis in foods, which are reported to be suitable to quantify native and heat treated gluten. The former, based on the 401/21 mAb (Skerritt and Hill, 1991), mainly binds to ω-gliadin and glutenin subunits and is now obsolete. The latter, based on the mAbs R5 (Valdes et al., 2003), recognises potential coeliac-toxic epitopes occurring repeatedly in α/β-,γ- and ω-gliadin fractions which are conserved in wheat, barley and rye varieties. The method uses a "cocktail extraction method", i.e. a disaggregating agent (guanidine hydrochloride) and a reducing agent (2-mercaptoethanol) in combination (García et al., 2005) that is able to solubilise gluten aggregates and has an acceptable repeatability and low LOD (1.5 mg/kg). However, both methods present limitations in quantifying barley proteins in gluten-free foods, such as oats, which is often contaminated with barley (Kanerva et al., 2006). The ELISA kit based on ω-gliadin underestimates the amount of barley prolamin, whereas the R5 antibody overestimates it. In the latter case, the problem may be overcome by using a hordein standard. A detailed comparison between the two methods has been published (Thompson and Mendez, 2008).

Deamidation is an industrial way to modify the protein structure for increasing solubility and gluten functionality that affects the accuracy of detection and quantification by immunoassays. In a model system (gluten treated with 0.1 M HCl at 100 °C for 2 h), deamidation decreased the recognition of the antibody R5 by 600 times when analysed by the sandwich method and 125 times by the competitive format, while it abolished completely the recognition by the ω-gliadin based antibody (Kanerva et al., 2011). A new monoclonal antibody mAb PQQ3B4 binding both gliadins and glutenin subfractions was selected, able to detect either native or modified prolamins to similar degrees from wheat and other cereals and proposed as a promising candidate for improved gluten quantification (Tranquet et al., 2012).

For gluten analysis in hydrolysed products (such as syrup and beer), competitive ELISA systems are more suitable than sandwich ELISAs because they allow detecting smaller peptide fragments (Haraszi et al., 2011). Some commercial assays, based on different antibodies, are available. A competitive ELISA assay based on the mAb R5 in combination with an efficient and compatible extraction (UPEX) solution is able to detect gluten in heat-treated and hydrolysed foods with a LOD of 0.36 µg/L and a LOQ of 1.22 µg/L for gliadins, respectively (Mena et al., 2012). For the same assay, a calibrator with a 1:1 mixture of hydrolysed gliadin from the Prolamin Working Group (PWG) and purified prolamins from rye and barley has also been used (Haas-Lauterbach et al., 2012).

PWG gliadin is a well-characterised material which has been proposed (and generally accepted) as a reference material for gluten (van Eckert et al., 2006), although it is specific for gliadin only and has some limitations for gluten analysis (Diaz-Amigo and Popping, 2013).

13.5.1.2. Lateral flow devices and dipsticks

LFDs and dipsticks for rapid and sensitive qualitative detection of gluten are available (Immer and Haas Lauterbach, 2010).

13.5.1.3. Biosensors

A number of biosensors for detecting gliadin contamination in gluten-free foods have been developed but are not yet commercially available. Two electrochemical biosensors have been described (Nassef et al., 2008; Nassef et al., 2009). One uses an antibody raised against the immunodominant epitope of gliadine with a LOD of 5.5 µg/L. The second is based on the adsorption of anti-gliadin Fab fragments on gold surfaces. Detection of gliadin was evaluated by impedance (LOD = 0.42 mg/L) and amperometry (LOD = 3.29 µg/L).

A quartz crystal microbalance biosensor incorporating gold nanoparticles was able to detect gliadin with a LOD of 8 µg/kg (Chu et al., 2012). Another biosensor used anti-gliadin antibody-conjugated immunomagnetic beads (IMBs) as the capture reagent to extract gliadin from food and fluorescence-

dye-loaded immunoliposomal nanovesicles (IMLNs) to form a fluorescent sandwich complex (Chu and Wen, 2013). The polyclonal antibody showed a slight cross-reactivity with barley and rye. The LOD for gliadin was 0.6 mg/L, consistent with those obtained with the mAbs R5-based sandwich ELISA kit.

13.5.2. Mass Spectrometry

Although MS has widely contributed to assess the structure of gluten, its use for the quantitative determination of gluten in food faces several challenges. Gluten proteins are not soluble in the salt buffers typically used for protein characterisation and have few sites for tryptic hydrolysis. However, by using LC-MS/MS it was possible to detect and quantify relevant wheat gluten peptides in food products with a LOD of 1-30 pg/mg and a LOQ of 10-100 pg/mg (Sealey-Voyksner et al., 2010).

Gluten proteins in red wines fined with gluten, in which gluten could not be identified by immunological methods, were isolated by precipitation with potassium dodecyl sulphate (KDS) and analysed by LC-MS/MS. Wheat gluten proteins were detected down to 1g/hL of commercial wheat gluten (Simonato et al., 2011). An LC-ESI-MS/MS method was applied (Weber et al., 2009a) to detect and identify gluten in beer from different sources. In contrast with the most common ELISA assays, this MS method allowed to discriminate wheat proteins from barley proteins.

By using a proteomic approach, the prolamin proteins present in purified hordeins, wort and beer were characterised and their relative amounts were quantified (Colgrave et al., 2012). MRM-MS was used as a robust and sensitive methodology to detect gluten hordein in beer. A comparison between ELISA and MS methods in the MRM mode for measuring hordein in beer (Tanner et al., 2013) showed that MS was more reliable than ELISA, as ELISA recognises only some epitopes of hordeins whereas MS measures peptides that are specific and unique, allowing quantification of hordein isoforms. Several beers manufactured with barley were found to contain unforeseen wheat proteins.

Although MS methods are more reliable than ELISAs for gluten analysis, they are mostly used as confirmatory methods at present and are more suitable for regulatory agencies and research laboratories than for screening and routine analysis.

13.5.3. DNA based methods

Several end-point and real-time PCR methods allow verifying the absence of wheat, barley and rye DNA in "gluten-free" products. A quantitative competitive PCR system using gel electrophoresis for the simultaneous detection of wheat, barley and rye in gluten-free food based on amplification of a non-coding region of the chloroplast *trn*L gene does not discriminate among the three cereals (Dahinden et al., 2001). The absolute LOD was 20 pg of DNA for wheat and 2 pg of DNA for rye and barley. A PCR method targeting the glutenin gene to detect wheat DNA in a number of raw and heat processed foods had a LOD of 21.5 pg of DNA (Debnath et al., 2009). A real-time PCR method for the specific detection of wheat, rye, barley and oats could discriminate among the four cereals, but no quantitative results were provided (Sandberg et al., 2003).

Another real-time PCR method for qualitative and quantitative detection of the rye (*Secale cereale* and *Triticosecale*) content in raw materials and processed foods was developed using a SYBR® Green detection system and a TaqMan® fluorogenic probe (Terzi et al., 2004). It was possible to detect 1 % of rye in a rye-rice model mixture. The SYBR® Green detection method was judged to be more precise than the TaqMan®.

A sensitive qPCR system employing the fluorescent dye SYBR® Green for wheat contamination in gluten-free food had a LOQ of 20 pg DNA/mg (Mujico et al., 2011). This DNA based method was more sensitive than the mAbs R5-based sandwich ELISA kit, able to detect wheat below the LOQ of the ELISA (< 1.5 mg/kg).

The performances of ELISA and PCR methods for the determination of gluten in different foods were evaluated by proficiency testing (Scharf et al., 2013). Although test kit-specific differences were observed for the ELISA kits, both ELISA and PCR methods showed reliable results for the determination of gluten and wheat in food.

13.6. "Gluten-free" food products and diets

A gluten-free diet excluding wheat, rye, barley and oats (because oats is commonly contaminated by other grains) is the conventional cornerstone treatment for the management of coeliac disease. Owing to individual variation and clinical heterogeneity of coeliac patients, it is difficult to find an acceptable value for trace amounts of gluten in foods which could be tolerated by the majority of coeliac patients (Stern et al., 2001; Hischenhuber et al., 2006).

The usual daily intake of gluten is 15-20 g in the adult European population. In coeliac patients any effort has to be undertaken to exclude gluten/gliadin from the diet. Early studies have shown that 100 mg of gliadin per day were able to induce coeliac specific histological lesions in children (Catassi et al., 1993). After a long-term dietary survey using naturally gluten-free products and also wheat starch-based products with reduced gluten content (Collin et al., 2004), a level of 100 mg/kg gluten was proposed for the dietary management of coeliac patients. Daily consumption of flour, which differs between European countries (range 10-500 g), needs to be considered.

In a low-dose double-blind placebo-controlled challenge trial carried out in Italy (Catassi et al., 2007), where 0, 10 or 50 mg of gluten were given to coeliac patients daily for 90 days, 50 mg gluten per day produced measurable damage to the small-intestinal mucosa. To keep gluten intake < 50 mg/day, which was considered to be safe for most coeliac patients, a limit of 20 mg/kg gluten in foods was proposed. This figure took into account high regional consumption of wheat substitutes, thus allowing a 'safe margin' according to dietary habits of patients (Catassi et al., 2007).

Based on these observations, Codex Alimentarius adopted in 2008 a revised codex standard for foods for special dietary uses addressed to persons intolerant to gluten (Codex Alimentarius Commission, 2008). "Gluten-free" foods were defined as dietary foods consisting of or made only from one or more ingredients which do not contain wheat, rye, barley, or oats, and the gluten content does not exceed 20 mg/kg of the food as sold or distributed to the consumer. In addition, the standard defined foods specially processed to reduce the gluten content to a level above 20 up to 100 mg/kg as foods consisting of one or more ingredients from wheat, rye, barley, oats or their crossbred varieties which have been specially processed to reduce the gluten content to these levels.

Based on this, the European Commission has issued a Regulation[9] concerning the composition and labelling of foods suitable for people intolerant to gluten, where the terms "gluten-free" (not exceeding 20 mg/kg) and "very low gluten" (not exceeding 100 mg/kg) are set. It applies from 1 January 2012.

Although the labelling of "gluten-free" and "very low gluten" foods is helpful for the dietary management of most coeliac patients, questions regarding low-dose and long-term gluten sensitivity, and the testing and toxicity of glutenin and gluten hydrolysates remain open. New standards, new methods of detection of gluten-related proteins in foods, and new therapies for coeliac disease are likely to be developed in the future (FDA (Food and Drug Administration), 2006; Donnelly et al., 2011; Sollid and Khosla, 2011).

13.7. Conclusion

Coeliac disease is a life-long autoimmune systemic disorder triggered by gluten and similar cereal storage proteins present in wheat, rye and barley. Its prevalence is estimated to be 0.5-1 %. Coeliac disease is under-diagnosed due to its various clinical manifestations. Diagnosis relies on a combination

[9] Commission Regulation (EC) No 41/2009 of 20 January 2009 concerning the composition and labelling of foodstuffs suitable for people intolerant to gluten, OJ L 16, 21.1.2009, p. 3–5.

of typical symptoms, presence of enteropathy responding to a gluten-free diet, demonstration of coeliac-specific antibodies and of the HLA DQ2/DQ8 haplotype. A gluten-free diet excluding wheat, rye, barley and oats (because commonly contaminated with other grains) is the conventional treatment for the management of coeliac disease. Methods for gluten analysis are available for the control of "gluten-free" products. ELISA methods, which are most frequently applied, present some analytical drawbacks. Mass spectrometry has not been used yet for quantification of gluten, whereas DNA-based methods are useful tools to detect eventual contaminations. The limit values of 20 and 100 mg/kg of gluten in "gluten-free" and "very low gluten" foods, respectively, help managing the diet of most coeliac patients efficiently.

14. Allergy to cereals containing gluten

14.1. Background

The term "cereal" indicates any kind of plant producing grains, which are milled in order to obtain edible flour. It follows that "cereals" do not belong to a single botanical family, though the majority are from the grass family, named *Poaceae* or *Gramineae* (wheat, spelt wheat, rye, barley, oats, rice, maize, millet, sorghum, tef). Some belong to the family of *Polygonaceae* (buckwheat), and others to the family of *Amaranthaceae* (quinoa).

From the grass family, rice (*Oryza sativa*) (Yamakawa et al., 2001), maize (*Zea mays*) (Pastorello et al., 2000; Scibilia et al., 2006; Weichel et al., 2006), millet (*Pannicum milliaceum*) (Bohle et al., 2003), sorghum (*Sorghum bicolor*) and teff (*Eragrostis tef*) are non gluten-containing cereals which may induce food allergy. From the non-grass family, buckwheat (*Fagopyrum aesculentum*) (Heffler et al., 2011) and quinoa (*Chenopodium quinoa*) are plants used as cereals.

Only some cereals (wheat, spelt wheat, rye, barley, oats, khorasan wheat or their hybridised strains) contain gluten, which is defined as the rubbery dough-forming protein that remains when wheat flour is washed to remove starch. Gluten consists of the seed storage proteins glutenin and gliadin (see section 13). Only cereals containing gluten have been included in Annex IIIa of Directive 2000/13/EC. Nevertheless, allergies to cereals are not only elicited by gluten proteins, but also by other proteins present in gluten-containing and in gluten-free cereals. The focus of this chapter is restricted to cereals containing gluten, following Annex IIIa.

Cereals are a major source of food in all parts of the world and account for 72 % of the protein in the human diet. World production of all cereal grains is about 1 600 billion tonnes annually. Wheat is the leading cereal grain, representing about one-third of the world cereal production, followed by rice and maize. Nearly two-thirds of the wheat produced is used for food. Wheat is consumed in different forms, all of which involve some degree of processing: products such as breakfast cereals are obtained from the whole kernel, but most of the wheat is milled into flour for baking. About 6 % of wheat undergoes industrial processing into gluten and starch, which are used in food as protein enrichment and as thickening agents, respectively.

IgE-mediated allergic reactions to cereals were first described as occupational diseases caused by the inhalation of cereal flour by bakers or millers ("baker's asthma"). Cereals can also induce immediate or delayed clinical reactions after ingestion (food allergy). The severity of symptoms varies from mild to severe (Armentia et al., 2002; Scibilia et al., 2006; Tatham and Shewry, 2008). Oral allergy syndrome, urticaria, flare-up of atopic dermatitis, respiratory and gastrointestinal symptoms, eosinophilic gastroenteropathy, non-coeliac gluten sensitivity and even anaphylaxis, which can also be induced by exercise, have been described in relation to cereal ingestion. The gluten-containing cereals described as causing IgE-mediated reactions are wheat, rye, barley, and oats.

14.2. Epidemiology

14.2.1. Prevalence

14.2.1.1. Europe

Population-based studies investigating the prevalence of cereal allergies in unselected populations are scarce (Table 5). The most commonly mentioned allergies are related to wheat and, to a lesser extent allergies related to barley, rye and oats (University of Portsmouth, 2013). It is sometimes difficult to differentiate between prevalence of cereal allergy (IgE-mediated and non IgE-mediated) and prevalence of cereal-related intolerances (including gluten sensitivity). In some cases, clinical symptoms of food allergy to cereals can be similar to those observed in food intolerance, particularly in children, and studies relying only on questionnaire-based methods are generally not reliable to differentiate between food allergy and food intolerance in relation to gluten-containing cereals.

Table 5: Estimated prevalence (%) of allergy to gluten-containing cereals in unselected European populations by type of cereal, age group and method of diagnosis.

	Cereals	Wheat	Barley	Rye	Oat
All ages					
Self-reported	-	0.9	-	-	-
Clinical history and sensitisation	-	0.9	1.7	0.9	1
Young children (≤ 3 years)					
Self-reported	0.2-2.3	0.8-2.1	1.3-1.8	-	-
Sensitisation	-	0-0.2 (SPT)	-	-	-
Clinician diagnosed	0.9-1.1	0.3-2.4	1.3-2	-	-
Clinical history and sensitisation	0	-	-	-	-
Clinical history and FC	-	0-0.4	-	-	-
Children /adolescents (> 3-17 years)					
Self-reported	1.5	0.2-1.5	1.8	-	-
Sensitisation	-	0.3-1.2 (SPT) 4 (IgE)	-	-	-
Clinician diagnosed	2	0.3-3.4	2.7	-	-
Clinical history and sensitisation	-	1.3		-	-
Clinical history and FC	-	-	-	-	-
Adults/elderly (≥ 18 years)					
Self-reported	-	0.8	-	-	-
Sensitisation	-	2.8-13.9 (SPT) 2.8-5.5 (IgE)	-	7.3-11.1 (SPT) 0-2.8 (IgE)	-
Clinical history and FC	-	0	-	-	-

FC = Food challenge; SPT = skin prick test; IgE = allergen specific IgE

Cereals

Three studies evaluated self-reported allergy to grains or cereals in Europe, but only one (Pyrhonen et al., 2009) detailed the cereals consumed (oats, maize, rice, millet and buckwheat). No data were available in adult populations. The estimated prevalence of cereal allergy ranged from 0.2 % at 18 months in Norway (Eggesbo et al., 1999) to 2.3 % at one year in Finland (Pyrhonen et al., 2009). Based on clinician's diagnosis, the estimated prevalence of cereal allergy was 1.1 % at one year, 0.9 % at two years and 2 % at three and four years in Finland (Pyrhonen et al., 2009). These two studies

examined IgE- and non IgE-mediated cereal allergies. Self-reported allergy to cereals was estimated at 1.2 % in young children in Sweden (Kristjansson et al., 1999). However, when the diagnosis was based on clinical history of food allergy and positive SPTs, this figure was zero.

Wheat

Several studies assessed the prevalence of self-reported wheat allergy (IgE- and non IgE-mediated). In young children (≤ 3 years), prevalence ranged from 0.8 % in Sweden (Ostblom et al., 2008a) to 2.1 % in Finland (Pyrhonen et al., 2009). The lowest prevalence (0.2 %) of self-reported wheat allergy was found in a group of 7-13 year olds in Greece (Zannikos et al., 2008). For the same age category (> 3-17 years), the highest prevalence was reported in France at 1.5 % (Touraine et al., 2002). Clinician-diagnosed wheat allergy was assessed in two studies, in which 0.3 % of one and eight year olds in Sweden (Ostblom et al., 2008b) and 2.4 % and 3.4 % of two and four year olds in Finland (Pyrhonen et al., 2009), respectively, were diagnosed with wheat allergy by a clinician.

Sensitisation determined via positive SPT was zero for one and three year olds in the UK (Venter et al., 2008), and 13.9 % in adults in Hungary (Bakos et al., 2006). The prevalence of wheat allergy based on a positive SPT and clinical history was estimated to be 0.9 % for all ages combined in Germany (Zuberbier et al., 2004). Based on positive IgE levels and clinical history, only one study (Ostblom et al., 2008b) reported a prevalence of 1.3 % among four year olds in Sweden.

Using a combination of history and SPT and/or OFC and DBPCFC, the prevalence of wheat allergy was 0.4 % in one year olds, 0.3 % in two year olds, 0.2 % in three year olds and 0.3 % in six year olds in the UK (Venter et al., 2006a; Venter et al., 2008). Based on clinical history and positive OFC/DBPCFC, no cases of confirmed wheat allergy were found in children < 3 years (n = 486), three years (n = 111), and > 3 years (n = 301), or in adults (n = 936), in Denmark (Osterballe et al., 2005).

Rye, barley and oats

In Finnish children, the prevalence of IgE- and non IgE-mediated clinician diagnosed allergy to barley and rye was 1.9 % in children one to four years of age (Pyrhonen et al., 2009). Sensitisation rates based on positive SPT and IgE levels to rye were between zero and 11.1 % in adults in Hungary (Bakos 2006). In a German population combining all ages, prevalence of allergy was estimated to be 2.2 %, 1.2 %, and 1.2 % for barley, rye and oats, respectively, based on a clinical history and positive SPTs (i.e. IgE-mediated allergy only) (Zuberbier et al., 2004). There are no studies available using food challenges to confirm diagnosis.

14.2.1.2. Outside Europe

Sensitisation rates to wheat in adults have been estimated to be 2.2 % in Australia based on positive SPTs (Woods et al., 2002) and 1.4 % in Japan based on serum IgE levels (Morita et al., 2012). When sensitisation rates were combined with clinical history, prevalence of wheat allergies was estimated to be zero in Australia and 0.2 % in Japan in the same studies. In the US the prevalence of wheat allergy in 0-3 year olds was 0.2 % when using food challenges (Bock, 1987) considering both IgE- and non IgE-mediated allergy.

14.2.2. Natural history

Wheat allergy resolves frequently by adolescence (Keet et al., 2009; Kotaniemi-Syrjanen et al., 2010).

In Finland, 28 children diagnosed with wheat allergy (median age 21 months) were tested annually by OFC (Kotaniemi-Syrjanen et al., 2010). Wheat was tolerated by 59 % of the children by the age of four years, by 69 % by the age of six, by 76 % by the age of eight, by 84 % at the age of 10, and by 96 % by the age of 16 years. Sensitisation to gliadin (SPT wheal size at least 5 mm) was significantly associated with a slower achievement of tolerance and an increased risk of asthma.

In the US, 103 children (median age 19 months) with a symptomatic reaction to wheat and a positive IgE test result were studied. Resolution of wheat allergy was determined on food challenge results. Resolution rates were 29 % by four years, 45 % by six, 56 % by eight, 62 % by 10, 65 % by 12 and 70 % by 14 years. In this referral population, higher wheat IgE levels were associated with an increased risk for persistence. However, 20 % of children with wheat IgE level > 100 kU/L outgrew their wheat allergy (Keet et al., 2009).

No data are available on the natural history of food allergy in relation to other gluten-containing cereals.

14.2.3. Time trends

Two studies on the prevalence of self-reported wheat allergy were conducted in Finland in 1980 and 2001 using similar methodology. Both IgE- and non IgE-wheat allergies were considered. At one year of age, self-reported allergy to wheat was estimated at 1 % in 1980 (Kajosaari, 1982) and at 2.1 % in 2001 (Pyrhonen et al., 2009). At two years of age, self-reported allergy to wheat was 1 % in 1980 (Kajosaari, 1982) and 2 % in 2001 (Pyrhonen et al., 2009). These two studies relied on questionnaire-based methods, and thus do not allow concluding about time trends of wheat allergy.

14.2.4. Severe reactions/anaphylaxis

Wheat may trigger severe anaphylactic reactions in children with wheat allergy (Cianferoni and Muraro, 2012). In Japan, wheat is often reported among the top three foods responsible for food-induced anaphylaxis. Wheat also appears to be the third trigger of food-induced anaphylaxis in children after milk and eggs (Imamura et al., 2008). In Europe, anaphylaxis to wheat seems to be less frequent than in Asia (Panesar et al., 2013).

Wheat has been also reported to be an important triggering factor for food-dependent exercise-induced anaphylaxis (FDEIA) (Morita et al., 2007) and is considered the most frequent cause of FDEIA in Japan (Aihara et al., 2001).

14.2.5. Factors affecting the prevalence of cereal allergy

In children, IgE-mediated wheat allergy is associated with birch pollen sensitisation and the development of allergic rhinoconjunctivitis later in childhood (Kotaniemi-Syrjanen et al., 2010). The timing of initial exposure to cereal grains and family history may also modify the risk of wheat allergy (Poole et al., 2006).

Some cereal allergic subjects would only develop symptoms if they exercise within a few hours after cereal ingestion. This condition usually results in anaphylactic reactions and is denoted as wheat-dependent exercise-induced anaphylaxis (WDEIA). In adults and adolescents, anaphylactic reactions to wheat are most often food-dependent exercise-induced anaphylaxis.

14.3. Identified allergens

14.3.1. Cereals containing gluten

Cereals containing gluten (wheat, rye, barley and to a lesser extent oats) are neighbours in the grass family and show similarities in chemical composition, functional properties and allergenic potential of their seed storage proteins (Battais et al., 2008; Tatham and Shewry, 2008). Identified allergens (IUIS database) are shown in Table 6.

Table 6: Allergens in cereals containing gluten

Common name/ *Scientific name*	Allergen	Biochemical name	Superfamily/family	Molecular weight[a] (kDa)
Wheat	Tri a 12	profilin	profilin	14
Triticum aestivum	Tri a 14	ns-LTP 1	prolamin	9

	Tri a 18	agglutinin isolectin 1	hevein-like domain	-
	Tri a 19	ω-5 gliadin	prolamin	65
	Tri a 25	thioredoxin	-	-
	Tri a 26	HMW glutenin	prolamin	88
	Tri a 36	LMW glutenin GluB3-23	prolamin	40
	Tri a 37	α-purothionin	-	12
Rye *Secale cereale*	Sec c 20	γ-secalin	-	70
Barley *Hordeum vulgare*	Hor v 12	profilin	profilin	14
	Hor v 15	α-amylase inhibitor BMAI-1 precursor	prolamin	14.5
	Hor v 16	α-amylase	-	-
	Hor v 17	β-amylase	-	-
	Hor v 20	γ-hordein 3	-	34
Oats[1] *Avena sativa*	N.A.	avenin	-	-

HMW = high molecular weight; LMW = low molecular weight; N.A. = not assigned; [1] Not in the IUIS database; [a] MW (SDS-PAGE)

Wheat is the prominent cereal to cause allergies in humans. Wheat grain proteins are traditionally divided into four classes on the basis of their solubility (Osborne): water-soluble albumins (15 % of the total), salt-soluble globulins (5 %), 70 % ethanol-soluble prolamins (seed storage proteins rich in prolin and glutamin), which include gliadins (40 %) and acid- or alkali-soluble glutenins (40 %). Glutenins and gliadins are the constituents of gluten, which is responsible for the baking quality of wheat flour. A more recent classification of wheat storage proteins is based on molecular characteristics rather than on solubility: high molecular weight prolamins, corresponding to high molecular weight-glutenin subunits (about 88 kDa); sulphur-poor prolamins, corresponding to ω-gliadins (65 kDa); and sulphur-rich prolamins, comprising low molecular weight-glutenin subunits, α-, β- and γ-gliadins (31-45 kDa).

The allergenic potential of cereal proteins was first demonstrated in wheat flour. Gliadin, the antigenic protein of wheat also triggering coeliac disease, was identified as the major allergen involved in wheat-dependent exercise-induced anaphylaxis (WDEIA) of adults and in immediate allergy to ingested wheat in children (Palosuo et al., 1999; Varjonen et al., 2000; Palosuo et al., 2001a; Battais et al., 2003; Battais et al., 2005; Denery-Papini et al., 2011). In these clinical studies, the 65 kDa ω-gliadin, a 40 kDa α-gliadin, γ-gliadins and also LMW and HMW glutenin subunits have shown clinical allergenic potential and IgE-binding using patients' sera. Non-gluten proteins from wheat, such as an α-amylase/trypsin inhibitor and lipid transfer proteins (LTP), cupins and profilins, have been identified as important B cell epitopes in wheat allergy (Sander et al., 2011).

Typical primary sequences found in gliadins triggering wheat allergy are QQIPQQQ and related sequences (Matsuo et al., 2004); PQQPFP, QQQFPGQQQQ and similar peptides from gliadin and glutenin (Denery-Papini et al., 2011). These sequences are similar to those triggering coeliac disease.

Tissue transglutaminase, an intestinal enzyme locally activated during exercise, is able to cross-link ω-5 gliadin-derived peptides causing a marked increase in IgE-binding, which may explain the role of this gliadin in WDEIA (Palosuo et al., 2003).

14.3.2. Other proteins from wheat, rye and barley

A non-gluten wheat protein fraction involved in baker's asthma contains water/salt soluble albumins and globulins. To this group belong the α-amylase inhibitors. The same group of non-gluten proteins has been recognised by sera from patients selected on the basis of history and positive SPT or IgE-

binding, and by sera from patients undergoing oral open or double-blind challenges (Pastorello et al., 2007; Battais et al., 2008).

Other cereal allergens have been described which are not included in the IUIS database. Two proteins of 20 kDa and 47 kDa, respectively, were identified as specific food allergens of wheat. These proteins were recognised by sera from patients with oral sensitisation to wheat confirmed by DBPCFC and no evidence of grass pollen allergy according to history or skin prick test results. Grass-sensitised patients, on the contrary, did not have IgE antibodies that bound to these fractions (Jones et al., 1995).

Wheat 15 kDa α-amylase inhibitor, the major allergen in baker's asthma, is able to sensitise not only by inhalation, but also via the gastrointestinal route, as suggested by the IgE-binding of sera from five atopic children with positive DBPCFC for wheat (James et al., 1997). Armentia et al. (Armentia et al., 2002) confirmed the finding that cereal allergens (wheat, barley and rye) were able to sensitise by inhalation or by ingestion. Similar proteins were involved in both routes (e.g. 11-16 kDa α-amylase inhibitor), judged by detection of cereal IgE-binding components (SDS-PAGE). Clinical significant reactivity was observed in children and adults in this study. Water-insoluble allergens (gluten, prolamins) were not investigated.

An allergen of the same molecular weight as wheat α-amylase inhibitor (16 kDa) recognised by the sera of atopic patients positive for wheat CAP-RAST and open challenge has been identified (Simonato et al., 2001a). That allergen was bound to a lesser extent by sera from non-atopic patients who had negative CAP-RAST for wheat despite a positive open challenge. These patients recognised some proteins of the gluten fraction, such as the 42 kDa protein. α-Amylase inhibitor was confirmed to be the most important wheat allergen in WDEIA. Other important allergens were LTP and LMW glutenin subunits (Pastorello et al., 2007; Bouchez-Mahiout et al., 2010). LMW glutenins behaved as independent allergens, partly sharing common epitopes with ω-5 gliadins. Primary sequences of non-gluten wheat allergens were dissimilar from gluten peptides (e.g. QARSQSDRQS for LTP1) (Denery-Papini et al., 2011).

Durum wheat (*Triticum durum*), einkorn (*Triticum monococcum*), emmer (*Triticum dicoccum*), spelt wheat (*Triticum spelta*) and khorasan wheat (*Triticum turgidum polonicum*) are other wheat species sharing antigenic potential with bread wheat (*Triticum aestivum*). The same applies to hybrids, such as triticale. Rye and barley also share epitopes with wheat (Armentia et al., 2002).

14.4. Cross-reactivities

Since almost all cereals belong to the *Gramineae* family, high degree of IgE cross-reactivity exists between allergens from cereal seeds and allergens from grass pollen (Sutton et al., 1982; Walsh et al., 1987; Sander et al., 1997; Palosuo et al., 2001b). Only two wheat specific allergens (20 and 47 kDa) did not cross-react with homologous grass pollen allergens (Jones et al., 1995). *In vitro* cross-reactivity has little clinical significance, since few grass pollen-allergic patients also have food allergy to cereals. The route of sensitisation may explain differences in clinical reactivity to the same allergens. For example, "baker's asthma" is a disease in which cereal allergens cause symptoms only when inhaled, and not when ingested.

As to the cross-reactivity among different cereal grains, cross-reaction between a 65 kDa gliadin, a 70 kDa secalin from rye and a γ-3 hordein from barley was demonstrated in WDEIA (Palosuo et al., 2001b). Although food allergy to cereals is often due to monosensitisation (Jones et al., 1995), 20 % of patients with cereal allergy demonstrate clinical reactivity (DBPCFC) to more than one cereal grain.

14.5. Effects of food processing on allergenicity

Wheat is usually consumed after heat treated and allergenicity survives thermal treatment (baking, cooking). Also complex fermentation processes, hydrolysis and deamidation are used for processing of cereals (Battais et al., 2008; Tatham and Shewry, 2008).

In one study (Simonato et al., 2001b) on the effect of bread baking on the *in vitro* digestibility and immunogenicity of wheat proteins, the wheat allergen α-amylase inhibitor was shown to be destroyed by heating, whereas prolamins were thermostable. The *in vitro* digestibility of bread crumb and crust was much lower than that of unheated dough, probably due to the formation of aggregates, cross-linking and of Maillard products, which were inaccessible to the proteolytic enzymes. However, the IgE-binding capacity remained unaltered in bread crumbs and even increased in the crust, demonstrating the maintenance or the formation of new epitopes. Deamidation of gliadin was shown to reduce IgE-binding (Kumagai et al., 2007).

Proteolytic enzymatic treatments as well as microwave heating were shown to decrease immunoreactivity of wheat flour, but also to affect its rheological properties, making it unsuitable for product development (Susanna and Prabhasankar, 2011).

Immunoreactivity of wheat bread made from wheat flour fermented with Lactobacilli was shown to be reduced by 20-60 %, depending on the antibody used for detection (Leszczyńska et al., 2012).

Anaphylaxis can also be elicited by wheat isolates used in the bakery and meat industry after treatment by acid, heat and enzymes (Leduc et al., 2003; Pelkonen et al., 2011). In WDEIA, reactivity to hydrolysed wheat, barley and rye proteins was high (Snégaroff et al., 2006).

14.6. Detection of allergens and allergenic ingredients in food

The detection of cereal allergens in food is more complicated than the detection of gluten due to the multiplicity of cereal proteins involved. Analytical techniques which have been applied to characterise wheat proteins include mono- and two-dimensional electrophoresis (Mamone et al., 2005), HPLC (Wieser et al., 1998), CE (Di Luccia et al., 2009) and MS (Weber et al., 2009a). PCR-based methods allow detecting the genomic DNA of the cereal, and occasionally of the gene encoding for a specific allergen (Zeltner et al., 2009). Integration of different technologies is advised to overcome the methodological difficulties intrinsic to cereal based materials. The gluten proteins gliadin and glutenin, which are also implicated in wheat allergy, can be detected with the same methods used for gluten (section 13.5). Specific methods for the detection of non gluten cereal allergens are scarce.

14.6.1. Immunological methods

1D- and 2D-PAGE coupled to Western blotting, ELISA with monoclonal or polyclonal antibodies, and LFDs have been used for detecting wheat allergens. ELISA kits and LFDs targeting different proteins, mainly wheat gliadin, are commercially available (Immer and Haas Lauterbach, 2010; Diaz-Amigo and Popping, 2012, 2013). The two sandwich ELISA developed for gluten analysis in foods may be used to detect wheat, barley and rye allergenic proteins in foods. The ELISA kit based on the mAb R5 (Valdes et al., 2003) actually detects prolamins from wheat, barley and rye, the accuracy depending on the food matrix, whereas the ELISA kit based on a mAb 401/21 (Skerritt and Hill, 1991) reacts mainly with HMW glutenin and ω-5 gliadin.

A double antibody sandwich ELISA (DAS-ELISA) based on anti-gliadin IgE as capture antibody and a biotinylated monoclonal antibody as detecting antibody, was developed for detection of gliadin in foods (Gujral et al., 2012). The method was able to detect gliadin in wheat, barley and rye with a LOD of 4 ng/mL gliadin in buffer, equivalent to 0.8 mg/kg in foods. The PWG gliadin proposed as reference material for gluten (van Eckert et al., 2010) can also be used for quantifying prolamins in gluten-containing cereals.

14.6.2. Mass spectrometry

MALDI-TOF and ESI-MS have been used to characterise cereal proteins for quality assessment, tracking of commercial frauds or searching technological properties, but also for identifying allergens. MALDI-TOF has been applied to detect cereal proteins through the accurate measurement of MW, while liquid chromatography coupled to ESI-MS (LC-ESI-MS) allows identifying the proteins.

Although a number of cereal allergenic proteins have been characterised using MS methods (Tatham and Shewry, 2008; Cunsolo et al., 2012), the quantification of cereal allergens by MS remains, however, a challenging task.

Wheat gliadins (α/β-,γ-,ω-gliadin) and HMW glutenin were identified by MALDI-TOF MS and nanoESI-MS/MS with preliminary 2DE and chymotryptic digestion (Mamone et al., 2005). MALDI-TOF/TOF MS allowed identification of serpin, α-amylase inhibitor, γ-gliadin and LMW glutenin in wheat after extraction of total wheat flour proteins, separation by 2DE and tryptic digestion (Akagawa et al., 2007).

Salt-soluble wheat extracts were separated by 1DE- and 2DE-PAGE and immunoblotting using sera of patients with allergy to ingested wheat. Proteins recognised by IgE separated on 2DE were analysed by MALDI-TOF and Q-TOF and those separated on 1DE were analysed by LCQ^{DECA} nLC-MS/MS IT. Wheat α-amylase inhibitors, β-amylase, and profilin, as well as barley α-amylase/trypsin inhibitor precursor, and β-amylase, were identified (Sotkovsky et al., 2008).

LMW and HMW glutenins, α- and γ-gliadins, and β-amylase can be detected by both MALDI-TOF MS (previous 2DE) and nanoLC-MS/MS (Mamone et al., 2009). HMW-glutenin subunits were detected by MALDI TOF MS and RP-HPLC/nESI-MS/MS in durum wheat (Muccilli et al., 2011; Lagrain et al., 2013). A heterotetrameric α-amylase inhibitor (ETI) was detected by MALDI-TOF MS in a hulled wheat emmer as an assembly of proteins highly similar to that found in durum wheat (Capocchi et al., 2013).

The beer proteome has been extensively investigated mainly for characterisation and quality control purposes. In these proteomic studies, several cereal allergenic proteins were detected. Different strategies were adopted for protein separation prior to MS analysis. Among 30 proteins from *Hordeum vulgare*, α-amylase inhibitors, γ-hordein and a globulin from *Triticum aestivum* were identified by using isoelectric focusing in solution followed by 2DE (Konecna et al., 2012). In another study, the Proteo-Miner-like fractionation step was incorporated with combinatorial peptide ligand libraries (CPLL) designed for beer proteins before gel electrophoresis (Fasoli et al., 2010). γ-Hordein 3 and a fragment of the α-amylase inhibitor were among the 20 proteins identified in beer. A gel-free shotgun proteome analysis of beer was performed with preliminary separation of proteins from polypeptides by size exclusion chromatography (SEC) (Picariello et al., 2012). Protein mixtures were reduced and alkylated, and the tryptic digests were analysed by μHPLC/ESI-MS/MS. The allergenic γ-hordein 3 and α-amylase inhibitor were found to be present along with peptides derived from α-amylase inhibitor and β-amylase. A number of hordein derived peptides that encrypt gluten-like sequence motifs were also detected.

14.6.3. DNA based methods

A number of real-time PCR systems for the detection and quantification of DNA of gluten-containing cereals has been described and several kits are commercially available. Two independent real-time PCR assays based on TaqMan® probes targeting γ-hordein and acetyl-CoA carboxylase sequences and suitable for the identification and quantification of barley and wheat have been described (Hernandez et al., 2005). The absolute LOD for both wheat and barley was 1 genome copy and the absolute LOQ was 10 genome copies, corresponding to approximately 50 and 150 pg of template DNA for wheat and barley, respectively. The methods were applied successfully to highly processed solid foods (bread, cakes, biscuits) but were not suitable to detect barley and wheat in beer, refined oils or soluble extracts of cereals due to the paucity of DNA present in these products. Another real-time PCR assay based on TaqMan® probes allowed detecting 2.5 mg/kg of wheat in vegetal food matrices and 5 mg/kg of wheat in meat products (Zeltner et al., 2009). A more sensitive qPCR system employing the fluorescent dye SYBR® Green was developed to detect wheat contamination in gluten-free foods with a LOQ of 20 pg DNA/mg of food (Mujico et al., 2011).

Specific detection and quantification of common wheat-derived DNA was also achieved by a real-time PCR assay targeting the ALMT1gene, an aluminium-activated malate transporter (Vautrin and Zhang, 2007). The absolute LOD and LOQ were 2 and 20 haploid genome copies of common wheat, respectively. A duplex real-time PCR for detection and quantitation of wheat- and barley-derived DNA targeting the gene PKABA1 used minor groove binding probes to distinguish between the two cereals (Ronning et al., 2006). The assay was specific and allowed simultaneous detection of wheat and barley in food samples with absolute LODs of 5 PCR forming units (PFU) (corresponding to 1.8 DNA copies) for wheat and 10 PFU (1.8-16 DNA copies) for barley.

14.7. Minimal (observed) eliciting doses

Oral challenges with different doses of wheat have been performed in clinical studies. However, only few patients with convincing history of wheat anaphylaxis have been challenged orally (Hischenhuber et al., 2006). In children with atopic dermatitis, 20 % showed a positive DBPCFC for wheat with doses ranging from 0.4 to 10 g of food (Sicherer et al., 2000a). In another study of 38 children and 41 adults with wheat allergy, 2.5 % of children reacted to doses less than 10 mg of wheat flour (single blind challenge). A MOED was not given by the authors (Moneret-Vautrin et al., 2003).

In a study conducted in Japan (Ito et al., 2008), 35 children sensitised to wheat underwent an OFC with noodles containing wheat flour (2.6 %) in stepwise increasing amounts (0.1, 1, 2, 5, 10 and 20-50 g). Twenty one patients reacted to the challenge. Children with a convincing history of wheat allergy were not challenged because of the high risk for anaphylaxis. One subject had a severe allergic reaction to 2.6 mg of wheat protein (MOED, first dose tested), whereas two reacted to 26 mg.

Adult subjects with suspected wheat allergy (convincing clinical history) were recruited in Italy (n = 24) and Denmark (n = 3) and underwent a DBPCFC with wheat flour (Scibilia et al., 2006). A minimum starting dose of 100 mg raw wheat flour was administered, followed by 500 mg, then 1 g, and 1.5 g; the last dose was then doubled (3 g, 6 g, 12 g) until symptoms were reported/observed or until the entire test meal was eaten. The cumulative dose schedule was 100 mg, 600 mg, 1.6 g, 3.1 g, 6.1 g, 12.1 g, and 25 g. Doses were administered at 20-min intervals. The same dose schedule was used for cooked wheat DBPCFC in patients who had a positive result to raw wheat. The MED was 100 mg of raw (three patients, first dose tested) and cooked (two patients) wheat flour.

The lowest reported MED/MOED in paediatric patients undergoing OFCs with wheat flour is 2.6 mg of wheat protein (first dose tested). The lowest reported MED/MOED in adult patients undergoing DBPCFC is 100 mg of wheat flour. However, doses of wheat triggering allergic reactions in sensitive individuals may be lower because highly sensitive patients have been excluded from the challenge studies available, where participants already reacted to the first dose tested.

14.8. Conclusion

IgE-mediated allergy to cereals is caused both by inhalation of cereal flour (baker's asthma) and by ingestion of cereal-based products (food allergy). Cereal-induced IgE-mediated food allergy is well-documented. DBPCFC studies have been performed confirming that cereals are able to elicit anaphylactic reactions. Wheat is the gluten-containing cereal most often reported to induce cereal allergy, compared to barley, rye, and oats. Prevalence of wheat allergy based on clinical history and positive FCs is as low as 0.4 % in young children. Wheat allergy frequently resolves during adolescence. Cereal seed storage proteins (gluten), but also non-gluten components, such as albumins and globulins, α-amylase inhibitor and lipid transfer proteins, are clinically relevant allergens. Immunological methods used for detection of gluten may be used for the detection of cereal glutenin and gliadin. Specific and sensitive PCR methods are available. MS methods have been extensively utilised for the identification of the allergenic proteins, but no limits of detection have been provided. The effect of food processing on allergenicity, including heat resistance of single allergens, is conflicting. The lowest reported MED/MOED in paediatric patients undergoing OFCs with wheat flour is 2.6 mg of wheat protein. The lowest reported MED/MOED in adult patients undergoing DBPCFC is 100 mg of wheat flour. However, doses of wheat triggering allergic reactions in sensitive

individuals may be lower because highly sensitive patients have been excluded from the challenge studies available, where participants already reacted to the first dose tested.

15. Allergy to milk and dairy products

15.1. Background

Milk is a liquid substance secreted by the mammary glands of females of all mammal species to support their offsprings' nutritional needs. Milk and dairy products are a source of proteins, fat, minerals, and vitamins and play a key role in human nutrition (Darewicz et al., 2011).

Milk allergy is an adverse immunological response to milk proteins of different mammalian species, particularly cow, goat and ewe, seen mainly in the paediatric age. It can be broadly divided into IgE- and non IgE-mediated disease, or mixed, involving other immunoglobulins, immune complexes and/or cell-mediated mechanisms. These differ in clinical presentation, diagnostic testing, and prognosis (Berni Canani et al., 2008). IgE-mediated reactions are characterised by an acute onset of symptoms generally within two hours after ingestion of or exposure to milk protein-containing food. IgE-mediated reactions to food typically involve the skin, gastrointestinal tract, and respiratory tract and may also include systemic reactions (anaphylactic shock). Non IgE-mediated immunological reactions (e.g. cell mediated) include food-protein-induced enterocolitis, proctocolitis, and enteropathy syndromes. These conditions primarily affect infants or young children who present with gastrointestinal symptoms, such as vomiting, abdominal cramps, diarrhoea, and occasionally blood in the stools, often associated with failure to thrive or poor weight gain. Examples of food allergy comorbidities with mixed IgE- and non IgE-mediated causes include eosinophilic oesophagitis and atopic dermatitis (Burks et al., 2012b).

15.2. Epidemiology

15.2.1. Prevalence

15.2.1.1. Europe

Forty studies have assessed the prevalence of cow's milk allergy (CMA) in Europe. The studies were from Denmark, Estonia, France, Finland, Germany, Greenland, Hungary, Iceland, Ireland, Italy, Norway, Portugal, Spain, Sweden, The Netherlands, Turkey and the United Kingdom. Data were published between the years 1982 and 2012 and included all age groups (University of Portsmouth, 2013).

Self-reported prevalence of CMA in young children (≤ 3 years) ranged from 2 % in Finland (Kajosaari, 1982) to 7.5 % in Norway (Eggesbo et al., 1999) at one year, from 4 % (Ostblom et al., 2008b) to 6.8 % (Pyrhonen et al., 2009) at two years, and from 1.3 % (Kilgallen and Gibney, 1996) to 5.9 % (Pyrhonen et al., 2009) at three years of age. Self-reported prevalence of CMA at one year was 4.5 % in Sweden (Ostblom et al., 2008b) and 5.3 % in Ireland, where reported adverse reactions to dairy products were 4-4.7 % at the same age (Kilgallen and Gibney, 1996). The highest self-reported prevalence was 10.8 % in Iceland at 18 months of age (Kristjansson et al., 1999). Studies in the same population subgroup (young children up to 3 years) which used other questionnaire-based methods (e.g. diagnosis by a physician) reported similar figures. In older children, the prevalence of clinician-diagnosed CMA was reported to be 1.8 % at eight years in Sweden (Ostblom et al., 2008a). In adults, prevalence based on self-reported diagnosis of food allergy ranged between 1.8 % (Schafer et al., 2001) in Germany to 3.3 % (Osterballe et al., 2009) in Denmark. Self-reported prevalence in the UK at all ages combined was 2.7 % (Young et al., 1994).

In young children, the prevalence of positive SPT to cow's milk proteins (CMP) was between zero in Estonia (Julge et al., 2001) and 0.9 % in Norway (Ro et al., 2012), whereas in older children it ranged from 0.2 % at seven years in the UK (Roberts et al., 2005) to 3.9 % at five to six years in Germany (Schafer et al., 1999). Higher sensitisation rates were generally observed in adults, ranging from 2.3 %

in Germany (Schafer et al., 1999) to 14.7 % in Hungary (Bakos et al., 2006). Based on serum specific IgE, sensitisation rates were between 4.8 % (Ro et al., 2012) and 25.8 % (Julge et al., 2001) in young children and between 8 % (Ostblom et al., 2008a) and 23.2 % (Julge et al., 2001) in older children, with lower rates generally reported for adults, ranging from 1 % in Finland (Isolauri et al., 2004) to 13.9 % in Hungary (Bakos et al., 2006).

Prevalence of CMA was generally lower when sensitisation tests were combined with a clinical history. Prevalence based on clinical history plus a positive SPT was 0.3 % and 0.6 % in Iceland and Sweden at 18 months, respectively (Kristjansson et al., 1999), 0.4 % at six to nine years in Turkey (Orhan et al., 2009), and 0.1 % in the overall population combining all ages (Zuberbier et al., 2004). Prevalence of CMA based on a clinical history plus a positive serum specific IgE was only reported in Turkey (0.2 %) in a category of age between 8-18 months (Kucukosmanoglu et al., 2008), and in Sweden (1.8 %) at four years of age (Ostblom et al., 2008b).

Few studies used food challenges to confirm diagnosis of allergy to CMP. Based on OFC, prevalence of CMA in Denmark was reported to be 1 % at one year, 0.5 % at two years, 0.3 % at three years and 0.2 % at five and 10 years (Host et al., 2002). Similar figures were reported for the same country some years later (Eller, 2009): 0.4 % at six months of life, 1.1 % at 18 months, 0.7 % at three years, and zero cases at 6 years. A prevalence of 0.3 % at 8-18 months was found in Turkey (Kucukosmanoglu et al., 2008), whereas higher rates (4.7 %) were reported in Finland in children < 34 months (Saarinen et al., 1999). When the diagnosis was based on DBPCFC, prevalence ranged between 0.1 % in Turkey (six to nine years) and 0.6 % (three years) in Denmark (Osterballe et al., 2005). Values for adults were within that range (0.3 %) in the only study available (Osterballe et al., 2005).

15.2.1.2. Outside Europe

In Western countries outside Europe, the prevalence of self-reported CMA in children up to 18 months ranged from 2.2 % in Canada (Soller et al., 2012) and 6.1 % in Australia (Osborne et al., 2011) to 13.1 % in the US (Bock, 1987). Similar figures were reported for adults in these countries: 1.9 % in Canada (Soller, 2012), 1.9-4.8 % in Australia (Woods et al., 2002), and 10.5 % in the US (Greenhawt et al., 2009).

Using a method which combined history of CMA, SPT and food challenges to determine a diagnosis of "probable or confirmed" CMA (both IgE- and non IgE-mediated), prevalence rates of CMA in the US were much lower (Bock, 1987): about 5 % in one year old children, 0.2 % at two years, and zero at 3 years. In the same country, prevalence of CMA was reported to be 0.3 % (Liu et al., 2010a) in young children and adolescents, 0.4 % in the overall population combining all ages (Liu et al., 2010a), and 1.4 % in adults (Vierk et al., 2007) for IgE-mediated reactions only.

15.2.2. Natural history

CMA can develop from the neonatal period and peaks during the first year of life, tending to remit in childhood. Reaction to cow's milk proteins (CMP) occurred at an average of 1.67 ± 1.67 days after initial exposure (Elizur et al., 2012).

In the 1990s, a Danish birth cohort study reported that more than 50 % of children outgrow their CMA at 1 year of age. However, subsequent studies have reported a longer duration of CMA, with tolerance developing in half of cases within the two years following diagnosis (Elizur et al., 2012). Referral studies indicate that 80 % of patients achieve tolerance within three to four years. A prospective study conducted in the United States showed that CMA resolved in 154 (52.6 %) subjects at a median age of 63 months in a cohort of 293 children aged three to 15 months at baseline (Wood et al., 2013).

Children with delayed reactions became tolerant faster than those with immediate reactions. Children with higher risk of persistence had respiratory symptoms at onset, severe atopic dermatitis, sensitisation to linear epitopes of CMA, and sensitisation to multiple foods and to respiratory allergens. A larger wheal diameter at SPT with fresh milk, high levels of specific IgE (especially to

casein), and antibody binding to other ingested and inhaled allergens, have been associated to longer duration of CMA (Skripak et al., 2007; Fiocchi et al., 2008). Low milk-specific IgE levels correlate with earlier onset of tolerance and a 99 % reduction in specific IgE concentrations for more than 12 months translates into a 94 % likelihood of achieving tolerance to cow's milk protein within that period (Shek et al., 2004). Tolerance of CMP correlates with reduced concentrations of specific IgE and IgG1.

15.2.3. Time trends

There are no data on time trends regarding CMA in Europe.

The prevalence of challenge-proven CMA in China was 1.6 % and 3.5 % in 1999 and 2009, respectively, among children from birth up to two years (Hu et al., 2010). Before one year, the prevalence was 1.3 % in the same country (Chen et al., 2011).

15.2.4. Severe reactions/anaphylaxis

Patients with CMA develop gastrointestinal symptoms in 32 to 60 % of cases, skin symptoms in 5 to 90 %, and anaphylaxis in 0.8 to 9 % of cases. This frequency of anaphylaxis is the main concern in many CMA studies. CMA has been reported to be responsible for up to 42 % of hospital admissions because of food induced anaphylaxis in childhood (Berni Canani et al., 2012) and up to 13 % of fatal food induced anaphylaxis (Bock et al., 2007).

15.2.5. Factors affecting prevalence of milk allergy

CMA is the most frequent milk allergy and it is often the first step of the allergic march.

In a review, nearly one third of children with atopic dermatitis were diagnosed with CMA after elimination diet and oral food challenge, and about 40 to 50 % of children less than a year of age with CMA also had atopic dermatitis (Fiocchi et al., 2010). The maintenance of tolerance in atopic patients is associated with persistently elevated milk-specific IgG4 antibody concentrations (Ruiter et al., 2007). In a prospective cohort study (Wood et al., 2013), low milk-specific IgE level (< 2 kU/L), SPT size (< 5 mm), and severity of atopic dermatitis were the baseline characteristics of patients with CMA, which were most predictive of resolution of their allergy. A smaller eliciting dose at oral food challenge also correlates with the duration of CMA.

15.3. Identified allergens

Milk from different ruminant species (e.g. cow, buffalo, sheep, goat), but also human milk, contains similar proteins regarding structural, functional and biological properties and its composition changes during lactation.

CMP are very heterogeneous regarding structure and function, and this heterogeneity is further increased by genetic polymorphisms or post-translational modifications (e.g. phosphorylation, glycosylation), which may affect their IgE-binding capacity and allergenicity (Malik et al., 1988; Bernard et al., 2000).

Cows' milk contains about 30-35 g of proteins per litre. The action of chymosin (rennin), or the acidification of the milk to pH 4.6, allows obtaining two fractions: lactoserum (whey) and coagulum (casein), which contain about 20 % and 80 % of the CMP, respectively. Cow's milk allergens are listed in Table 7.

Whey contains essentially globular proteins, mostly β-lactoglobulin (BLG) (whose homologue is not present in human milk), α-lactalbumin (ALA), and lactoferrin (LF), which are synthesised in the mammary gland, while other proteins, such as bovine serum albumin (BSA) or immunoglobulins (Igs) come from the blood. In the coagulum, the casein (CAS) fraction comprises four proteins coded by different genes carried on the same chromosome: αS1-, αS2-, β-, and κ-caseins. Owing to the great

variability observed in human IgE response, no single protein or protein structure accounts for a major part of milk allergenicity. Studies on large populations of allergic patients show that most are sensitised to BLG, CAS, ALA, BSA, LF, and Igs (EFSA, 2004). Polysensitisation to several proteins is observed in about 75 % of patients with CMA (Goldman et al., 1963a; Goldman et al., 1963b; Restani et al., 1995; Docena et al., 1996; Wal, 2002). CAS and BLG, as well as ALA, are major allergens, and sensitisations to these proteins are closely linked. However, all CMP appear to be allergenic. About 35-50 % of milk allergic patients are sensitised to CMP present in very low quantities, such as BSA, Igs, and especially LF (Fiocchi et al., 2010) and, occasionally, only these CMP (e.g. lactoferrin) are responsible for the clinical symptoms observed. Sensitivity to BSA appears to be independent of other CMP (Wal et al., 1995).

In IgE-mediated allergy, circulating antibodies recognise specific molecular regions on the antigen surface (epitopes), which are classified according to their specific amino acid sequence (sequential or linear epitopes) or the folding and conformation of their protein chains (conformational epitopes). Subjects with transient milk allergy produce IgE antibodies primarily directed at conformational epitopes (dependent on the protein tertiary structure), whereas those with persistent allergy also produce IgE antibodies against sequential epitopes, which are heat stable (Cooke and Sampson, 1997; Chatchatee et al., 2001; Vila et al., 2001; Busse et al., 2002; Jarvinen et al., 2002). Greater IgE epitope diversity and higher IgE affinity are associated with more severe milk allergy (Wang et al., 2010).

Table 7: Cow's (*Bos domesticus*) milk allergens

Allergen	Biochemical name	Concentration (g/L)	Molecular weight[2]	pI[3]
Whey proteins		~ 5.0		
Bos d 4	α-lactalbumin	1-1.5	14.2	4.8
Bos d 5	β-lactoglobulin	3-4	18.3	5.3
Bos d 6	bovine serum albumin	0.1-0.4	67.0	4.9-5.1
Bos d 7	immunoglobulin	0.6-1.0	160.0	-
Bos d Lactoferrin	Lactoferrin[1]	0.09	80.0	8.7
Caseins		~ 30		
Bos d 8		20-30		
Bos d 9	α_{s1}-casein	12-15	23.6	4.9-5.0
Bos d 10	α_{s2}-casein	3-4	25.2	5.2-5.4
Bos d 11	β-casein	9-11	24.0	5.1-5.4
N.A.	γ_1-casein[1]		20.6	5.5
N.A.	γ_2-casein[1]	1-2	11.8	6.4
N.A.	γ_3-casein[1]		11.6	5.8
Bos d 12	κ-casein	3-4	19.0	5.4-5.6

1 www.allergome.org; 2 MW (SDS-PAGE); 3 isoelectric point; N.A = not assigned

15.3.1. Whey allergens

Whey allergens include ALA, BLG, BSA, bovine Igs and lactoferrin.

ALA (Bos d 4) is a monomeric globular protein of 123 amino acid residues with four disulphide bridges and a MW of 14.2 kDa. It is a regulatory component of the enzymatic system of galactosyl transferase responsible for the synthesis of lactose. It possesses a high affinity binding site for calcium, and this binding stabilises its secondary structure. The complete amino acid sequence of bovine ALA shows extensive homology with hen's egg white lysozyme but also with human ALA (EFSA, 2004). The role of ALA in milk allergy is controversial and prevalence data across studies vary between zero and 80 % of patients reacting to this protein (Besler et al., 2002).

BLG (Bos d 5), the most abundant cow's milk whey protein, occurs naturally in the form of a 36 kDa dimer in many other species but is not present in human milk. Each subunit is a polypeptide of 162 amino acid residues, and the molecule contains two disulfide bridges and one free cysteine. This structure is responsible for the main physicochemical properties and for the interaction with casein

during heat treatments. BLG is relatively resistant to acid and enzymatic hydrolysis. The tertiary structure of BLG is known. It belongs to the lipocalin family and is considered a retinol-binding protein. Lipocalins have a high allergenic potential and several allergens of animal origin belong to this family. They share a well-conserved sequence homology in their N-terminus moiety, where tryptophan at position 19 is always present. Crystallographic studies revealed a very similar folding, called β barrel structure, with the same arrangements of eight (or 10) antiparallel β sheets (EFSA, 2004). There are two main isoforms of this protein in cow's milk, the genetic variants A and B, which differ only by two point mutations at amino acids 64 and 118. The prevalence of allergic subjects reacting to this protein is between 13 and 76 % (Restani et al., 2009).

BSA (Bos d 6) can bind water, fatty acids, hormones, bilirubin, drugs, as well as calcium, potassium, and sodium. Its main function is the regulation of the colloidal osmotic pressure in blood (Fiocchi et al., 1995). The tertiary structure of BSA is stable, and its 3D conformation is well documented. The protein contains three homologous domains (I to III) and consists of nine loops linked by 17 covalent disulphide bridges. Most of the disulphide bonds are well protected in the core of the protein and are not easily accessible to the solvent. BSA is involved in other allergies such as beef. It correlates with the clinical features of lip oedema, urticaria, cough and rhinitis. It accounts for between zero and 88 % of sensitisation events, while clinical symptoms occur in up to 20 % of patients (Martelli et al., 2002). Bovine Igs (Bos d 7) are seldom triggering clinical symptoms in CMA.

15.3.2. Casein allergens

The four casein allergens are collectively known as Bos d 8. Each individual casein (αS1-, β-, αS2- and κ-casein) represents a well-defined chemical compound but they cross-link to form ordered aggregates (micelles) which are in suspension in lactoserum. The proportion of different caseins in micelles is relatively constant (ca. 37 %, 37 %, 13 % and 13 %, respectively) but their distribution within the micelles is not uniform. The micelles have a central hydrophobic part and a peripheral hydrophilic layer where major sites of phosphorylation containing phosphoserine residues are present, responsible for the calcium binding and transfer properties of caseins. αS1-, αS2-, β-, and κ-casein have little primary structure homology and their functional properties also differ (e.g. αS1-, αS2-, and β-casein appear to be calcium-sensitive, while κ-casein is not). However, the four caseins display common features, which differ from other CMP. Another group, the γ-caseins, are present in very low quantities in milk and are by-products of β-casein proteolysis.

Caseins are phosphorylated proteins with a loose and highly hydrated tertiary structure, which are not significantly affected by severe heat treatments, but are susceptible to proteinases and exopeptidases. Multi-sensitisations to the different caseins most often occur in patients sensitised to the whole casein fraction (Bernard, 1999). The composite allergen Bos d 8 exhibit limited sequential homology. In spite of this, polysensitisation of many casein fractions is usually observed, perhaps due to cross-sensitisation through some common or closely related epitopes. Sensitisation is particularly frequent against α-casein (100 %) and κ-casein (91.7 %) (Restani et al., 1995). Several studies have identified αS1-casein as a major allergen inducing strong immediate or delayed allergic reactions (Ruiter et al., 2006). αS1-Casein was found to contain both conformational and sequential IgE epitopes (Schulmeister et al., 2009).

15.4. Cross-reactivities

The sequence similarity (expressed in percentages) between milk proteins from different mammalian species is shown in Table 8. The greatest homology is between cow's, sheep's and goat's milk proteins as Bos (oxen), Ovis (sheep), and Capra (goat) that are genera belonging to the *Bovidae* family of ruminants. The proteins in their milks consequently have less structural similarity with those from the *Suidae* (pig), *Equidae* (horse and donkey), and *Camelidae* (camel and dromedary) families and also with those in human milk. It is noteworthy that the milks of camels and dromedaries (as well as human milk) do not contain BLG.

Due to high sequence homology, there are frequent cross-reactions between milk proteins from different species. Clinical reactions to milk from different species are similar. Sequence homology in caseins range between 80 and > 90 %, so high IgE cross-reactivity between ewes', goats' and cows' milk casein occurs in most patients with CMA (Dean et al., 1993; Spuergin et al., 1997; Bernard, 1999; Restani et al., 1999). However, the IgE response may also be species-specific, with clinical manifestations occurring after consumption of sheeps' and/or goats' cheese but not of cows' milk or other dairy products (Wuthrich and Johansson, 1995). In a subject with CMA, the risk of an allergic reaction to goat's milk is up to 92 %, to donkey's up to 17 %, and to horse's up to 4 % (Sicherer, 2001; Jarvinen and Chatchatee, 2009).

Allergy to sheep's milk can also evolve into allergy to cow's milk. Mare's and donkey's milks have proved sometimes useful to some patients, but uncertainties remain about chemical composition and hygienic control. The same considerations apply to *Camelidae* (camel and dromedaries) milks, which could represent an alternative to cow's milk for allergic subjects because of their low sequence homology with cow's milk and the absence of BLG, provided that problems related to availability and technological processing to avoid new sensitisation are adequately addressed (Restani et al., 2002).

Adverse reactions to soy have been reported in milk allergic patients fed with soy-based formulae as cows' milk substitutes. A 30 kDa glycinin-like protein from soybean that cross-reacts with cows' milk casein has been isolated and partially sequenced (Rozenfeld et al., 2002).

Table 8: Sequence homology between mammalian milk proteins (in percentage, relative to cow's milk proteins)

Protein	Goat	Ewe	Buffalo	Sow	Mare	Donkey	Dromedary	Human
ALA	95.1	97.2	99.3	74.6	72.4	71.5	69.7	73.9
BLG	94.4	93.9	96.7	63.9	59.4	56.9	Absent	Absent
BSA	–	92.4	–	79.9	74.5	74.1	–	76.6
αs_1 CAS	87.9	88.3	-	47.2	-	-	42.9	32.4
αs_2 CAS	88.3	89.2	-	62.8	-	-	58.3	-
β CAS	91.1	92.0	97.8	67.0	60.5	-	69.2	56.5
κ CAS	84.9	84.9	92.6	54.3	57.4	-	58.4	53.2

- = Allergen is not present in the Swiss-Prot DataBank; ALA = α-lactalbumin; BLG = β-lactoglobulin; BSA = bovine serum albumin; CAS = casein.

15.5. Effects of food processing on allergenicity

The structure and properties of CMP and the structure and location of their IgE-binding epitopes, and particularly of linear epitopes, need to be considered while interpreting the impact of food processing on milk allergenicity.

Milk may undergo extensive processing (e.g. thermal treatment), also by novel processes such as high-pressure treatment, extrusion or ultrasound, which can significantly alter structural characteristics of milk allergens and thereby increase or attenuate their antigenic potential (Maleki and Hurlburt, 2004).

15.5.1. Heat treatment

Cow's milk is usually marketed after it has been subjected to technological process, usually pasteurisation, which reduces potential pathogen load (70-80 °C for 15-20 s). Ultra-high temperature (UHT) processing with flash heating (at 135-145 °C for 0.5-4 s), and evaporation for the production of powdered infant formula (dry blending or wet mixing-spray drying process), have a minor or no effect on the allergenic potential of CMP.

Comparative studies have shown no difference in antigenicity between raw and heated milks (Werfel et al., 1997). However, in some cases, the aggregation of new protein polymers capable of binding specific IgE has been demonstrated. After boiling BSA at 100 °C for 10 min, dimeric, trimeric, and higher polymeric forms increased and all maintained their IgE-binding properties (Restani et al., 2004). The persistence of allergenicity in heat-treated milk is clinically confirmed by the fact that, in some children, CMA develops after the ingestion of heat-treated milk. Domestic heating processes can only modify conformational epitopes, which might lose their binding capacity to a specific IgE antibody, while sequential epitopes maintain their allergenic potential even after heating (Sampson, 2004). CMP contain both types of epitopes. Even though a slight reduction of antigenicity can be observed in whey proteins, which experience a limited unfolding of their globular structure upon heating, insignificant alterations in binding properties are reported with caseins, which have mainly linear and thermostable epitopes.

Vigorous heating (such as that used for certain sterilisation processes; 121 °C for 20 min), but also the less drastic pasteurisation process, could increase milk allerginicity by enhancing uptake of peptides by Peyer's patches in the intestine (Roth-Walter et al., 2008). Furthermore, CMP can be oxidised during industrial treatment, resulting in the formation of modified/oxidised amino acid residues, particularly in BLG, which may be responsible for the development of new immunologically reactive structures.

The effects of heat treatment on the antigenicity of ALA and BLG in whey protein isolate (WPI) were studied via *in vitro* competitive ELISA inhibition tests with rabbit serum (Bu et al., 2009). The antigenicity of ALA and BLG increased with increasing temperature from 50 to 90 °C. However, the antigenicity of both proteins decreased remarkably above 90 °C. When treated at 120 °C for 20 min, the antigenicity of ALA decreased by 25 % compared with the untreated sample.

Boiling milk for 10 minutes reduces the SPT response in patients who react to BSA and BLG, whereas wheel diameter remains the same in those sensitised to caseins (Norgaard et al., 1996).

One study evaluated whether patients with CMA could tolerate extensively heated (baked) milk products in 100 children undergoing food challenges with heated milk (Nowak-Wegrzyn and Fiocchi, 2009). Sixty-eight children (68 %) tolerated the extensively heated milk, 23 reacted to the heated milk, and 9 tolerated both the heated and the unheated milk. Heated milk-tolerant subjects had significantly smaller SPT wheels, lower milk-specific and casein specific IgE, and lower IgE/IgG4 ratios to casein and BLG compared with the heated milk-reactive subjects.

15.5.2. Enzymatic hydrolysis

Enzymatic hydrolysis of CMP reduces their allergenicity. However, specific IgE from patients with CMA may recognise enzymatic digestion products of whey proteins (i.e. BLG and ALA) or CAS (Fiocchi et al., 2010). Attempts have been made to classify formulas into partial and extensively hydrolysed products according to the degree of protein fragmentation, but there is no agreement on the criteria on which to base this classification.

15.5.3. Fermentation

Lactic acid bacteria (LAB) have a complex proteolytic system consisting of proteinases, peptidases and peptide transport systems that contribute to milk protein degradation during fermentation (Bertrand-Harb et al., 2003; El-Ghaish et al., 2011a). Specific LAB strains have proteolytic activity

against some antigenic proteins, such as ALA, BLG, αS1-casein and β-casein, and may decrease their IgE binding capacity (Tzvetkova et al., 2007; El-Ghaish et al., 2011b). However, the degradation of antigenic proteins by LAB does not always lead to significant changes in their IgE-binding capacity (Ehn et al., 2005; Kleber et al., 2006), and reductions in protein IgE-binding capacity do not always correlate with less allergenicity (Jedrychowski, 1999).

The evidence available indicates that the extent to which milk proteins are hydrolysed and the peptide pattern generated may depend on the LAB strain used and on fermentation conditions. It also indicates that proteolytic degradation of antigenic proteins is not always associated with reductions in their IgE binding properties and their allergenicity, as some epitopes may be broken down in the process, while others previously buried may become accessible.

15.5.4. Combined treatments

Hydrolysed infant formulas are produced from caseins or whey proteins by a combination of heat treatments and enzymatic hydrolysis (Restani et al., 2006). Allergenicity of milk may be decreased by enzymatic treatment with proteases followed by ultrafiltration, which removes the remaining high molecular weight peptides and the residual protein.

Another attempt to reduce allergenicity involves the use of proteolysis combined with high pressure. Different authors have shown increased fragmentation of BLG if proteolysis occurs after or during the application of high pressure (Peñas et al., 2006a). The partial ineffectiveness of proteolysis under ordinary atmospheric conditions may be due to the inability of enzymes to reach epitopes that are less exposed. However, thermal denaturation can also induce the formation of aggregates with greater resistance to hydrolytic attack, as is the case with BLG (Restani et al., 2006).

Small clinical studies have reported controversial results with hydrolysed formulas, depending on the enzymes used and on the degree of hydrolysis. The incidence of reported adverse effects in allergic infants fed partially or extensively hydrolysed milk (either casein or whey) formulas in tertiary care centres range around 45-65 % and 3-6 %, respectively (Giampietro et al., 2001; Caffarelli et al., 2002; Fiocchi et al., 2010).

15.6. Detection of allergens and allergenic ingredients in food

Several analytical methods have been developed to determine the presence of milk and of milk-derived allergens in foods. Immunological methods, in particular ELISA, are commonly used, which may provide semi-quantitative/quantitative results. The milk powder NIST SRM 1549 has been used as reference material. DNA-based methods consisting of the PCR amplification of oligonucleotidic sequences specific for the allergenic ingredient are rarely used for the detection of milk traces in food products owing to the relatively low DNA content (Tregoat and van Hengel, 2010). Separation techniques, such as 2D-electrophoresis, CE, and HPLC, eventually coupled to mass spectrometry, are also successfully used.

15.6.1. ELISA

Numerous ELISA kits for the detection of milk-derived allergens are commercially available, with sensitivity down to 1 mg/kg (Poms et al., 2004a). Most test kits are based on competitive ELISA and detect BSA, casein, BLG or whey proteins with LODs between 0.1 and 5 mg/kg. Monoclonal and more suitable polyclonal antibodies have been used against either BLG or casein.

An inter-laboratory study was performed in order to validate an ELISA kit based on a rabbit polyclonal antibody for the quantitative determination of BLG in foods (Stumr et al., 2009). The LOD was 0.07 mg BLG/kg and the LOQ was 0.22 mg BLG/kg.

Lateral flow devices and dipsticks, which are used for rapid screening, are commercially available. The former detect casein and whey residues in food products down to 0.12 mg/kg (Schubert-Ullrich et al., 2009).

Antibodies are also used in combination with biosensors and other detection technologies. Surface plasmon resonance (SPR) was used as a label-free technology for the simultaneous quantification of α-, β- and κ-casein in raw and heat-treated dairy products (Dupont and Muller-Renaud, 2006). The LODs were of 870, 85 and 470 ng/mL, respectively. A resonance-enhanced absorption (REA) biosensor with a direct immunoassay on a chip, in which the read-out antibody was labelled with monodisperse colloid gold clusters, was used for detecting BLG in processed milk (Hohensinner et al., 2007). A very good sensitivity (LOD of 10 ng/L) for casein was obtained with a localised surface plasmon resonance (LSPR) immunosensor based on a gold-capped nanoparticle substrate on which anti-casein antibodies were immobilised (Minh Hiep et al., 2007).

In several foods, e.g. fermented dairy products, linear epitopes can be hydrolysed though retaining the allergenic potential. Epitopes released from the parent proteins tend to be underestimated or to escape the most commonly utilised sandwich ELISA-based tests (de Luis et al., 2007). In similar cases, competitive ELISA tests can be successful in detecting as low as 5 mg/kg of "hidden" milk-derived peptides in complex foods (Monaci et al., 2006).

15.6.2. Capillary electrophoresis and mass spectrometry

Capillary electrophoresis (CE) with a laser-induced fluorescence detector has been efficiently used for the detection of ALA, BLG and BSA (Veledo et al., 2005).

MS has been used for identifying and characterising CMP and as confirmatory method to support ELISA results. The so-called "bottom-up" approach, which involves the enzymatic (tryptic) digestion of the protein, followed by a LC-MS/MS, is generally used. The method is not suitable for quantitative determinations, unless the digestion step is perfectly reproducible and a standard marker peptide is available. A confirmatory method based on LC/selected reaction monitoring (SRM)-MS/MS was developed and validated for the quantification of milk traces in foods (Lutter et al., 2011). Tryptic peptides of BLG and β-, αS2-, and κ-casein were selected as markers for quantification. Internal standard peptides containing isotopically labelled amino acids were used for quantification. LOD values were 0.2-0.5 mg/kg.

A similar procedure was followed for the determination of α- and β-casein, ALA and BLG in foods (Ansari et al., 2011). After tryptic digestion of the four proteins, several peptides were identified by LC-MS/MS. Seven of these peptides were synthesised and used for calibration of the LC-MS/MS system. The peptides were determined down to 1 ng/mL in food samples.

An HPLC-QpQ-MS method is available for the detection of whey proteins (ALA and BLG A and B) in fruit juices. The method does not involve a digestion step, but is based on the detection of selected fragment ions used as markers. The LOD and the LOQ were estimated at 1 and 4 µg/mL, respectively (Monaci et al., 2011).

15.6.3. Detection of CMP in wine

Several reports regard the detection of CMP used as fining agents in wine by ELISA. A sandwich ELISA was used for the detection of residual casein in wine with an LOD of 8 ng α-casein/mL wine (Rolland et al., 2008). α- and β-caseins in fined wines were detected at 0.2 µg/mL (Weber et al., 2009b). A commercial ELISA kit for the detection of caseinates (LOD of 0.28 mg/kg; LOQ of 0.76 mg/kg) has been validated in an inter-laboratory trial (Restani et al., 2012).

MS has also been used for the detection of residual CMP in wine. An LC/high resolution (HR)MS method has been developed for the analysis of milk proteins in incurred cookies and white wine spiked with milk powder and caseinate, respectively (Monaci et al., 2011). The method is based on the identification of peptides in the tryptic digest of proteins using HPLC coupled to MS using the Orbitrap analyser. On account of the high mass accuracy and resolution provided by the Orbitrap, it was possible to identify four peptides as markers of casein using accurate values of the mass/charge ratio (m/z) of their ions. LODs ranged from 39 to 51 µg/mL, and referred to the amount of protein

initially added to the wine. The HR-MS-based method has been further developed to detect simultaneously milk and egg proteins in wine by using isotopically labelled (15N-valine-containing) peptides of ovalbumin and αS1-casein. LODs were in the range of 0.4 and 1.1 µg/mL. One study (Tolin et al., 2012a) revealed the presence of residual milk allergens in commercial wines by LC-MS/MS.

15.7. Minimal (observed) eliciting doses

There are several reports documenting severe allergic reactions to very low amounts of CMP. CMPs (including BLG) are excreted through breast milk and have been reported to induce severe allergic reactions in breast-fed infants at concentrations of about 5 ng/mL (from 0.5 to 50 ng/mL) in breast milk (Axelsson et al., 1986; Machtinger and Moss, 1986; Host and Samuelsson, 1988; Sorva et al., 1994). Fatal anaphylaxis occurred after ingestion of a meal sausage containing the amount of cow's milk equivalent to 60 mg of casein (Kjelkevik et al., 1997). Frozen desserts containing trace amounts of whey proteins (9 µg/mL) triggered anaphylaxis in a three year old boy (Laoprasert et al., 1998). A fatal reaction has been documented with inhaled milk proteins in a dairy shop (Barbi et al., 2004).

Data are also available from DBPCFCs in CMA subjects. Most studies have been conducted exclusively in children (Hill et al., 1984; Host and Samuelsson, 1988; Baehler et al., 1996; Patriarca et al., 2002; Fiocchi et al., 2003b; Devenney et al., 2006; Flinterman et al., 2006b; Morisset et al., 2007; Staden et al., 2007; Longo et al., 2008; Skripak et al., 2008; Caminiti et al., 2009; Orhan et al., 2009), few in children and adults (Morisset et al., 2003a; Lam et al., 2008), and only one in adults (Norgaard and Bindslev-Jensen, 1992). Studies were variable in size, challenge protocol and type of food tested. The total number of patients showing objective symptoms during the DBPCFC in a given study ranged from two to 60. The lowest MOEDs also varied widely among studies, ranging from 3.3 to 1 815 mg of total protein (Remington, 2013).

More recent studies in children with CMA report similar results. In a population of 633 children referred consecutively to a tertiary Centre in Germany for the evaluation of suspected CMA through an OFC, 10 % experienced reactions already at the first dose (0.1 mL of milk, equivalent to 3 mg of proteins). Of these, 4 % experienced a severe reaction (Rolinck-Werninghaus et al., 2012). In another study conducted in the Netherlands, 38 (33 %) of 224 consecutive children undergoing a DBPCFC owing to suspected CMA reacted to the challenge. In three children, a reaction was observed after the first dose (18 mg of total protein), whereas more than 50 % of subjects reacted at doses > 100 mg of total protein (Dambacher et al., 2013). In a tertiary Centre in the Netherlands, where 93 children where challenged through a DBPCFC with CMP, 5 % reacted to the first dose of 0.2 mg of protein (Blom et al., 2013).

In paediatric patients with IgE-mediated CMA, minimal eliciting doses (MED) for subjective symptoms have been reported to be, on average, two to six times lower than for objective symptoms (Blom et al., 2013).

Concerns have been raised against the possibility of children with CMA reacting to lactose following incidents after inhalation of lactose-containing drugs, possibly because of contamination with CMP. However, no single case of an adverse reaction to lactose ingestion has been reported among children with CMA, and a prospective study on the allergenicity of whey-derived lactose investigated by serology and DBPCFC did not document such reactions (Fiocchi et al., 2003a). Indeed, some products intended for use by milk-allergic children may contain lactose (Fiocchi et al., 2010), and elimination of lactose from the diet of children with CMA is not warranted.

15.8. Conclusion

Milk is a common cause of allergic reactions in childhood. Most CMPs, even those present at low concentrations, are potential food allergens. Prevalence of CMA in unselected European populations using food challenges to confirm diagnosis has been estimated to be around 1 % in children and 0.5 % in adults. Heat treatments can decrease or increase the allegenicity of CMPs depending on the

temperature and duration of the treatment. Fermentation and hydrolytic processes may decrease allergenicity depending on the microorganisms used and the reaction conditions. ELISA and MS techniques are available for the detection of CMPs in food products. Data available from case reports or DBPCFCs do not allow deriving a level of exposure which could be safe for most milk-allergic consumers, since the amount of CMPs, which may trigger allergic reactions in sensitive individuals varies widely. The lowest reported MOED in milk allergic patients undergoing DBPCFC was 200 μg of milk protein. Since this was the first dose tested, allergic reactions to lower doses cannot be excluded.

16. Allergy to eggs

16.1. Background

Female animals of many species, including birds, reptiles, amphibians and fish lay eggs, but hen's eggs are the most frequently consumed by man. Egg products are used widely by the food industry. Properties such as binding, emulsification, coagulation and adhesion are important for the production of a large number of food products, such as dairy, confectionary, beverages, ready prepared meals, cakes, icings, custard fillings and frozen bakery products.

In Western countries, egg allergy is one of the most frequent allergies in childhood together with milk and peanut (Eggesbo et al., 2001; Nwaru and Sheikh, 2012). Clinical symptoms include anaphylactic, immediate (IgE-mediated) and delayed immunological reactions that can affect all organ systems of the body. The skin, the gastrointestinal and respiratory tracts are typically involved.

16.2. Epidemiology

Self-reported diagnosis of egg allergy is usually based on parental perception of the allergic disease. Due to the relatively good prognosis of egg allergy, highest prevalence rates are observed between one and three years of age.

16.2.1. Prevalence

16.2.1.1. Europe

The prevalence of egg allergy in unselected European populations has been assessed in 17 countries (35 studies), including Denmark, Estonia, Finland, France, Germany, Greece, Greenland, Hungary, Iceland, Ireland, Italy, Norway, Portugal, Spain, Sweden, Turkey and the UK. Studies were published between 1980 and 2012 (University of Portsmouth, 2013)

Self-reported prevalence of egg allergy at one year ranged from 1.5 % in Norway (Eggesbo et al., 1999) to 6 % in Finland (Kajosaari, 1982). At two years, the range was between 3 % (Eggesbo et al., 1999; Ostblom et al., 2008a), 2008) and 7 % (Kajosaari, 1982) and between 2 % (Kilgallen and Gibney, 1996) and 9 % (Kajosaari, 1982) at three years of age. When the diagnosis was made by a physician, the prevalence at one year of age ranged from 1.9 % in Italy (Frongia and Bellamo, 2005) and Finland (Pyrhonen et al., 2009) to 2.6 % in Sweden (Ostblom et al., 2008a). In older children (> 6 years), the self-reported prevalence of egg allergy ranged between 1 % (Kajosaari, 1982) and 2.1 % (Zannikos et al., 2008) except in two studies conducted in Turkey in 2010 (Mustafayev et al., 2012)and Spain in 2000 (Martínez-Gimeno et al., 2000), where the prevalence was 5.6 % and 13 %, respectively. In adults, the range was between 0.4 % in Germany (Schafer et al., 2001) and 2 % in Turkey (Gelincik et al., 2008).

Some studies report on sensitisation rates assessed by SPT and/or specific IgE levels. In young children (≤ 3 years), the prevalence of positive SPT to eggs ranged from 1.4 % (Venter et al., 2008) in the UK to 5.2 % (Julge et al., 2001) in Estonia. Lower sensitisation rates were reported for older children, ranging from zero (Julge et al., 2001; Ronchetti et al., 2008) to 2.8 % (Schafer et al., 1999) (Ro et al., 2012), and for adults, between 0.4 % to 1.9 % (Schafer et al., 2001), except in Hungary,

where 7.3-11.1 % of adult subjects were sensitised to egg yolk as assessed by positive SPT. Higher sensitisation rates were observed when specific IgE levels were used for diagnosis. In younger children, sensitisation rates were between 4.2 % and 20.6 % (Julge et al., 2001), whereas in older children ranged between 0.4 % (Krause et al., 2002) and 22.7 % (Julge et al., 2001). In adults the figures were zero to egg yolk (Bakos et al., 2006) and 2.8 % to egg white.

Prevalence of egg allergy was generally lower when sensitisation tests were combined with clinical history. When SPT was used, prevalence was 1.5 % in 18 month olds in Sweden (Kristjansson et al., 1999), 0.1 % in adults in Turkey (Gelincik et al., 2008), and 0.2 % in the overall German population combining all ages (Zuberbier et al., 2004). When serum specific IgE was used, the highest prevalence was observed in Sweden (0.6 %) (Ostblom et al., 2008b) and the lowest in Turkey (0.1 %) (Gelincik et al., 2008). Studies performed in eight European centres are in keeping with these sensitisation rates (Burney et al., 2013).

Studies providing data about the prevalence of egg allergy based on clinical history and confirmed by food challenges (OFC or DBPCFC) are limited. In Denmark (Eller et al., 2009), prevalence of egg allergy was estimated to be 0.2 % at six months of life, 2.6 % at 18 months and 2.3 % at three years, decreasing to 0.6 % at six years. Lower rates (1.6 %) were reported in the same country at three years of age using DBPCFC instead of OFC. In other countries, prevalence of egg allergy among children six years of age based on OFC was 0.1 % in Turkey (Orhan et al., 2009) and 1 % in Finland (Kajosaari, 1982).

In adults, challenge proven egg allergy data come from two studies, both reporting 0.1 % prevalence in Denmark (Osterballe et al., 2005) and Turkey (Gelincik et al., 2008). The same prevalence rate was reported in Germany for all ages combined based on clinical history and DBPCFC (Zuberbier et al., 2004).

16.2.1.2. Outside Europe

In an Australian study (Osborne et al., 2011) amongst 2 079 children 11-15 months of age, the prevalence of any sensitisation to raw egg white was 16.5 %. The prevalence of challenge-proven raw egg allergy was 8.9 %, 80.3 % of which could tolerate baked egg. These figures are much higher than those reported in Europe, the reason(s) for which are unclear.

The prevalence of challenge-proven egg allergy in China was 2.9 % and 5 % in 1999 and 2009, respectively, among children from birth up to two years (Chen et al., 2011). A rate of 2.5 % was also reported in another study (Hu et al., 2010) conducted in the same country.

16.2.2. Natural history

Egg allergy is frequently outgrown in later life. Resolution rates vary among studies, probably owing to differences in patient selection and methods used to assess egg allergy. In a retrospective chart review in North America, ~ 40 % and ~ 70 % of egg allergic children with clear clinical history of an IgE-mediated allergic reaction to egg ingestion or egg specific IgE > 2 kU/L had developed tolerance to concentrated egg at 10 and 16 years of age, respectively (Savage et al., 2007). In Spain, 50 % of 42 children with egg allergy developed tolerance at around four years of age and only 26 % remained allergic at five years (Montesinos et al., 2010), whereas egg allergy tended to resolve in 55 % of 58 egg allergic children patients in the first six years of life (Boyano-Martinez et al., 2002). A high level of egg-specific IgE was correlated to egg allergy persistence (Savage et al., 2007; Caubet et al., 2011). In an Australian study of 130 challenge proven egg allergic children, egg allergy resolved by two years in 66 %. The resolution of egg allergy was lower in children with baked egg allergy at one year of age than in children with baked egg tolerance (13 % vs. 56 %, respectively) (Peters et al., 2013).

16.2.3. Time trends

Based on self-reported diagnosis of egg allergy, two cross sectional studies were carried out in 1980/2001 and in 1995/2005 in Finland and the UK, respectively. In both cases methodologies used and age groups studies were similar, and thus it is possible to compare prevalence rates over time.

In Finland (Kajosaari, 1982; Pyrhonen et al., 2009), prevalence of egg allergy reported by parents of young children was higher in 1980 than in 2001 at all ages. Prevalence of self-reported egg allergy in 1980 and 2001 was 6 % and 2.7 % in one year olds, 7 % and 4 % in two-year olds, and 9 % and 3.6 % in three-year olds, respectively. Conversely, self-reported prevalence of egg allergy increased from 0.7 % to 3 % between 1995 and 2005 in the UK in 15 year-old adolescents (Emmett et al., 1999; Pereira et al., 2005).

Owing to the high risk of bias of questionnaire based methods for the diagnosis of food allergy and based on the available data, the Panel notes that there is no evidence for a change in the prevalence of egg allergy in Europe over the timeframe assessed.

16.2.4. Severe reactions/anaphylaxis

Severe life-threatening events and fatal anaphylaxis to egg in children are less common than to peanut or milk. Over the 15-year period between 1990 and 2005, six series of food-related anaphylaxis in children from four different countries (UK, USA, Sweden and Germany) have been published, recording 31 deaths and 132 life-threatening reactions (Sampson et al., 1992; Allen et al., 2007; Pumphrey and Gowland, 2007). The triggers of fatal reactions were egg 7 %, milk 17 %, peanut 48 % and peanut or tree nut 62 %. Both fatalities to egg occurred in young children (three months and two years).

16.2.5. Factors affecting prevalence of egg allergy

The onset of egg sensitisation is related to the introduction of eggs in the diet, although there seems to be other routes (prenatally through the placenta, skin, and respiratory route by inhalation).

Although egg allergy is among the most common food allergy in infants and young children, environmental risk factors specific for egg allergy remain largely unknown. Egg sensitisation at one year of age is predictive of asthma in later life (Kulig et al., 1998; Tariq et al., 2000). IgE antibodies against egg proteins are associated with a higher risk of developing asthma at the age of three years (Nickel et al., 1997). A high level of egg specific IgE was correlated to egg allergy persistence. It is unclear whether continued exposure to cooked eggs induces immunological changes associated with tolerance induction in egg allergic children (Lemon-Mule et al., 2008), or whether the introduction of heated/baked egg into the infants' diet from four to six months of age may modify the development of egg allergy and sensitisation (Fleischer et al., 2013).

16.3. Identified allergens

Major allergens of the eggs of *Gallus domesticus* are known, characterised and classified as Gal d 1-6 by the IUIS (Table 9). However, major allergen sources are still unassigned and their relevance in human egg allergy is still unknown (Mine and Zhang, 2002; Amo et al., 2010).

3691 **Table 9:** Hen's (*Gallus domesticus*) egg allergens.

Fraction	Allergen	Biochemical name	Concentration	Molecular weight[a]
Egg white	Gal d 1	ovomucoid	11 %	28
	Gal d 2	ovalbumin	54 %	44
	Gal d 3	ovotransferrin	13 %	78
	Gal d 4	lysozyme C	3.5 %	14
Egg yolk	Gal d 5	serum albumin (α-livetin)	48 %	69
	Gal d 6	YGP42	-	35[b]

3692 [a] MW (SDS-PAGE); [b] kDa

3693 Clinically relevant egg allergens have been identified both in the egg white and the egg yolk fractions.
3694 Based on SPT, RAST assays and CRIE, the most common egg allergens are ovomucoid, ovalbumin
3695 and lysozyme (Mine and Yang, 2008).

3696 Ovomucoid (Gal d 1), one of the major egg allergens for clinical reactions (Bernhisel-Broadbent et al.,
3697 1994), is a highly glycosylated protein containing 186 amino acids which exhibits trypsin inhibitory
3698 activity. The molecule consists of three structurally independent domains, has nine intramolecular
3699 disulphide bridges, and displays 20-25 % of carbohydrates entities (Kato et al., 1987). Specific IgE to
3700 Gal d 1 in hen's egg white appears to be a risk factor for persistent egg allergy and indicates that
3701 neither raw nor heated egg is likely to be tolerated (Caubet et al., 2011).

3702 Ovalbumin (Gal d 2) is a phosphoglycoprotein comprising 54 % of egg's white total protein content.
3703 Its complete sequence of 385 amino acids has been determined (Nisbet et al., 1981). Ovotransferrin
3704 (Gal d 3) displays an N domain and a C domain, belongs to the transferrin protein family and has iron-
3705 scavenging properties (Li-Chan and Nakai, 1989). Lysozyme (Gal d 4) is a glycosidase containing
3706 four disulfide bonds with bacteriolytic activity. It is used in the food industry to maintain product
3707 quality and reduce the incidence of spoilage.

3708 Serum albumin (α-livetin; Gal d 5) is involved in the bird egg syndrome and sensitisation is most
3709 likely to occur via inhalation (Jacobsen et al., 2008). It consists of 589 amino acid residues and is
3710 homologous to mammalian serum albumins (47 and 44 % identity to human and bovine albumins,
3711 respectively). The protein has one potential glycosylation site and 35 cysteine residues.

3712 Gal d 6 is the newly identified yolk glycoprotein YGP42, a fragment of VTG-1, which has been
3713 described in monosensitised egg allergic patients (Amo et al., 2010). It is heat resistant but sensitive to
3714 pepsin digestion. The VTG-derived proteins are the major yolk components. Cleavage of VTG-1 and
3715 VTG-2 produces apolipovitellins and phosvitins, which are components of the water-insoluble yolk
3716 granular lipoproteins. The C-terminal part of VTGs gives rise to yolk glycoproteins YGP40 and
3717 YGP42, which are major components of the yolk plasma (Mann and Mann, 2008).

3718 IgE antibodies of egg allergic children directed against conformational structures seems to indicate an
3719 earlier recovery from disease compared with those children who have developed IgE antibodies
3720 against linear epitopes (Jarvinen et al., 2007; Leonard et al., 2012).

3721 **16.4. Cross-reactivities**

3722 Clinical cross-reactivities of primary egg allergic individuals are generally restricted to other avian
3723 eggs, although primary sensitisations to duck and goose eggs without sensitisation to hens' eggs have
3724 been reported (Añíbarro et al., 2000). Hens' egg white immunologically cross-reacts with egg white
3725 from turkey, duck, goose and seagull (Langeland, 1983). The level of cross-reactivity is related to the
3726 extent of sequence homology of the shared protein, and a homology of around 50 % is required in
3727 most instances to allow IgE-binding and trigger adverse reactions (Ferreira et al., 2004). All egg
3728 whites contain moieties able to bind human IgE antibodies of patients with allergy to hens' egg white.
3729 Several cross-reacting proteins in egg white were also detected in egg yolks and to some extent in

chicken sera and meat. Individuals who react to chicken meat are generally sensitised to chicken serum albumin. Occasionally, patients with allergies to chicken and other avian meats are able to eat eggs without symptoms (Cahen et al., 1998; Añíbarro et al., 2000). The probability of cross-reactions is likely to be affected by interspecies relationships (Kelso et al., 1999) and possibly by different chicken breeds (Egger et al., 2011).

16.4.1. Bird-egg syndrome

Patients with allergy to egg yolk may also present respiratory symptoms caused by bird exposure at home (Szepfalusi et al., 1994; Quirce et al., 2001). The identified cross-reacting allergens include α-livetin (Gal d 5), which is partially heat-labile. Incubation of pooled sera from patients with bird-egg syndrome with bird feather extracts led to complete blocking of IgE-binding to allergens in egg yolk and bird feather extracts. Serum from patients with egg white allergy did not react with allergens in egg yolk or bird feather extract (Szepfalusi et al., 1994).

16.4.2. Birds' nest allergy

Anaphylaxis after ingestion of edible nests of *Collocalia* species, used in Chinese cuisine (Ou et al., 2001), has been reported. Immunochemical characterisation of a putative 66 kDa allergen revealed homology with the egg white allergen ovoinhibitor, a serine protease inhibitor (Goh et al., 2000; Goh et al., 2001).

16.5. Possible effects of food processing on allergenicity

A number of studies have explored the effects of different food processing methods, such as heat treatments, enzymatic proteolysis, irradiation, or high-pressure treatments, on the allergenicity of egg in food products (Mine and Yang, 2008).

16.5.1. Thermal processing

Thermal processing is often undertaken to enhance flavour, consistency and microbiological safety, rather than to reduce allergenicity. When egg white is subjected to heat, its globular proteins change in structure and conformation. Ovalbumin, the most abundant protein in egg white, unfolds completely when heated in a solution of pH 10 (Van Kleef, 1986). The unfolded, randomly coiled ovalbumin molecules are mainly cross-linked via covalent disulphide cross-links.

Effects of heating (and chemical denaturation procedures) on the IgE-binding capacity (Mine and Zhang, 2002; Manzocco and Nicoli, 2012; Shin et al., 2013) and allergenicity (Koplin et al., 2010; Burks et al., 2012a) of major egg allergens have been described. Many egg allergic individuals react to cooked and raw eggs (Langeland, 1982a, 1982b). However, some individuals react only to raw eggs and tolerate cooked eggs (Kemp, 2007; Burks et al., 2012a). These individuals often exhibit lower egg-specific IgE levels (Boyano Martinez et al., 2001).

Heating and freeze drying can reduce the allergenicity of egg for some patients (Urisu et al., 1997; Nowak-Wegrzyn and Fiocchi, 2009), but this process does not reliably prevent IgE-binding or clinical reactions, probably because the major allergen ovomucoid is heat stable.

16.5.2. Enzymatic treatments

Enzymatic proteolysis may reduce the allergenicity of egg allergens by targeting sequential epitopes (Wal, 2003). During enzymatic hydrolysis, the functional properties of egg proteins, such as foaming and gelling, are usually lost. The IgE-binding capacity of egg was reduced by applying a combination of thermal treatments and enzymatic hydrolysis, while maintaining flavour and texturising properties (Hildebrandt et al., 2008).

16.5.3. γ-Irradiation

Radiation technology has been explored in a number of studies for the modification of egg allergens (Seo et al., 2007). Treatment doses up to 3 kGy are applied to ensure a bacteriological quality for liquid, frozen, or dehydrated egg white preparations. γ-Irradiation > 10 kGy may alter the structure of ovalbumin and decrease its IgE-binding capacity. γ-Irradiation in combination with heat treatment may reduce the IgE-binding properties of ovomucoid (Kim et al., 2002).

16.5.4. Egg-derived products used in food processing

16.5.4.1. Egg lysozyme and lecithin

Egg lysozyme (E1105) is used by the food industry as bactericide to prevent the growth of anaerobic bacteria and in the preparation of medications (Fremont et al., 1997). Egg lysozyme in medications, including vaccines, has been reported to trigger adverse reactions in egg allergic individuals at doses in the mg and µg range (Ledesma Benitez et al., 2007; Perez-Calderon et al., 2007; Artesani et al., 2008).

Egg lecithin is used as emulsifier (E322), although it is increasingly replaced by soy lecithin (Gultekin and Doguc, 2013). The possibility of residual allergenicity in food products manufactured using egg lecithin has been reported in a DBPCFC (Palm et al., 1999). Any white egg proteins present in pharmaceutical products may potentially trigger anaphylactic reactions.

16.5.4.2. Wine clarification

Egg white is commonly used in the clarification of wines throughout the world. In view of the variable use of egg-derived fining agents and processes, the presence of fining agents in the finished product is variable. Following Commission Regulation (EU) 1266/2010[10] and the expiration of the temporary exemption from labelling, wine labels must state whether egg products have been used in the fining process as of July 2012.

16.6. Detection of allergens and allergenic ingredients in food

16.6.1. Immunological methods

16.6.1.1. ELISA

The most frequent methods used for egg allergen analyses are based on ELISA techniques preferably targeting ovalbumin and ovomucoid.

An ELISA assay based on polyclonal antibodies specific to whole egg proteins (Yeung et al., 2000) with a LOD of 0.2 mg/kg and a sandwich ELISA assay which used ovalbumin and dehydrated egg white solids as antigens with a LOD of 1 mg/kg (Hefle et al., 2001) have been developed and applied to numerous foods. Two more sensitive indirect competitive ELISA are now available for the detection of both native and denatured ovomucoid in hen's egg white with LODs of 0.041 ng/mL (Li et al., 2008) and 30 ng/mL (Dong-Hwa et al., 2010) in processed foods.

Many ELISA kits with variable performance and inherent limitations are commercially available (Schubert-Ullrich et al., 2009; Shoji, 2009). ELISA kits may target total egg protein, egg white proteins, ovomucoid, ovalbumin, or ovomucoid and ovalbumin together, with LODs from 0.08 to 0.6 mg/kg and LOQs between 0.3 and 1 mg/kg. False positive and false negative results can be expected as a consequence of several factors, such as matrix effects or cross-reactivity between ovalbumin and other avian eggs, such as pheasant, goose, duck or quail, probably owing to the high sequence homology.

[10] Commission Regulation (EU) No 1266/2010 of 22 December 2010 amending Directive 2007/68/EC as regards labelling requirements for wines. OJ L 347, 31.12.2010, p. 27-28.

Most important are the effects of thermal processes on the detectability of egg allergens, on account of the reduced recognition of the modified native protein by antibodies and/or the decreased solubility of the proteins. Three commercial ELISA kits were evaluated and found to be highly affected by heat treatments (Fu et al., 2010). The underestimation was attributed to changes in the immunoreactivity of residual proteins rather than to differences in the amount of protein extracted. The effects of processing on the accuracy and precision of five ELISA commercial kits were tested for the simultaneous presence of peanut, egg and milk in incurred dark chocolate (Khuda et al., 2012a) and sugar cookies (Khuda et al., 2012b). The effect on accuracy and precision of ELISA kits was found to depend more on the heating conditions than on the type of matrix. Tempering (46 °C for 4 h) had no significant effect on the detection of egg in chocolate, whereas baking (190 °C for 25-30 min) negatively affected the recovery and variability of egg proteins in sugar cookies when using all five ELISA kits. Similar results were obtained in baked cookies incurred in a non-wheat flour matrix using two commercial ELISA test kits and flow citometry as detection methods (Gomaa and Boye, 2013). No recoveries were obtained for egg proteins under some thermal treatments.

The solubilisation of egg allergenic proteins is a critical issue to be tackled when using immunoassays. The addition of sodium dodecyl sulphate (SDS) and 2-mercaptoethanol (2-ME) to the extraction buffer greatly improved the extraction of proteins from raw eggs, boiled eggs and fried noodles, as 2-ME acts as a reducing agent cleaving the disulphide bonds and SDS acts as surfactant (Watanabe et al., 2005). An ELISA assay for egg proteins employing this extraction method used an anti-SDS-ovalbumin antibody rather than an anti-native ovalbumin antibody to allow recognition of the denatured protein. The method was applied to incurred processed samples allowing high recoveries and was validated in a collaborative study (Matsuda et al., 2006).

The reference material NIST RM-8445 (spray-dried whole egg) for allergen detection is available. Another egg reference material NIST RM-8415 (egg powder), used for nutritional studies, was found unsuitable for allergen detection immunoassays owing to the low solubility of the proteins. Several commercial ELISA kits were evaluated for the analysis of egg spiked with NIST RM 8445 in wheat flour (raw) and egg containing cookies (Diaz-Amigo, 2010). An incurred reference material for the analysis of egg allergens in baked foods is also available (Dumont et al., 2010).

16.6.1.2. Lateral flow devices and dipsticks

Lateral flow devices which provide fast qualitative data are commercially available, with LODs from 0.5 to 5 mg/kg. A dipstick assay based on a non-competitive ELISA format, where the antibody was directly spotted on a nitrocellulose membrane and the detection performed with an antibody coupled to peroxidase, was also developed, with a LOD of > 20 µg/kg egg proteins in food (Baumgartner et al., 2002).

16.6.1.3. Biosensors

Several optical-based biosensors have been described for the detection of ovalbumin. Polymer brush modified cap-shaped gold nanoparticles have been used as sensing elements using localised SPR with a LOD of 100 nM (Anraku et al., 2007). The target of this sensor being sugars, specificity for ovalbumin needs to be demonstrated.

An optical resonance enhanced absorption (REA)-based immunochip sensor in direct and sandwich assay formats using antibodies functionalised with gold nanoparticles has been proposed as a rapid colorimetric method for detecting ovalbumin and ovomucoid in foods (Maier et al., 2008). The biosensor gave reproducible and selective results with a LOD of 1 ng/mL, enabling high-throughput screening.

An optical planar waveguide array platform has also been developed for the detection of multiple allergens, including ovalbumin, using fluorescence sandwich immunoassays with a LOD of 25 pg/mL in buffer and of 1.3 ng/mL (13 ng/g) in pasta (Shriver-Lake et al., 2004).

A label-free voltammetric immunosensor, based on the ovalbumin antibody immobilised on carboxyphenyl modified graphene has been used for the detection of ovalbumin in the concentration range between 1 pg/mL and 0.5 mg/ mL with a LOD of 0.83 pg/mL in phosphate buffer saline (PBS) buffer (Eissa et al., 2013).

16.6.2. Mass spectrometry

An LC-ESI-MS/MS method was compared with commercial ELISA kits for the detection of ovalbumin in egg white, whole egg and incurred (with egg white powder) pasta before and after heating (Azarnia et al., 2013). Protein extraction was performed with the buffers recommended by the ELISA kits producers. Several peptides were selected following tryptic digestion of the protein, none of which was detected by MS in cooked samples or by the ELISA kits in all incurred pasta samples. This shows that both MS and ELISA methods are affected by matrix, processing and extraction conditions.

A multi-method for the detection of seven allergenic foods (egg, milk, soy, hazelnut, peanut, walnut and almond) based on LC-QpQ-MS/MS implied extraction of the allergenic proteins from the food matrix (incurred reference bread material baked with a standard recipe), digestion with trypsin and selection of the marker peptides. Peptides were separated by HPLC and analysed in the MRM mode, with a LOD of 50 µg/g (Heick et al., 2011a). This method was found to be superior for the detection of egg allergens to the commercial ELISA kits (Heick et al., 2011b).

16.6.3. Detection of lysozyme in dairy products

An indirect inhibition ELISA for the specific detection of lysozyme in hen's egg white with a LOD of 0.264 µg/mL (Vidal et al., 2005) and a competitive ELISA to quantify the amount of lysozyme in cheese using a commercially available monoclonal antibody (Schneider et al., 2010b), with a LOD of 2.73 ng/mL, have been described.

A rapid chemoluminescent immunoassay based on bacterial magnetic particles conjugated to an antibody in a fully automated system was also used to detect lysozyme with a LOD of 10 ng/mL (Sato et al., 2001), as well as an on-line coupled capillary isotachophoresis-capillary zone electrophoresis (CITP-CZE) method, which allowed a good separation, with a LOD of 0.25 µg/mL and a LOQ of 1 µg/mL (Kvasnička, 2003).

Lysozyme is used in cheese to prevent blowing by *Clostridium tyrobutyricum.* Lysozyme was efficiently detected and quantified in milk and cheese (LOQ 0.8 mg/kg) by using a RP-HPLC in connection with a fluorescence detector (Pellegrino and Tirelli, 2000), whereas a commercial ELISA kit was unsuitable for the detection of lysozyme in cheese on account of the low recovery owing to the interaction between lysozyme and other proteins in cheese and of matrix interferences during the immunological reactions (Kerkaert et al., 2010)

Lysozyme was found to remain unaltered during ripening (up to 24 months) of a hard-type cheese by using SELDI-TOF/MS (Dragoni et al., 2011). Another method which combines immunocapture purification and MALDI-TOF-MS analysis was also developed for the detection of lysozyme in cheese samples (Schneider et al., 2010a), with a LOD of 5 mg/kg lysozyme in cheese.

16.6.4. Detection of egg products in wine

Egg white proteins are used as fining agents in wines. Lysozyme may also be added to wines as a stabiliser for its antimicrobial activity. By applying a competitive ELISA assay to laboratory-fined wines, lysozyme was detected in the range of approximately 0.01-0.06 mg/L and dried egg white at 0.2 mg/L (Weber et al., 2007). A specific sandwich ELISA was established using commercially available monoclonal and polyclonal antibodies for ovalbumin detection in wine with a LOD of 1 mg/L (Rolland et al., 2008). The method was applied to a panel of commercially available bottled wines, where egg residues were detected in two red wines fined with whole eggs.

In order to overcome the poor sensitivity of immunological methods in a matrix rich of interfering substances like wine, a direct LC-MS/MS (nano-HPLC/ESI-Q-TOF) method for detecting residual egg proteins (ovalbumin, ovomucoid and lysozyme) in red wine fined with a commercial egg white preparation was developed (Tolin et al., 2012b). On the basis of three peptides taken as markers, it was possible to unequivocally detect the presence of egg white in wines treated with the minimal dose commonly adopted for red wine fining (5 g/hL). When the method was applied to a panel of commercial red wines, the presence of egg proteins was demonstrated in some, with an estimated minimal residual concentration of ovalbumin of about 0.1 µg/L (Tolin et al., 2012a).

In order to achieve quantitative measurements of egg (ovalbumin and lysozyme) and milk (casein) proteins in white wine by MS, a method based on HR-MS has been described (Monaci et al., 2013). The method implies previous ultrafiltration of wine, tryptic digestion of the dialysed wine extracts and LC/HR-MS. Tryptic peptides were selected as quantitative markers of the allergenic proteins. Analyses were performed on wines fined with either caseinate or egg-white powder at concentrations of 0.25 and 10 mg/L, respectively. LODs were 0.4 and 1.1 mg/L, respectively.

16.6.5. DNA-based methods

The limitations of DNA-based techniques for the detection of egg in foods relate to the low content of DNA in eggs and to the fact that egg DNA cannot be distinguished from chicken DNA, which may lead to misinterpretation of the data, obtained when analysing complex food mixtures.

Two tetraplex qPCR were developed for the simultaneous detection of eight allergenic foods, among which egg, with specificity and sensitivity in the range of 0.01 % (Köppel et al., 2010). Two quantitative hexaplex real-time PCR systems for the detection and quantification of 12 allergenic ingredients (among which eggs) in foods became available thereafter (Köppel et al., 2012). The two tests showed good specificity and sensitivity (LOD of at least 0.01 % for all allergenic ingredients) in mixed foods. The inherent sensitivity was lower for eggs owing to the low amount of DNA present. However, the two multiple PCR systems are suitable as screening tools in routine analysis.

16.7. Minimal (observed) eliciting doses

Some egg allergic patients react to small (µg) amounts of egg (Wuthrich, 2000; Wuthrich and Ballmer-Weber, 2001).

A number of studies performed for different purposes (i.e. diagnostic, threshold-finding and immunotherapy trials) have reported on MED/MOED following food challenges mostly in children (Atkins et al., 1985; Caffarelli et al., 1995; Eggesbo et al., 2001; Knight et al., 2006; Staden et al., 2007; Benhamou et al., 2008; Orhan et al., 2009; Blom et al., 2013), but also in adults and children combined (Norgaard and Bindslev-Jensen, 1992; Morisset et al., 2003a) and in adults only (Unsel et al., 2007). Studies vary in size, in the challenge protocol used and in the type of food preparation tested (Taylor et al., 2013). The total number of patients showing objective symptoms during the challenge in a given study ranged from one to 53. The lowest MOEDs also varied widely among studies, ranging from 0.21 to 583 mg of total egg protein (Blom et al., 2013; Remington, 2013). Raw egg white, whole raw egg and whole cooked (boiled, fried or baked) egg were tested in these studies. Doses (as mg of total protein) of raw egg white eliciting allergic reactions were significantly lower than doses of both raw and cooked whole egg, possibly owing to the higher proportion of egg allergens in egg white protein.

Hefle et al. (2003) used spray-dried whole egg (SDWE) to determine the individual threshold doses in 39 egg-allergic individuals. Most subjects did not react with objective symptoms to a cumulative dose of 330 µg SDWE (150 µg egg protein), whereas one subject reacted to the first dose of 30 µg SDWE (14 µg egg protein).

Minimal doses reported to elicit objective symptoms in egg allergic individuals are variable depending on the study population, challenge protocol and food matrix tested. The lowest reported MOEDs in

egg allergic patients undergoing food challenges of 14 µg of egg protein could be even lower considering that the individual already reacted to the first challenge dose tested.

16.8. Conclusion

Egg proteins are frequent triggers of allergic reactions. Prevalence of challenge proven egg allergy in unselected populations is about 1.5-2.5 % in young children (< 3 years), whereas lower prevalence rates have been reported in older children and adults (from 0.1 % to 1 %). A number of egg allergens have been identified and characterised. Most egg allergic individuals exhibit IgE-binding to sequential epitopes of egg white. However, both egg white and egg yolk derived proteins have been described to trigger clinical allergic reactions. Heat denaturation and other food processing treatments do not reliably reduce the allergenicity of egg. A number of methods of detection are available, based on ELISA assays, MS and PCR technologies. Specific methods for the detection of lysozyme in dairy products and of egg products in wine based on these technologies have also been developed. Minimal eliciting doses of ingested egg proteins reported to trigger reactions in clinical studies range from few micrograms to milligrams. Most egg allergic individuals are likely to react to raw egg proteins in the low milligram level.

17. Allergy to nuts

17.1. Background

Nuts include a wide variety of fruits or seeds of various species contained within a hard shell. These species do not form a taxonomic group. Almonds are not nuts, but are included in this section because specifically mentioned in Annex IIIa. Nuts are consumed in many forms, varying from raw seeds to roasted snacks. The intake of tree nuts, peanuts, and unspecified nuts consumed in the EU was 2.23 g/d for the entire population. The mean intake of total nuts varied ~ 8-fold from Northern to Southern Europe, ranging from 0.61 g/d in Sweden to 4.83 g/d in Spain. Walnuts, almonds, pistachios, and hazelnuts are tree nut most consumed in Europe (Jenab et al., 2006). Nuts are known to trigger a wide range of allergic manifestations in sensitive individuals, ranging from OAS to anaphylaxis.

Hazelnut belongs to the family of *Betulaceae*, a group of plants whose pollen is often responsible for respiratory symptoms. Brazil nut does not belong to the subclass of *Rosidae*, like hazelnut, English walnut, black walnut, almond, cashew nut, macadamia nut and Queensland nut, but to the subclass of *Asteridae*, like sesame seeds and *Apiaceae* (carrot and celery). Pecan nut (*Carya illinoinensis*) is closely related to walnut and belongs to the same family of *Juglandaceae*. The *Rosaceae* family includes almonds (*Prunus dulcis* or *Prunus amygdalus*), but also apple, pear and *Prunoideae* fruits (peach, apricot, plum and cherry). Cashew nut (*Anacardium occidentale*), pistachio (*Pistacia vera*) and mango belong to the same *Anacardiaceae* family. Chestnut (*Castanea sativa*) belongs to the *Fagaceae* family, together with trees such as oak and beech.

17.2. Epidemiology

17.2.1. Prevalence

17.2.1.1. Europe

Data on the prevalence of tree nut allergy in unselected European populations by type of nut, age group and method of diagnosis are depicted in Table 10. Prevalence data come from a number of different European countries (i.e. Finland, Germany, Greenland, Hungary, Iceland, Norway, Spain, Sweden, The Netherlands, Turkey and the UK), but geographical comparisons are difficult to make because country-based studies differ in the type of nut, age group and method of diagnosis investigated.

3996 **Table 10:** Estimated prevalence of tree nut and almond allergy in unselected European populations
3997 by type of nut, age group and method of diagnosis.

	Tree nuts (unspecified)	Hazelnut	Walnut	Almond	Cashew nut	Brazil nut	Pistachio	Pecan nut
All ages								
Self-reported	1.7 %	-	-	-	-	-	-	-
Sensitisation	-	23 %		-	-	-	-	-
Clinical history and sensitisation	-	4.5 %	1.4 %	-	-	-	-	-
Clinical history and FC	-	2.2 %	1 %	-	-	-	-	-
Young children (≤ 3 years)								
Self-reported	0-2 %	-	-	0 %	-	-	-	-
Sensitisation	-	0.2 %	-	0.3 %	0.2 %	0.3 %	-	-
Clinician diagnosed	0.3-0.4 %	-	-	-	-	-	-	-
Clinical history and sensitisation	0 %	-	-	0 %	-	-	-	-
Children /adolescents (> 3-17 years)								
Self-reported	1.3-6.9 %	0.3-1.5 %	0.1-1.2 %	3.8 %	-	-	0.8 %	-
Sensitisation	-	0.1-0.4 %	0.1-4.5 %	0.5 %	0.4 %	0.5 %	-	0.2 %
Clinical history and sensitisation	-	0.1 %	-	-	0.1 %	-	-	-
Clinical history and FC	-	0-0.1 %	0-0.4 %	-	-	-	-	-
Adults/elderly (≥ 18 years)								
Self-reported	0.1 %	-	-	-	-	-	-	-
Sensitisation	-	0-11.3 %	3.7 %	0 %	-	-	-	-
Clinical history and sensitisation	-	0 %	-	-	-	-	-	-
Clinical history and FC	-	0 %	0 %	-	-	-	-	-

3998 FC = food challenge.

3999 The prevalence of self-reported allergy to any nut was 1.7 % in the general population (UK) (Young et
4000 al., 1994), ranging from 0.1 % in adults (Turkey) (Orhan et al., 2009), to 1.3 % (The Netherlands)
4001 (Brugman et al., 1998) and 6.9 % (Spain) (Martínez-Gimeno et al., 2000) in children.

4002 The prevalence of self-reported hazelnut allergy ranged from 0.3 to 1.5 % in children (Turkey) (Orhan
4003 et al., 2009; Mustafayev et al., 2012). No data are available for other population subgroups or the
4004 general population. Data on sensitisation rates are more abundant and somehow contradictory.
4005 Although sensitisation rates based on positive SPT have been reported to be as high as 23 % in the
4006 general German population (Zuberbier et al., 2004), lower rates have been observed in German
4007 (11.3 %) (Schafer et al., 2001) and Hungarian adults (2.8-3.6 % by SPT; 0-9.2 % by specific IgE)
4008 (Bakos et al., 2006), whereas sensitisation rates in children and adolescents were very low in Turkey
4009 and the UK (0.1-0.4 %). Prevalence of hazelnut allergy based on positive clinical history plus
4010 sensitisation (4.5 %) and on clinical history plus food challenge (2.2 %) was again higher in the
4011 German general population than in 4-year old children in the UK (0.1 %; history plus SPT; (Tariq et
4012 al., 1996) or in any specific population subgroup in Turkey, where the prevalence of hazelnut allergy
4013 using food challenges was close to zero (Gelincik et al., 2008; Orhan et al., 2009; Mustafayev et al.,
4014 2012).

Some of the studies above have also assessed the prevalence of walnut allergy, which appears to be even lower than the prevalence of allergy to hazelnuts. As for hazelnuts, prevalence of self-reported allergy is low (0.1-1.2 %), but data are only available for Turkish children. Sensitisation rates based on positive SPT were 3.7 % in Hungarian adults and 0.1-4.5 % in Turkish children. Prevalence of walnut allergy based on positive clinical history plus sensitisation (1.4 %) and on clinical history plus food challenge (1 %) in the German general population was again higher than in any specific population subgroup in Turkey, where the prevalence of walnut allergy using food challenges was 0-0.4 %.

Prevalence data from unselected European populations regarding almond allergy are available almost exclusively for children and is limited to self-reported allergy and sensitisation rates, with or without clinical history. Whatever the method used, prevalence was low in both adults and children. Self-reported allergy ranged from 0 % in young children (Iceland and Sweden) (Kristjansson et al., 1999) to 3.8 % in older children (Sweden) (Ostblom et al., 2008b), whereas sensitisation rates ranged from 0.3 to 0.5 % (UK) ((Roberts et al., 2005; Venter et al., 2008), respectively).

Prevalence data for tree nuts other than hazelnut and walnut are scarce and almost limited to sensitisation rates (positive SPT and/or specific IgE) in children. Sensitisation rates (positive SPT) to cashew nut were 0.2 % in young children (UK) (Venter et al., 2006b) and 0.4 % in older children (UK) (Roberts et al., 2005), whereas prevalence of cashew nut allergy in older children based on clinical history and positive SPT was only 0.1 % (Turkey) (Tariq et al., 1996). Sensitisation rates to Brazil nut in young and older children (0.3 and 0.5 %, respectively) and sensitisation rates to pecan nuts in older children (0.2 %) were similar to cashew nut and were assessed in the same studies. The only available data for pistachio referred to self-reported allergy in older children (0.8 %; Turkey) (Mustafayev et al., 2012).

17.2.1.2. Outside Europe

Most studies on the prevalence of nut allergy in unselected populations conducted outside Europe (mainly in the US and Canada) address allergy to unspecified nuts. Prevalence of self-reported allergy to tree nuts in Canada was 1.2 % in the general population and 1.1 % in adults (Canada) (Ben-Shoshan et al., 2010). Lower rates (0.6 %) were observed in Australian adults (Woods et al., 1998). In children, prevalence of self-reported allergy was generally higher, ranging from 1.7 % in Canada (Ben-Shoshan et al., 2010) to 4.7 % in Singapore (Shek et al., 2010).

Data on prevalence of tree nut allergy based on clinical history or diagnosis by a clinician was quite consistent across countries, ranging from 0.2-0.4 % in children and from 0.9 to 1.6 % in adults in the US (Sicherer et al., 1999; Sicherer et al., 2003; Sicherer et al., 2010).

Only one study reported on prevalence of allergy to a particular tree nut. Based on clinical history and specific IgE concentrations, 2.2 % of six to eight year old Taiwanese were allergic to pistachio (Wan and Chiu, 2012).

No prevalence studies were available in unselected, non-EU populations where allergy to particular tree nuts has been confirmed by challenge studies.

17.2.2. Natural history

Little is known about the natural history of nut allergy. Patients with diagnosed nut allergy are generally advised to avoid eating nuts for the rest of their lives, but some patients outgrow their allergy.

The proportion of subjects who outgrow tree nut allergy was evaluated using nut challenges in a group of children with a history of acute allergic reactions to nuts and evidence of nut-specific IgE or positive nut-specific IgE level and no history of nuts ingestion (Fleischer et al., 2005). The authors concluded that 8.9 % of children acquired oral tolerance (nine out of 101 with a history of prior nut reactivity), but this level of resolution of nut allergy may be underestimated. It was also observed in

the same study that none of the patients whose nut allergy resolved had a history of reacting to more than two different nuts, so patients with allergy to multiple nuts may be less likely to outgrow allergy.

17.2.3. Time trends

A random-calling telephone survey conducted across the United States in 1997, 2002, and 2008 observed an increase in self-reported tree nut allergy in children (0.2 %, 0.5 %, and 1.1 %, respectively) (Sicherer et al., 1999; Sicherer et al., 2003; Sicherer et al., 2010). Prevalence rates of hospital admissions for food-induced anaphylaxis in Australia increased by 350 % between 1994 and 2005, mostly in children below four years of age (11 cases per 100 000 population in 2005) and mostly due to peanut and tree nut anaphylaxis (39 % of all cases of anaphylaxis), whereas the increase in the frequency of admissions was more modest in older age groups and in relation to other allergies (Liew et al., 2009).

A study on self-reported allergy to nuts (unspecified) conducted in Finland in 1980 (Kajosaari, 1982) showed a 2 % prevalence at 1 year of age, zero at two years, and 2 % at three years. A similar study conducted in 2001 (Pyrhonen et al., 2009) found a 0.8 % prevalence at one year of age, 2 % at two years, and 1.4 % at three years.

Data from studies using oral food challenges on time trends for nut allergy are lacking.

17.2.4. Severe reactions/anaphylaxis

In comparison with other foods, allergic reactions to nuts seem to be particularly severe and are characterised by multi-systemic or respiratory symptoms. It has been estimated that nuts represent the triggering factor for about 1/3–1/4 of all anaphylactic reactions attributed to food consumption (Cianferoni and Muraro, 2012; Huang et al., 2012).

Registers of anaphylaxis deaths are kept since 1992 in both the UK and the US. Out of the 37 food-induced fatalities reported from 1992 to 2000 in the UK, 10 were attributable to peanut, five to walnut and 10 to other non-specified nuts (Pumphrey, 2000). The next UK survey (up to 2006) reported 48 additional deaths, from which nine were attributed to nuts (Pumphrey and Gowland, 2007). In the USA, 32 fatal cases were registered in the first period (up to 2000), 20 caused by peanut, three by walnut, two by Brazil nut, two by pecan nut, one by pistachio and two by non-specified nuts (Bock et al., 2001). In the next period (2001-2006), 31 additional cases were identified, eight of which were associated with tree nut consumption (Bock et al., 2007).

An epidemiological study on the cases of anaphylaxis requiring emergency treatment in the Northwest of England reported 23 cases of reactions to nuts out of 172 total cases of anaphylaxis (Pumphrey and Stanworth, 1996). Another study reported 14 paediatric cases of severe food allergic reactions to nuts, especially cashew nut (seven cases) out of 55 severe non-fatal reactions recorded in the UK and Ireland from 1998 to 2000 (Macdougall et al., 2002).

17.2.5. Factors affecting prevalence of nut allergy

Allergy to one type nut is a risk factor for developing allergy to other type of nuts. Multiple sensitisations, assessed as positive SPT, was found in 19 % of sensitised children at the age of two years and 86 % of children at 5-14 years. Similarly, clinical reaction to multiple nuts was found in 2 % of children at two years and 47 % at 14 years (Clark and Ewan, 2003). Retrospective analysis of 201 patients with peanut allergy showed that at the time of peanut allergy diagnosis, almost one-third of patients were sensitised to one or more tree nuts and became sensitised to an increasing number of tree nuts with advancing age (Fleischer, 2007).

One randomised placebo-controlled double-blind study showed the prolonged effect of sublingual immunotherapy with a standardised hazelnut extract on clinical symptoms of hazelnut allergy (Enrique et al., 2008). However, these results were not confirmed in other studies (van Hoffen et al., 2011).

17.3. Identified allergens

The majority of nut allergens are seed storage proteins, such as vicilins, legumins and 2S albumins. Other nut allergens are PR proteins (chitinases, Bet v 1 homologues, and LTP) and structural proteins (profilins and oleosins). Profilins are panallergens (present in pollens, nuts, seeds, fresh fruit and other vegetables). Additional proteins have recently emerged as allergens in tree nuts, including manganese superoxide dismutase (MnSOD), 60S acidic ribosomal protein P2, and cytosolic small heat shock protein.

17.3.1. Hazelnut

Hazelnut (pollen and non-pollen related) allergens are shown in Table 11.

Table 11: Hazelnut (*Corylus avellana*) allergens

Allergen	Biochemical name	Superfamily/family	Molecular weight[a]
Cor a 1	PR-10	Bet v 1	17
Cor a 2	profilin	profilin	14
Cor a 8	ns-LTP 1	prolamin	9
Cor a 9	11S globulin (legumin-like)	cupin	40
Cor a 11	7S globulin (vicilin-like)	cupin	48
Cor a 12	oleosin	oleosin	17[b]
Cor a 13	oleosin	oleosin	14-16[b]
Cor a 14	2S albumin	prolamin	15-16[b]

[a] MW (SDS-PAGE); [b] kDa

The hazelnut (*Corylus avellana*) allergen first identified (Cor a 1) binded IgE from 63 out of 65 patients with DBPCFC-confirmed OAS to hazelnut (Ortolani et al., 2000; Pastorello et al., 2002a). Cor a 1 and Cor a 2 are homologues of the major birch pollen allergen Bet v 1 (Hirschwehr et al., 1992). Cor a 2 shows high amino acid sequence identity (77-91 %) with other plant profilins and similar tertiary structure (Radauer et al., 2006), and has been described as a food allergen in seven of 17 hazelnut allergic patients with concomitant birch pollen allergy (Lüttkopf et al., 2002a).

Pollen-unrelated hazelnut allergy was initially described in adults from a Mediterranean region who were sensitised to the LTP Cor a 8 (Schocker et al., 2000). It was demonstrated that the primary sensitiser to Cor a 8 is the protein Pru p 3 from peach (*Prunus persica*) (Hartz et al., 2010). The limited sensitisation potential of Cor a 8 seems to be explained by the rapid lysosomal degradation during antigen processing and the lack of dominant T cell epitopes (Schulten et al., 2011).

Cor a 14 represents a second member of the prolamin superfamily that is associated with hazelnut allergy (Pastorello et al., 2002a; Garino et al., 2010). Cor a 14 bound IgE from 5 out of 15 patients (Garino et al., 2010). Clinical, demographic and epidemiological data on sensitisation to Cor a 14 remain limited.

Severe forms of hazelnut allergy are related to two allergens of the cupin superfamily: Cor a 9 (11S legumin) and Cor a 11 (7S vicilin). Reactivity to Cor a 9 was demonstrated in 12 out of 14 patients with systemic reactions (Beyer et al., 2002b) and in four out of seven patients with severe hazelnut allergy (Hansen et al., 2009). Sensitisation to Cor a 9 can appear in very young infants prior to tree pollen sensitisation and independently from sensitisation to its homologues in legumes like soy or peanut (Verweij et al., 2011). IgE-binding to Cor a 11 was found in 31 of 65 adult patients with hazelnut OAS (Lauer et al., 2004). Sensitisation to Cor a 11 was seen in 12 of 32 of children with systemic reactions to hazelnut and only in one out of eight adult patients (Verweij et al., 2012).

The role of Cor a 12 and Cor a 13, two oleosins identified as hazelnut allergens, remain to be established (Akkerdaas et al., 2006).

17.3.2. Walnut

Walnut allergens are listed in Table 12. Only Jug r 1, Jug r 2 and Jug r 3 are reported in the IUIS database.

Table 12: Walnut allergens

***Scientific name* (common name)**	**Allergen**	**Biochemical name**	**Superfamily/family**	**Molecular weight[a]**
Juglans regia (English walnut)	Jug r 1	2S albumin	prolamin	14
	Jug r 2	vicilin	cupin	44
	Jug r 3	ns-LTP 1	prolamin	9
	Jug r 4	11S globulin	cupin	58
Juglans nigra (Black walnut)	Jug n 1	2S albumin	prolamin	15
	Jug n 2	vicilin	cupin	56

[a] MW (SDS-PAGE)

The first allergen identified in English walnut (*Juglans regia*) was Jug r 1, a protein belonging to the 2S albumin family with its subunits joined by disulphide bridges (Teuber et al., 1998). The recombinant walnut 2S albumin was found to be a major allergen, as it was recognised by 12 of 16 patients (75 %). This protein is similar to allergens present in Brazil nut, castor bean, cottonseed, and mustard seed (Robotham et al., 2002).

Teuber et al. (1999) identified a second major allergen in walnut, a recombinant protein belonging to the vicilin-like protein family (Jug r 2). Jug r 2 binded IgE in sera from nine out of 15 walnut allergic patients (60 %). Despite its high amino acid sequence identity (70 %) with peanut vicilin Ara h 1, this allergen does not cross-react with homologous peanut proteins (Teuber et al., 1999).

Two other major walnut allergens are Jug r 3, a lipid-transfer protein, and Jug r 4, an 11S legumin-like globulin. Jug r 3 and Jug r 4 bound IgE in sera from 78 % (Pastorello et al., 2004) and from 57-65 % of walnut allergic patients, respectively (Roux et al., 2003; Wallowitz et al., 2006a). Jug r 1 and Jug r 3 appear to be the most potent allergens of walnut (Rangsithienchai et al., 2013).

The information about black walnut (*Juglans nigra*) allergens is much more limited. Two recombinant allergens were identified: Jug n 1, a 2S seed storage albumin, and Jug n 2, a vicilin seed storage protein. The Jug n 1 and 2 were found to be 96 % and 97 % identical to Jug r 1 and 2, respectively.

17.3.3. Almond

Almond (*Prunus dulcis*) allergens include Pru du 3, Pru du 4, Pru du 5, and Pru du 6 (Table 13).

Pru du 6, the most fully described almond allergen, is amandin, a legumin that forms 65-75 % of the extractable proteins in almonds (Sathe et al., 2002). Pru du 6 is hexameric, and each polypeptide comprises a large acidic α-chain and a small basic β-chain. The two chains are linked by a disulphide bond. Two isoforms have been identified: Pru du 6.01 and Pru du 6.02. Pru du 6.01 was recognised by 50 % and Prud du 6.02 by 28 % of almond allergic patients (Willison et al., 2011).

Pru du 3 consists of three isoallergens (Chen et al., 2008). It is usually accumulated in the outer epidermal layers of plant organs and is thought to be responsible for the stronger allergenicity of the peels in comparison to the inner layers of almonds (Costa et al., 2012b). Pru du 4 has $\geq$ 90 % sequence identity with profilins from a variety of plant sources, including apple, cherry, peach, orange and melon, and is cross-reactive to ryegrass pollen profilins (Rodríguez-Perez et al., 2003; Tawde et al., 2006).

Pru du 5 is a 60S acidic ribosomal protein (Abolhassani and Roux, 2009). The biological function of this protein is based on the successive addition of amino acid residues to a polypeptide chain during

protein biosynthesis. It exhibits 81 % identity and 94 % homology with the protein ARP60S from tomato, which may indicate possible cross-reactivity between them (López-Matas et al., 2011).

Four other potential allergens have been identified: Pru du 1, Pru du 2, Pru du 2S albumin, and Pru du γ-conglutin (Costa et al., 2012b).

Table 13: Almond (*Prunus dulcis*) allergens

Allergen	Family	Superfamily/family	Molecular weight [a]
Pru du 3	ns-LTP 1	prolamin	9
Pru du 4	profilin	profilin	14
Pru du 5	60s acidic ribosomal prot. P2		10
Pru du 6	amandin, 11S globulin (legumin-like protein)	cupin	ca. 360

[a] MW (SDS-PAGE)

17.3.4. Cashew nut

Allergens from cashew (*Anacardium occidentale*) are listed in Table 14 and include three major allergens classified as seed storage proteins: Ana o 1, a 7S vicilin-like protein with homotrimer subunits (Wang et al., 2002), Ana o 2, an 11S globulin member of the legumin family (Wang et al., 2003), and Ana o 3, a 2S albumin (Robotham et al., 2005). Ana o 1, Ana o 2, and Ana o 3 have been recognised by the serum of 50 % (Wang et al., 2002), 62 % (Wang et al., 2003), and 81 % (Robotham et al., 2005) of patients with an allergy to cashew nut, respectively. The molecular structure of Ana o 2 closely resembles that of soybean Gy2 glycinin (Robotham et al., 2010). Ana o 3 is highly homologous to the walnut allergen Jug r 1 (Wang et al., 2003).

Table 14: Cashew nut (*Anacardium occidentale*) allergens

Allergen	Biochemical name	Superfamily/Family	Molecular weight[a]
Ana o 1	vicilin-like protein	cupin	50
Ana o 2	legumin-like protein	cupin	55
Ana o 3	2S albumin	prolamin	14

[a] MW (SDS-PAGE)

17.3.5. Brazil nut

Brazil nut allergens are listed in Table 15.

Table 15: Brazil nut (*Bertholletia excelsa*) allergens

Allergen	Biochemical name	Superfamily/family	Molecular weight[a]
Ber e 1	2S albumin (sulphur-rich)	prolamin	9
Ber e 2	11S globulin	cupin	29

[a] MW (SDS-PAGE)

Ber e 1, the first major allergen identified in Brazil nut (*Bertholletia excelsa*), is a sulphur-rich 2S albumin seed storage protein. Its immunogenicity was tested using sera from nine patients showing allergic reactions after ingestion of Brazil nut. Eight out of nine showed IgE-binding to the 2S albumin (Nordlee et al., 1996). A subsequent study confirmed that Ber e 1 was the major allergen of Brazil nut, as it was recognised by all 11 patients with documented history of anaphylactic shock or laryngeal oedema after ingestion of the nut (Pastorello et al., 1998). Ber e 1 does not trigger an allergenic response on its own, as other components of the lipid fraction are required (Mirotti et al., 2013).

Another recognised Brazil nut allergen is Ber e 2, a 11S globulin legumin-like protein that showed IgE-binding in 12 out of 27 Brazil nut sensitised patients (Beyer et al., 2002b).

17.3.6. Pecan nut

There are two pecan (*Carya illinoinensis*) allergens listed in the IUIS database (Table 16).

Table 16: Pecan nut (*Carya illinoinensis*) allergens

Allergen	Biochemical name	Superfamily/family	Molecular weight (kDa)
Car i 1	2S albumin	prolamin	16
Car i 4	legumin	pupin	55.4[a]

[a] subunit of hexameric protein

Car i 1 is a 2S albumin seed storage protein consisting of two subunits connected by a disulphide bond. IgE-binding to Car i 1 was shown in 22 out of 28 sera from patients with convincing histories of allergic reactions to pecan nut (Sharma et al., 2011b). In turn, Car i 4 is a hexameric legumin 11S seed storage protein. Each monomer consists of basic and acidic subunits linked by disulphide bonds. Car i 4 was bound by serum IgE from 16 out of 28 subjects allergic to pecan (Sharma et al., 2011a).

17.3.7. Pistachio

Pistachio (*Pistacia vera*) allergens are listed in table 17.

Table 17: Pistachio (*Pistacia vera*) allergens

Allergen	Biochemical name	Superfamily/family	Molecular weight[a]
Pis v 1	2S albumin	prolamin	7
Pis v 2	11S globulin subunit	cupin	32
Pis v 3	vicilin	cupin	55
Pis v 4	MnSOD	-	25.7
Pis v 5	11S globulin subunit	cupin	36

[a] MW (SDS-PAGE); MnSOD = manganese superoxide dismutase

Pis v 1, which belongs to the 2S albumin family, shows structural similarity to cashew allergens with 64 % sequence identity to Ana o 3 and 48 % to Ana o 2 (Wang et al., 2003; Robotham et al., 2005). Pis v 2, a 11S globulin, has similar sequence homology with Jug r 4 of English walnut (50 %), Cor a 9 of hazelnut (47 %) and Ber e 2 of Brazil nut (46 %) (Beyer et al., 2002b; Wallowitz et al., 2006a). Nineteen out of 28 patients with pistachio allergy showed IgE-binding to Pis v 1 and 14 out of 28 (50 %) to Pis v 2 (Ahn et al., 2009).

Pis v 3 is a 7S vicilin-like protein (Willison et al., 2008). Pis v 4 is a manganese superoxide dismutase (MnSOD)-like protein (Ayuso et al., 2007), and Pis v 5 is an 11S globulin acidic subunit (Ahn, 2007). They are all recognised as minor pistachio allergens, showing IgE-binding in 7 out of 19 patients (Willison et al., 2008), and 10 out of 25 patients (Noorbakhsh et al., 2010a), respectively.

17.3.8. Chestnut

European chestnut (*Castanea sativa*) allergens are shown in Table 18.

Table 18: Chestnut (*Castanea sativa*) allergens

Allergen	Biochemical name	Superfamily/family	Molecular weight[a]
Cas s 1[1]	PR-10	Bet v 1 (profilin)	22
Cas s 5	chitinase	(hevein-like domain)	-
Cas s 8	ns-LTP 1	LTP	12 – 13
Cas s 9	cytosolic heat shock protein	(heat shock protein)	17[b]

[1] Not included in the IUIS database; [a] MW (SDS-PAGE); [b] kDa

Cas s 5 is a chitinase, which contains an N-terminal domain with homology to the hevein-like domain of rubber latex hevein. By analysing recombinant Cas s 5 with and without the N-terminal hevein-like domain, it was shown that the majority of the Cas s 5-reactive IgE from patients with the latex-fruit allergy syndrome was directed to this domain, though some evidence for reactivity with the C-terminal catalytic domain was also found (Diaz-Perales et al., 1998). These findings explain why many chestnut allergic individuals are also allergic to latex (Raulf-Heimsoth et al., 2007).

Studies regarding other chestnut allergens are less common. Cas s 1 is a pollen protein, which shows significant amino acid sequence similarity at the N-terminus with the major birch pollen allergen Bet v 1 and is antigenically closely related to it (Kos et al., 1993). Cas s 8, a member of the lipid transfer protein (LTP) family, has 53 % identity to apple Mal d 3 and 50 % identity to peach Pru p 3 fruit allergens (Lee et al., 2005; Sánchez-Monge et al., 2006). Six out of nine patients (66 %) sensitised to chestnut but not to latex had positive SPT response to Cas s 8 (Blanco et al., 2006).

Cas a 9 is useful to identify patients with systemic reactions, which are more common in children (De Knop et al., 2011; Verweij et al., 2011).

17.3.9. Macadamia and Queensland nut

There are no designated allergens for macadamia (*Macadamia integrifolia*) and Queensland nut (*Macadamia ternifolia*) to date although strong serum IgE-binding to a protein of 17.4 kDa from both raw and roasted extracts of macadamia has been reported (Sutherland et al., 1999).

17.4. Cross-reactivities

17.4.1. Cross-reactivity among nuts and between nuts and peanuts

Allergy to nuts is almost exclusively induced by non pollen-mediated food sensitisation. Only allergy to hazelnut can be due to sensitisation to birch pollen or, less frequently, to mugwort pollen (Hirschwehr et al., 1992; Caballero et al., 1997).

Allergy to nuts is characterised by a high frequency of life-threatening anaphylactic reactions, so when allergy to a single nut is demonstrated, the patient is often advised to avoid the entire nut group. It is estimated that 20-50 % of peanut allergic patients are also allergic to tree nuts (Ewan, 1996; Sicherer et al., 2003).

It is still disputed if cross-reactivity between peanuts and tree nuts is related to taxonomic proximity or rather results from structural homology of IgE-binding epitopes present in several tree nuts and peanuts (Wallowitz et al., 2004; Maleki et al., 2011). Studies on cross-reactivity among nuts and between nuts and peanuts include mainly *in vitro* studies, but there are some studies on IgE-binding and clinical studies.

Peanut-specific IgE antibodies that cross-react with tree nut allergens and may contribute to the manifestation of tree nut allergy in peanut allergic subjects have been identified (de Leon et al., 2005). The structurally related cross-reactivity between Ara h 3 and tree nut allergens such as Jug r 4 of walnut, Cor a 9 of hazelnut, or Ana o 2 of cashew nut appears to be unrelated to the botanical origin of the allergens and suggests that individuals allergic to peanut should avoid tree nuts, unless the allergy status in relation to all other nuts is clarified (Barre et al., 2007; Ball et al., 2011).

Cross-reactivities among tree nuts are mostly related to botanical family associations (Hasegawa et al., 2009; Noorbakhsh et al., 2011), although some studies reported IgE cross-reactivity among nuts not showing taxonomic relationship (de Leon et al., 2003). It has been proposed grouping of tree-nuts into cross-reacting groups (Goetz et al., 2005). Walnut, pecan nut, and hazelnut, which are members of the same botanical subclass, form a strongly cross-reactive group, whereas walnut and pecan nut, which are members of the same *Juglandaceae* family, showed the strongest cross-reactivity. Also cashew

and pistachio, which showed strong cross-reactivity, are both members of the botanical family *Anacardiaceae*.

17.4.2. Cross-reactivity between nuts and other foods

The major hazelnut allergen Cor a 1 was demonstrated to be cross-reactive with the birch pollen major allergen Bet v 1 (Hirschwehr et al., 1992). The 18 kDa allergens from hazelnut kernel and hazel pollen were cloned and tested using sera from 43 patients with positive DBPCFC to hazelnut (Lüttkopf et al., 2002b). Four recombinant variants of the major hazelnut allergen Cor a 1.04 were synthesised. These variants showed only 63 % identity and partial IgE cross-reactivity with the major hazel pollen allergen Cor a 1.01, but 85 % identity with the major birch pollen allergen Bet v 1. This suggests that the epitopes of hazelnut Cor a 1.04 are less related to hazel pollen than to birch pollen. The presence of specific IgE to Cor a 1 identifies patients with birch pollen allergy, which is more common among hazelnut-sensitised adults.

In Northern Europe, where birch pollen allergy is common, most cases of hazelnut allergy develop secondarily to birch pollen allergy because of an immunological cross-reactivity between birch and hazelnut. In contrast, in Southern Europe, where birch pollen allergy is rare, hazelnut allergy is more often a primary allergy.

The hazelnut profilin Cor a 2 also displays cross-reactivity with a birch pollen homologous allergen, but the clinical relevance of this immunological cross-reactivity seems, however, low (Hirschwehr et al., 1992; Wensing et al., 2002a).

Latex-fruit syndrome represents a well known phenomenon of cross-reactivity caused by the presence of chitinase I both in latex (known as hevein Hev b 6.02; Hev b 11) and several food products (especially fruits), although other allergens may be involved. Chitinase I is present also in chestnut (Cas s 5) and shares common epitopes with natural latex antigens, which can explain sensitisation to chestnut in subjects allergic to latex (Blanco et al., 1999; Diaz-Perales et al., 1999; Sánchez-Monge et al., 2000; Blanco, 2003).

Four important nut allergens belong to a family of lipid transfer proteins (LTP): Pru du 3 of almond, Cas s 8 of chestnut, Cor a 8 of hazelnut, and Jur r 3 of walnut. Owing to structural homology, LTPs from different allergen sources are generally IgE cross-reactive. A high degree of IgE cross-reactivity has been observed among allergenic LTPs within the *Rosaceae* family, and particularly with the peach allergen Pru p 3, which possesses more epitopes and/or epitopes with higher IgE-binding affinity compared with other LTPs. Peach represents a primary sensitiser to LTPs (Egger et al., 2010) and the level of specific IgE to peach LTP seems to be a main factor associated with cross-reactivity to other plants, including nuts (Asero, 2011).

17.5. Possible effects of food processing on allergenicity and derived products

Nuts are often subjected to a variety of processing conditions, which may affect their allergenic potential.

17.5.1. Thermal processing

Hazelnut, which is often used in pastries, partially loses its allergenicity after roasting. One study investigated the IgE-binding pattern of raw and roasted hazelnut (Pastorello et al., 2002a) and found that the major allergen Cor a 1 loses its IgE-binding capacity in roasted hazelnut, while the minor allergen LTP, recognised by a distinct subset of patients without birch pollinosis, was heat-resistant. However, 5 out of the 17 patients sensitised to Cor a 1.04 who underwent a DBPCFC with roasted hazelnut reacted with mild OAS to the challenge (Hansen et al., 2003), whereas in another clinical study, a decreased allergenicity of roasted hazelnut compared to raw hazelnut was observed in patients with birch pollen allergy during an oral challenge (Worm et al., 2009). This suggests that roasting can decrease, but not abolish, clinical reactions to hazelnut in birch pollen allergic patients sensitised to Cor a 1.04. This is supported by the observation that thermal processing results in partial or complete

depletion of the stimulatory activity of basophils only in some subjects with systemic allergic reactions to hazelnut (Cucu et al., 2012c). Similarly, in a DBPCFC heat-processed (roasted) hazelnut and native hazelnut were given orally in increasing amounts. The dosage by which allergic reactions were elicited varied from 0.01 to 2.0 g for native hazelnut, with a median of 0.1 g, and from 0.01 to 10.0 g for roasted hazelnut, with a median of 0.23 g (Worm et al., 2009). *Ex vivo* basophil activation measured by flow cytometry showed that significantly higher allergen extract concentrations were needed to induce 50 % basophil activation in roasted vs. native hazelnut.

Contrary to hazelnut, allergen Ber e 1 belonging to the prolamin superfamily present in Brazil nut is inherently stable to thermal treatment (Venkatachalam et al., 2008).

The IgE-binding capacity assessed by ELISA and Western blot assays was significantly lower for the protein extract prepared from steam-roasted than from raw and dry-roasted pistachio nuts (Noorbakhsh et al., 2010b).

A meta-analysis based on the results of 32 individual studies found that thermal processing may reduce the IgE-binding capacity of proteins of the PR-10 family present in hazelnut (Cor a 1) and almond (Pru du 1), but has a little influence on the allergens belonging to LTPs and seed storage proteins in hazelnut, almond, cashew, Brazil nut, walnut, pecan and pistachio (Masthoff et al., 2013).

In some cases thermal treatment may enhance the allergenicity of nuts. This was observed in pecan nut, which develops new allergens upon heating as a result of the Maillard reaction (Berrens, 1996). These modifications have a clinical significance: an anaphylactic reaction to cooked pecan nuts was reported by a patient who showed specific IgE antibodies exclusively against allergenic determinants present in aged or heated pecan, but not in fresh pecans (Malanin et al., 1995). On the contrary, Maillard reaction decreases the IgE and IgG binding properties of the hazelnut allergen Cor a 11 (Iwan et al., 2011).

17.5.2. Other treatments

Antigenic stability of proteins in several nuts subjected to various processing methods, including γ-irradiation alone or in combination with blanching, pressure cooking, oven roasting, frying, and microwave heating, was demonstrated using Western blotting and ELISA (Su et al., 2004). While heat processing may inactivate certain structural epitopes of hazelnuts, such treatments are unlikely to affect the allergenicity of almonds, cashew nuts and walnuts. In aqueous solutions with pH values between 5.0 and 7.0 and high pressure, a temperature exceeding 110 ^{o}C is needed to denature Ber e 1, the major allergen of Brazil nut (van Boxtel et al., 2008).

Enzymatic treatments can also influence the allergenicity. It has been shown that treatment with trypsin or elastase decreases the IgE-binding capacity of hazelnuts (Wigotzki et al., 2000). High stability to pepsin digestion has been shown in relation to Ber e 1, an allergen present in Brazil nut (Moreno et al., 2005). Opposed to this, mice sensitised to cashew and then undergoing provocation challenges with pepsin-digested cashew proteins showed less severe allergic reactions compared to native cashew proteins (Kulis et al., 2012). Pepsin and trypsin destroy IgE-binding of Bet v 1-related food allergens (including hazelnut allergen Cor a 1.04) but not their T-cell activating properties (Schimek et al., 2005).

There is only limited information available about influence of different methods used for preparation of nut oils on their allergenicity. Teuber et al. (Teuber et al., 1997) examined a range of nut oils (walnut, almond, hazelnut, pistachio, and macadamia) finding that oils that had undergone less processing at lower temperatures tended to demonstrate higher protein concentration. Those oils with most protein and least processing tended to demonstrate the strongest IgE-binding within each group of nut oil extracts.

Despite several effects of processing on the antigenicity of nut allergens, nuts are generally considered as relatively resistant to processing.

17.6. Detection of allergens and allergenic ingredients in food

17.6.1. Immunological methods

Different ELISA assays (sandwich, competitive) have been described for the detection of nut allergens with high sensitivity and LOD as low as 0.1 mg/kg. Numerous kits are commercially available (Poms et al., 2004a; Schubert-Ullrich et al., 2009; Fielder et al., 2010). All tests provide quantitative results, based on in-house reference materials, and present variable cross-reactivity among nuts. Matrix effects and food processing may also affect the detection of nut allergens by ELISA (Garber and Perry, 2010). Lateral flow devices and dipsticks are also commercially available and mostly used for screening purposes (Schubert-Ullrich et al., 2009; Fielder et al., 2010).

17.6.1.1. Hazelnut

Many ELISA methods have been developed for hazelnut by using monoclonal or polyclonal antibodies against raw or processed foods (Holzhauser and Vieths, 1999; Koppelman et al., 1999; Blais and Phillippe, 2001; Scheibe et al., 2001; Stephan et al., 2002). Commercial products containing hazelnuts have been tested, including chocolate (Ben Rejeb et al., 2003). The performance of four commercial ELISA kits was compared in the presence or absence of wheat proteins in processed foods (Cucu et al., 2011). A significant loss of accuracy was observed for three of the four kits as result of the Maillard reaction.

A sandwich ELISA with a LOD of 0.7 ng/mL in the range of 1-2.5 µg of hazelnut protein/g of food (Akkerdaas et al., 2004), and a hazelnut-specific indirect competitive ELISA based on polyclonal chicken antibodies raised against processed hazelnut proteins (Cucu et al., 2012d), with a LOD of 1.36 µg/mL, have been proposed.

Another sandwich ELISA operating in optical and electrochemical modes and targeting the allergen Cor a 9 was devised (Trashin et al., 2011), with a LOD of 4 ng/mL or 0.1 µg of hazelnut protein/g of food. A time-resolved fluoroimmunoassay (TRFIA) for the detection of hazelnut protein traces in food matrices has been developed and validated (Faeste et al., 2006), with a LOD of 0.1 mg/kg and a LOQ of 0.33 mg/kg. A sensitive biosensor based on a highly specific monoclonal antibody is able to detect hazelnut proteins in olive oil (Bremer et al., 2009).

17.6.1.2. Walnut

ELISA kits are available for the detection of walnut soluble proteins in processed foods with a LOD of 0.39 ng/mL, corresponding to 0.156 µg of walnut soluble protein/g of food (Doi et al., 2008). Mild cross-reactivity with pecan and hazelnut was observed. An ELISA test was built to detect raw and roasted walnut allergens with a LOD of 1 µg/g in several matrices (Niemann et al., 2009). Substantial cross-reactivity was observed with pecan. The performance of a walnut ELISA kit in processed foods was evaluated in an inter-laboratory study by analysing incurred samples with 10 µg of walnut soluble protein/g of food. The results obtained were reliable (Sakai et al., 2010).

17.6.1.3. Cashew nut

A sandwich ELISA for the detection of anacardein (i.e. the predominant cashew nut protein fraction) with previous immune-adsorption showed good specificity when tested against several nuts and seed proteins potentially cross-reactive (Wei et al., 2003). The LOD was 1µg/g of food in processed food products. A more recent ELISA test with the same LOD but substantial cross-reactivity with pistachio and, to a lesser extent, with hazelnut, has also been published (Gaskin and Taylor, 2011).

17.6.1.4. Brazil nut

An indirect competitive ELISA for the detection of Brazil nut in food based on polyclonal antibodies rose against the 2S albumin, with a LOD of 1µg/g, showed negligible cross-reactivity with other nuts and legumes (Clemente et al., 2004). A polyclonal competitive inhibition ELISA has been proposed for detecting the other major Brazil nut allergen 11S globulin (Sharma et al., 2009). The LOD was 10-

90 ng/mL. A remarkable food matrix effect, which affected protein recovery from spiked samples, was observed.

In order to avoid raising antibodies from animals, probes were produced *in vitro* by isolation of recombinant antibodies specific for the Brazil nut protein and used in an indirect phage-ELISA (de la Cruz et al., 2013). For Brazil nut protein extracts the LOD was 0.9 µg/mL and the LOQ 1.2 µg/mL. The sensitivity of the assay slightly increased for the detection of roasted Brazil nuts (LOD 0.4 µg/mL, LOQ 0.6 µg/mL). In a binary mixture model with wheat flour, the LOD and LOQ were established at 5 and 20 mg/g on account of strong matrix interferences.

17.6.1.5. Pecan nut

Only an ELISA method for detecting pecan proteins in the range of 32-800 ng/mL (Venkatachalam et al., 2006) and a more sensitive ELISA with a LOD of 1 ng/mL in complex matrices (Polenta et al., 2010), which showed extense cross-reactivity with walnut, have been described.

17.6.1.6. Almond

ELISA, lateral flow devices, dipsticks and biosensors are commercially available immunological methods for detection of almonds (Costa et al., 2012b). These tests are generally rapid and sensitive, with a LOD of 0.1 mg/kg of almond protein in food samples for ELISAs and 1 mg/kg for LFDs (Schubert-Ullrich et al., 2009).

17.6.1.7. Multiplex immunoassays

A multiresidue enzyme immunoassay (under a competitive indirect format) was developed for the simultaneous detection of four tree nuts (hazelnut, almond, cashew and Brazil nuts) and peanuts in a single run (Ben Rejeb et al., 2005). The LOD was < 1 µg/g of protein for all allergenic ingredients. The method was applied to chocolate samples.

The performance of three commercial sandwich ELISA kits for the detection of almonds was compared (Garber and Perry, 2010). The LOD for almonds spiked into several cooked foods varied from 3 to 39 mg/kg depending on the food matrix and the ELISA kit.

17.6.2. Mass Spectrometry

17.6.2.1. Hazelnut

Determination of hazelnut has been performed by LC-MS/MS through selection and measurement of specific marker peptides. After extraction and trypsin digestion of hazelnut proteins, six peptides were identified by MS/MS as specific for hazelnut and synthesised to be used as standards for developing a LC-MS/MS method in the selected reaction monitoring mode (SRM). Depending on the peptide, the lowest concentrations determined were 3.1 or 4.2 ng/mL (Ansari et al., 2012).

17.6.2.2. Pecan

The effect of processing on detectability of pecan proteins by proteomic tools was evaluated (Polenta et al., 2012). Despite the high homology between the majority of pecan and walnut proteins, three proteins were unambiguously identified from pecan origin: 7S vicilin, 11S legumin and a putative allergen 11. Peptides from the tryptic digestion of putative allergen 11 were highly specific for pecan, allowing to detect the presence of fentomoles (or ng) of proteins with a LOQ of 2.2 ng/mL comparable with that observed with the ELISA test.

17.6.2.3. Multiplex MS methods

An LC-LIT-MS/MS method for the simultaneous detection and quantification of the five allergens Ana o 2 (cashew nut), Cor a 9 (hazelnut), Pru du 1 (almond), Jug r 4 (walnut) and Ara h 3/4 (peanut) in a single short run has been developed (Bignardi et al., 2010). The method is based on the detection

of selected specific marker peptides for every target protein. The peptide mixtures obtained from the tryptic digestion of the protein extract were separated on a particle-packed column, identified and quantified by linear ion trap (LIT) MS detection, under the SRM mode, with LODs from 10 to 55 mg/kg and LOQs of 37 to 180 mg/kg. When performing a preliminary clean up step by size-exclusion chromatography, before enzymatic digestion of the proteins, the sensitivity was highly improved for every allergen. LODs ranging from 0.1 to 1.3 mg of nut/kg for biscuits and from 5 to 15 mg of nut/kg for chocolate and LOQ values in the 0.3-4.5 mg nut/kg range for biscuits and in the 18-50 mg of nut/ kg range for chocolate were obtained (Bignardi et al., 2013).

A multi-method for the detection of seven allergens, including hazelnut, walnut and almond, based on LC-QpQ-MS/MS in MRM mode is available (Heick et al., 2011a). On the basis of selected marker peptides obtained from the tryptic digested extracted proteins, it was possible to detect the seven allergens also in incurred food samples with LOD values of 5 and 3 mg/kg for hazelnut and almond, respectively, and of 70 mg/kg for walnut.

17.6.3. DNA-based methods

PCR-based methods for nut allergen detection have been extensively reviewed (van Hengel, 2007; Monaci and Visconti, 2010).

17.6.3.1. Hazelnut

A real-time PCR method based on the Cor a 11 gene with an absolute LOD of 13 pg hazelnut DNA, corresponding to approximately 27 genome equivalents, has been proposed. When applied to model pastry samples with a defined hazelnut content, a practical detection limit of 0.01 % (w/w) hazelnut was obtained (Piknova et al., 2008). A species-specific real-time PCR protocol was devised with a LOD of 9.6 pg of hazelnut DNA, corresponding to 20 genome copies (D'Andrea et al., 2009). In flour samples spiked with known amounts of hazelnut, the LOD was 0.001 % hazelnut, corresponding to 10 mg/kg. A single-tube nested real-time PCR system allowed to decrease the LOD to 0.5 pg of hazelnut DNA, corresponding to one DNA copy (Costa et al., 2012a). A high resolution TaqMan real-time PCR for detecting hazelnut DNA with a LOD of 0.1 mg/kg of the target in food samples has also been published (López-Calleja et al., 2013). A comparative evaluation of the performance of ELISA and real-time PCR in detecting and quantifying hazelnut in food model system showed that, although ELISA appeared to be more sensitive, both techniques had matrix effects and lack of robustness when detecting hazelnut in processed foods (Platteau et al., 2011c). A duplex real-time PCR for the simultaneous detection of sesame and hazelnut had a LOD of 5 mg/kg for hazelnut has been reported (Schoringhumer et al., 2009).

17.6.3.2. Almond

Almond has been detected in foods by applying the single-tube nested real-time PCR system (Costa et al., 2013). The system allowed lowering the LOD of the conventional real-time PCR from 100 mg/kg to 50 mg/kg of spiked almond in food. The absolute LOD was 1.28 pg of almond DNA, corresponding to 3.9 DNA copies. The system showed cross-reactivity with peach and apricot, which belong to the same *Rosaceae* family and have a high homology regarding DNA encoding for the allergen Pru du 6.

17.6.3.3. Brazil nut, walnut, pistachio, pecan, macadamia and cashew nut

A specific real-time PCR method for the detection of Brazil nut in processed food was compared to a commercially available qualitative lateral flow device (Röder et al., 2010), showing a LOD $\leq$ 5 mg/kg in spiked foods.

A series of real-time PCR methods for the detection of walnut, pistachio, pecan, macadamia and Brazil nut in foods were developed by the same research group (Brežná et al., 2006; Brežná et al., 2008; Brežná and Kuchta, 2008; Brežná et al., 2009; Brežná et al., 2010). The absolute LOD were 0.24 ng DNA for walnut, 0.012 pg DNA for pistachio, 1 pg DNA for pecan nut, 1.45 pg DNA for macadamia nut, and 10 pg DNA for Brazil nut. Using a series of model pastry samples with defined nut contents,

practical LODs of 0.01 %, 0.0004 %, 0.01 %, 0.02 %, and 0.1 % for walnut, pistachio, pecan nut, macadamia nut, and Brazil nut, respectively, were estimated. A real-time PCR method for the detection of cashew nuts in confectionery was described by the same group (Piknová and Kuchta, 2007). The absolute LOD was 1.25 pg DNA, corresponding to approximately 2.5 genome equivalents. Using a model pastry sample with defined cashew nut content, a practical LODs of 0.01 % was obtained.

Another more sensitive real-time PCR system was devised with an absolute LOD of 0.5 pg genomic cashew DNA, corresponding to 10 copies DNA. The practical LOD for a pesto Genovese sauce was 2 mg/kg (Ehlert et al., 2008).

17.6.3.4. Multiplex PCR

A LOD of 0.01 % was obtained in two tetraplex real-time PCR assays to detect simultaneously eight allergens, among which hazelnut and almond (Köppel et al., 2010). In two hexaplex real-time PCR system proposed by the same group (Köppel et al., 2012), DNA of 12 allergenic foods among which cashew, hazelnut, almond, pistachio and walnut, were detected with an LOD of 0.1 % for all analytes. Detection of cashew nut, pecan nut, pistachio, hazelnut, macadamia nut, almond, walnut and brazil nut by employing a multiplex ligation-dependent probe amplification (MLPA) method was obtained with a LOD of 5 mg/kg for each allergenic ingredient (Ehlert et al., 2009). By using the same method, hazelnut DNA was detected with a LOD of 1.4 ng, corresponding to 105 DNA copies (Mustorp et al., 2011). In a multiplex real-time PCR for detecting DNA of allergens in foods, the LOD was of 5 pg for almond, hazelnut and peanut and 0.5 pg for cashew, walnut and sesame (Pafundo et al., 2010).

17.6.3.5. PCR coupled to other techniques

An electrochemical low-density DNA array coupled to PCR has been devised, with a LOD of 0.3 and 0.1 nM for Cor a 1.03 and Cor a 1.04, respectively. A PNA-array was used in combination with a duplex PCR for the simultaneous detection of hazelnut and peanut with a LOD of 50 pg DNA (Rossi et al., 2006).

17.7. Minimal (observed) eliciting doses

Nut-induced fatalities have been described after the ingestion of foods apparently free from nuts (Ortolani et al., 2000; Wensing et al., 2002a), suggesting that even little amounts may elicit severe allergic reactions.

Few studies have been performed to determine minimum observed eliciting doses (MOED) for nuts and are limited to hazelnut and cashew nut.

In a European multicentre study (Italy, Switzerland and Denmark), DBPCFCs were performed in 86 subjects with clinical history of hazelnut allergy, positive SPT and specific IgE (Ortolani et al., 2000). Of these, 67 (77.9 %) reacted to the food challenge, which started with 1.4-1.5 g (about one hazelnut) in Italy and Denmark and with 2.7 g in Switzerland. Doses were doubled every 10-15 minutes. Mean eliciting doses ranged from 1.4 g in Denmark and 2.7 g in Switzerland (first dose tested) to 15.3 g in Italy. Minimal eliciting doses in Italy were not reported. In this study, eliciting doses were apparently unrelated to the severity of symptoms.

In a DBPCFC study on 29 hazelnut allergic patients 3-17 years of age, doses eliciting subjective reactions varied from 1 mg to 100 mg of hazelnut protein (equivalent to 6.4-640 mg of hazelnut meal), while objective symptoms were observed in two patients after 1 and 1000 mg of protein, respectively (Wensing et al., 2002a). As for cashew nut, the MOED in a DBPCFG with 31 cashew allergic children was 2.3 mg of protein (Blom et al., 2013).

Data from DBPCFCs shows that minimal doses of nuts eliciting allergic reactions in susceptible individuals may be below 1 mg of protein.

17.8. Conclusion

Nuts are common trigger of systemic allergic reactions, which can be life, threatening. Clinical cross-reactivities among nuts and between nuts and peanuts are frequent, as well as between hazelnut and birch pollen. Prevalence of nut allergy among the general population varies depending on the nut. Prevalence rates of 2.2 % based on clinical history and food challenges have been reported for hazelnut. Nut allergens are generally resistant to processing, although thermal treatments may reduce the IgE-binding capacity of PR-10 in hazelnut and almond. Many sensitive ELISA, MS, and PCR methods are available for the detection of nut allergens. ELISA kits may present serious cross-reactivities among nuts. Data from DBPCFCs shows that minimal doses of nuts eliciting allergic reactions in susceptible individuals may be below 1 mg of protein.

18. Allergy to peanuts

18.1. Background

Peanut (*Arachis hypogea*) is a member of the legume family, which also includes pea, bean, soybean, lupin, lentil and fenugreek. Peanut consumption has increased during the last decades because of its content of easily digested proteins and its versatility. It can be consumed raw as a vegetable, crushed or ground as "butter", roasted or salted as snack, incorporated into candies, and used to produce oil, extracted by solvents or pressure. The wide uses of peanuts and derived products in processed foods make inadvertent exposure frequent. For example, peanut butter is often used in restaurants to harden soft foods or to "glue down" and close egg rolls; peanuts that have been pressed, deflavoured and reflavoured are sold as e.g. walnuts or almonds (Loza and Brostoff, 1995).

18.2. Epidemiology

18.2.1. Prevalence

Peanut allergy is one of the most common forms of IgE-mediated reactions to food.

18.2.1.1. Europe

Studies on the prevalence of peanut allergy and sensitisation to peanut in unselected populations have been conducted in 10 European countries, including Denmark, France, Germany, Hungary, Iceland, Norway, Sweden, The Netherlands, Turkey and the UK. There is much variation in the type of data available regarding the age ranges considered and the methods used for diagnosis, which makes difficult comparisons among studies (University of Portsmouth, 2013).

The highest prevalence rate of self-reported peanut allergy (15 %) was observed in a group of 15-17 year old French children(Touraine et al., 2002), whereas the lowest, which was close to zero, was observed among 18 month old young children in Iceland (Kristjansson et al., 1999).

Studies on the prevalence of sensitisation to peanut were based on positive SPT and/or serum specific IgE levels. In young children (0-3 years old), rates of positive SPT ranged from 0.4 % (Venter et al., 2008) to 2.8 % (Ro et al., 2012). In older children (> 3 years) prevalence of positive SPT ranged from 0.7 % (Mustafayev et al., 2012) to 5.1 % (Nicolaou et al., 2010). Rates of positive SPT in adults were between 6.4 % (Bakos et al., 2006) and 6.8 % (Schafer et al., 2001). For specific IgE levels, the only study from Norway in young children reported a prevalence of sensitisation of 3.4 % (Ro et al., 2012), whereas in older children the prevalence of sensitisation ranged between 2.6 % (Krause et al., 2002) and 12.2 % (Nicolaou et al., 2010). The latter study used a low cut-off point for determining sensitisation (0.2 kU/L), which may explain the higher sensitisation rates observed. The rate of sensitisation determined by SPT in the same study was much lower (5.1 %). In adults, sensitisation rates to peanut were between zero (Bakos et al., 2006) and 3.1 % (Bjornsson et al., 1996) when serum specific IgE levels were used for diagnosis.

The prevalence of peanut allergy based on OFC was zero (95 % CI: 0.0-4.2%) in the young children in Denmark (Osterballe et al., 2005) and ranged from 0.1 % in Turkey (Mustafayev et al., 2012) to 1.4 % in the older children in the UK (Grundy et al., 2002). No data based on OFC are available in adults.

Data on the prevalence of peanut allergy in young children using DBPCFC are not available. In older children, it ranged from zero in Turkey (Orhan et al., 2009) to 1.8 % in the UK (Hourihane et al., 2007).

18.2.1.2. Outside Europe

More than 50 studies on the prevalence of sensitisation to peanut and peanut allergy have been conducted in different countries outside Europe, mainly in the US. Again, the use of very diverse methods of diagnosis of peanut allergy makes the comparison among studies difficult. The rates of peanut allergy based on self-reports ranged from zero (Oh et al., 2004) to 8.4 % (Greenhawt et al., 2009). Sensitisation rates based on positive SPT ranged from 0.3 % (Hu et al., 2010) to 8.6 % (Arbes et al., 2005), and on specific IgE levels between 7.6 % (Liu et al., 2010a) and 13.5 % (Kumar et al., 2011). Lower rates were reported when clinical history and positive SPT were used for diagnosis, ranging from zero (Dalal et al., 2002) to 0.4 % (Woods et al., 2002). Only one study outside Europe used OFC and reported a prevalence of peanut allergy of 2.9 % in a group of Australian children 12-15 months old (Osborne et al., 2011).

18.2.2. Natural history

It was considered for a long time that no oral tolerance to peanut developed in peanut allergic patients. However, some individuals outgrow their peanut allergy (Hourihane et al., 1998). In one study, peanut allergy had resolved in 18 % of individuals participating in oral peanut challenges. The chances of negative results on a challenge despite clear reactions in the past are increased in subjects who do not have allergies to other foods at the time of the challenge. In another study, 21.5 % of individuals aged 4 to 20 years with a serum peanut-specific IgE level < 21 kIU/L who underwent oral food challenges did not develop a reaction, likely indicating resolution of their allergy (Skolnick et al., 2001).

Based on data from several studies, it is estimated that 20 % of peanut allergic children will outgrow their peanut allergy later in life. Peanut-specific IgE levels can be used to decide which patients with peanut allergy should be considered for a formal OFC (Fleischer et al., 2003). However, peanut allergy may also recur after resolution. A recurrence rate of approximately 8 % was determined in patients who outgrew their peanut allergy (Fleischer et al., 2004).

18.2.3. Time trends

Three sequential cohorts of children (age 3-4 years) born in the same geographical area (Isle of Wight, UK) were assessed for peanut sensitisation and peanut allergy. Cohort A included children born in 1989 (Tariq et al., 1996) and was assessed at four years of age (n = 981). Cohort B included children born between 1994 and 1996 (Grundy et al., 2002) and was assessed between three and four years of age (n = 1246). Cohort C included children born in 2001-2002 (Venter et al., 2008) and was assessed at three years of age (n = 642). Peanut sensitisation was defined by a positive SPT to peanut, whereas peanut allergy was defined by a positive OFC in patients with a positive SPT or with history of immediate systemic reaction. Peanut sensitisation increased significantly from 1.1 % (95 % CI: 0.7-2.3 %) in Cohort A to 3.3 % (95 % CI: 2.4-4.5 %) in Cohort B (p = 0.001) before falling back to 2.0 % (95 % CI: 1.1-3.5 %) in Cohort C (p = 0.145 as compared to cohort B). Similarly, peanut allergy increased from 0.5 % (95 % CI: 0.2-1.1 %) in Cohort A to 1.4 % in Cohort B (p = 0.023), with a subsequent fall to 1.2 % (95 % CI: 0.6-2.3 %) in Cohort C (p = 0.850 as compared to cohort B).

A prospective study conducted in Olmsted County, Minnesota, indicated an increase of more than 3-fold in the annual incidence of peanut allergy, namely from 2.05 cases per 10,000 children in 1999 to 6.88 cases per 10,000 children in 2007 (Rinaldi et al., 2012). The prevalence of peanut allergy in children in 2007 was 0.65 %. Incident peanut allergy was defined as a positive history of IgE-mediated type 1 reaction to peanuts and at least one of the following criteria: a positive blood test (specific IgE

> 0.35 kU/L), a positive SPT (≥ 3.0 mm), a positive food challenge.

Even if the study conducted in the US indicates an increase in the prevalence of peanut allergy in the past years, the Panel considers that the available data do not allow concluding on whether the prevalence of peanut allergy has changed in the UK between 1993 and 2005 and no data are available from other European countries.

18.2.4. Severe reactions/anaphylaxis

Peanut is the most common cause of severe or fatal food-induced anaphylaxis. The most severe reactions have been observed in subjects with asthma. In an American registry of fatal food-induced anaphylaxis, 37 of the 63 fatalities recorded in a 12-year period were caused by peanut (Bock et al., 2001, 2007). In the UK, 10 out of 37 fatalities to food recorded from 1992 to 1998 were caused by peanut (Pumphrey, 2000). A two-year prospective study in a paediatric population in the UK described three deaths (none caused by peanut) and 55 severe or near fatal food allergic reactions, 10 of which caused by peanut (Macdougall et al., 2002).

18.2.5. Factors affecting prevalence of peanut allergy

Allergy to peanuts manifests very early in life. According to a voluntary registry (Sicherer et al., 2001), 89 % of peanut allergic subjects are younger than 18 years of age (median age 5 years). Most children experience their first allergic reaction to peanuts at a median age of 14 months, which occurs during the first known exposure in 74 % of them. The high incidence of peanut allergy in very young children who do not frequently consume this food suggests the potential role of foetal and infant (through breast milk) exposure to allergens ingested by the mother (Vadas et al., 2001) or even skin application of peanut oil-containing ointment in children with eczema (Lack et al., 2003). The relationship between maternal peanut intake during pregnancy or lactation and allergic disease development in children is controversial.

Two studies in the UK suggest that early oral exposure (< 12 months) to peanuts may decrease the frequency of peanut allergy (Du Toit et al., 2008), while early non-oral exposure may have the opposite effect (Fox et al., 2009). Prospective studies in infants at high risk for food allergy are lacking.

18.3. Identified allergens

Peanut kernels contain over 50 different types of proteins (about 23-27 % protein by weight), 19 of which bind IgE from sera of peanut allergic subjects (Clarke et al., 1998). Peanut allergens are shown in Table 19.

Ara h 1 and Ara h 2 were identified and characterised in the early 1990s (Burks et al., 1991b; Burks et al., 1992b) and are the most extensively studied. Ara h 1, Ara h 2, and Ara h 3 are considered the major peanut allergens (Burks et al., 1998), as well as Ara h 6 in some studies (Flinterman et al., 2007).

Ara h 1 is a 7S globulin (vicilin) which belongs to the cupin superfamily, whereas Ara h 2, 6 and 7 are 2S albumins (conglutin) which belong to the prolamin superfamily. Ara h 2 has high sequence homology with Ara h 6. As a result of their stability to heat and gastrointestinal digestion, many allergens of the prolamin superfamily may account for severe allergic reactions. Ara h 3 and Ara h 4 are nearly identical isoforms and are 11S globulins (legumins) of the cupin superfamily. Ara h 4 is considered an isoform (Ara h 3.02) of Ara h 3. Ara h 6 and Ara h 7 show a low amino acid sequence identity to each other and to the other peanut conglutin Ara h 2, even though the three proteins belong to the same 2S albumin family. Ara h 6 seems to be responsible for severe allergic reactions (Becker et al., 2001). Ara h 5 belongs to the profilin family. Profilins show high sequence homologies even if from distantly related plants and are known panallergens involved in cross-reactions between pollen and plant foods (Radauer and Breiteneder, 2007). Ara h 8 is a pathogenesis-related protein (PR)-10

and it is of relevance to peanut allergic patients with birch pollen allergy because of the cross-reactivity to the homologous Bet v 1 allergen (Mittag et al., 2004a). Ara h 9 is a ns-LTPs. Ara h 10 and 11 (oleosins) have more recently been recognised. Allergenic oleosins are found in legumes, nuts, and seeds.

Different immunological patterns of peanut allergy have been observed. For instance, peanut-allergic patients are commonly sensitised to Ara h 1, Ara h 2, and/or Ara h 3 in the USA, to Ara h 9 in Spain and to Ara h 8 in Sweden. This demonstrates heterogeneity in the immunological phenotype of peanut allergy in different geographical areas (Vereda et al., 2011b).

Table 19: Peanut (*Arachis hypogea*) allergens

Allergen	Biochemical name	Superfamily/family	Molecular weight[a]
Ara h 1	7S globulin (vicilin-type)	cupin	64
Ara h 2	conglutin (2S albumin)	prolamin	17
Ara h 3	11S globulin (legumin)	cupin	60.34 (fragment)
Ara h 5	profilin	profilin	15
Ara h 6	conglutin (2S albumin)	prolamin	15
Ara h 7	conglutin (2S albumin)	prolamin	15
Ara h 8	PR-10	Bet-v1	17
Ara h 9	ns-LTP	prolamin	9.8
Ara h 10	oleosin	oleosin	16[b]
Ara h 11	oleosin	oleosin	14[b]
Ara h 12	defensin	-	8 kDa (reducing), 12 kDa (non reducing), 5.184 kDa (mass)
Ara h 13	defensin	-	8 kDa (reducing), 11 kDa (non reducing), 5.472 kDa (mass)

[a] MW (SDS-PAGE); [b] kDa

18.4. Cross-reactivities

18.4.1. Cross-reactivity between peanuts and other legumes

Peanut has structurally homologous proteins and share common epitopes with other members of the legume family such as peas, beans, clover, lupin and lentils (Vereda et al., 2011b). Peanut allergic patients show extensive serologic cross-reactivity with members of the legume family (Jensen et al., 2008). Studies demonstrated that 38 % to 79 % of subjects with clinical reactions to a single legume showed IgE-binding (positive SPT/RAST) to a variety of legumes (Sicherer, 2002). This will not necessarily lead to clinical reactions. In a study using oral challenges, only 5 % of patients with peanut allergy had a positive clinical challenge to more than one legume (Sicherer, 2002).

18.4.1.1. Lupin

β-conglutin (Lup an 1) was the major lupin allergen cross-reacting with peanut proteins, as observed in IgE binding and SPT studies in peanut allergic individuals (Ballabio et al., 2013).

Significant sequence and molecular homology between Ara h 8 and the pathogenesis related protein PR-10 of white lupin suggests that these proteins could in part be responsible for some of the reported cross-reactivities in peanut allergic individuals (Guarneri et al., 2005).

A large study performed in France and Belgium showed that 14.5 % of adults and 17 % of children with peanut allergy had cross-sensitisation with lupin (Gayraud et al., 2009). A study performed in the UK showed that sensitisation to lupin was observed significantly more often in peanut allergic children and teenagers (34 %) than in non peanut-allergic patients (4 %) (Shaw et al., 2008).

Cross-reactivity to lupin in peanut allergic patients is of clinical relevance. In a study of 24 peanut allergic subjects, 11 (44 %) had positive SPTs to lupin flour and seven out of the eight subjects who underwent a DBPCFC with lupin flour reacted, indicating clinical cross-reactivity between peanut and lupin (Moneret-Vautrin et al., 1999). In a study of 23 peanut allergic patients who underwent a DBPCFC with lupin flour, 15 (68 %) showed clinical reactions (Leduc et al., 2002). In another study, sensitisation to lupin was found in 82 % of 39 patients allergic to peanut, of which 35 % showed clinically relevant symptoms after challenge (Peeters et al., 2009).

18.4.1.2. Soybean

Ara h 1 and Ara h 2 cross-react *in vitro* with soybean allergens. In five children with a history of anaphylactic reactions to peanuts, IgE binding to Ara h 1 and Ara h 2 decreased by 79 % and 76 %, respectively, after pre-incubation of the sera with soy extract (Eigenmann et al., 1996; Burks et al., 1998). The soybean glycinin G1 acidic chain shares IgE epitopes similarity with peanut Ara h 3 (Beardslee et al., 2000). However, the prevalence of clinical reactions to soy in peanut allergic patients is low, < 10 % (Sicherer, 2002). The report from Sweden in 1999 raised concern over soy allergy in peanut-allergic individuals. Four fatalities were reported due to ingestion of foods containing a low concentration of soy in asthmatic patients severely allergic to peanut with no previously known allergy to soy (Foucard and Malmheden Yman, 1999).

18.4.1.3. Peas

A study described three patients with a history of severe allergic reactions after ingestion of pea who had peanut-related symptoms, in one case confirmed by DBPCFC (Wensing et al., 2003). These patients reacted to the peanut major allergen Ara h 1 and to the pea allergen vicilin. The immunoblotting inhibition experiments demonstrated that pea was probably the first sensitiser, as IgE binding to peanut was inhibited by pea but IgE binding to pea was not, or only partially, inhibited by peanut.

18.4.2. Cross-reactivity between peanuts and tree nuts

It is estimated that 20-50 % of peanut allergic patients are also allergic to tree nuts (Ewan, 1996; Sicherer et al., 2003; Glaspole et al., 2011).

Correlation between serum levels of peanut-specific IgE and hazelnut, Brazil nut as well as almond-specific IgE in peanut-allergic children suggests that cross-reactive immune responses underlie co-allergy to peanut and tree nuts (Glaspole et al., 2011). Peanut-specific IgE antibodies that cross-react with tree nut allergens and may contribute to the manifestation of tree nut allergy in peanut allergic subjects have been identified (de Leon et al., 2005). The structurally related cross-reactivity between Ara h 3 and tree nut allergens such as Jug r 4 of walnut, Cor a 9 of hazelnut, or Ana o 2 of cashew nut appears to be unrelated to the botanical origin of the allergens and suggests that individuals allergic to peanut should avoid tree nuts, unless the allergy status in relation to all other nuts is clarified (Barre et al., 2007; Ball et al., 2011). The major peanut allergen, Ara h 2, shares common IgE binding epitopes with almond and Brazil nut allergens, which may also contribute to the high incidence of tree nut sensitisation in peanut allergic individuals (de Leon et al., 2007).

SPT/RAST cross-reactivity between peanut and tree nuts does not imply the occurrence of clinical cross-reactivity. In a study performed in the UK over a 5-year period from 2006, 145 children diagnosed as peanut or tree nut allergic were challenged (Ball et al., 2011). In those with peanut allergy challenged with tree nuts, none of the 72 with negative SPTs to tree nuts reacted on challenge, whilst only 7 of 22 (31.2 %) with positive SPTs did.

18.5. Effects of food processing on allergenicity

18.5.1. Thermal processing

Heat treatments may enhance peanut allergenicity by 90-fold. It has been documented that roasting

increases the allergenicity of peanuts more than frying or boiling because of dry heating at high temperature (Maleki et al., 2000; Beyer et al., 2001). Ara h 1 and Ara h 2 increase their IgE binding capacity after roasting due to structural modifications or functional alterations, although the exact mechanisms are unknown (Maleki et al., 2000). After roasting, Ara h 1 forms highly stable trimers by intermolecular cross-linking, while Ara h 2 forms intramolecular cross-links without forming higher order structures. Ara h 2 functions as a weak trypsin inhibitor, the activity of which increases approximately 3.5-fold after roasting (Maleki et al., 2003). In addition to being more resistant to trypsin digestion itself, Ara h 2 was found to protect Ara h 1 from degradation by trypsin.

The IgE binding capacity of whole peanut protein extracts prepared from boiled peanuts was 2-fold lower than that of extracts prepared from raw or roasted peanuts, as shown using sera of 37 peanut-allergic patients (Mondoulet et al., 2005). The IgE binding capacity of purified Ara h 1 and Ara h 2 prepared from roasted peanuts was also higher than that of their counterparts prepared from raw or boiled peanuts, whereas the IgE binding capacity of purified Ara h 1 and Ara h 2 was particularly increased by roasting. The decrease in allergenicity of boiled peanuts seems to result mainly from a transfer of low MW allergens into the water during cooking. Boiling (100 °C for 15 min) resulted in partial loss of Ara h 1 secondary structure and formation of rod-like branched aggregates with reduced IgE-binding capacity and impaired ability to induce mediator release (Blanc et al., 2011), whereas roasted Ara h 1 retained the IgE-binding capacity of the native protein.

The fact that peanuts are most commonly eaten after roasting in the USA could explain the higher prevalence of peanut allergy in this population as compared to China, where peanuts are eaten after frying or boiling (Beyer et al., 2001).

18.5.2. Enzymatic hydrolysis

Hydrolysis of roasted peanut protein extract with proteases decreased the IgE-binding capacity of the soluble protein fraction, with a higher effect of the endoprotease alcalase as compared to that of the exoprotease flavourzyme (Cabanillas et al., 2012). Hydrolysis of peanut flour extracts with alcalase, pepsin, or flavourzyme reduced its IgE-binding capacity. However, the IgE-binding capacity during hydrolysis was retained, suggesting that such hydrolysates are not necessarily less allergenic (Shi et al., 2013).

18.5.3. High pressure processing

The effect of pressure treatment was investigated on a mixture of Ara h 2 and Ara h 6 (Johnson et al., 2010). The structure of these allergens remained practically unchanged after 700 MPa treatments at 20 °C and 80 °C. Another study showed that dynamic high-pressure microfluidisation treatment changed the secondary structure of Ara h 2 and decreased its IgE-binding capacity (Hu et al., 2011).

18.5.4. Preservation treatments

18.5.4.1. Effect of pH

One study aimed at determining the effects of various pH conditions on the IgE-binding capacity of major peanut allergens (Kim et al., 2012). The IgE-binding capacity of Ara h 1, Ara h 2 and Ara h 3 was significantly reduced after treatment with acetic acid (pH 1.0) or commercial vinegar (pH 2.3), whereas there was no substantial change at pH 3.0 and 5.0 when compared with raw peanuts.

18.5.4.2. Other preservation treatments

Pulsed UV radiation appeared to be effective in reducing the IgE-binding capacity of peanut extracts and liquid peanut butter (Chung et al., 2008b). The γ-irradiation (1-10 kGy) induced significant changes in the secondary and tertiary structures of purified Ara h 6, and the IgE-binding capacity of purified Ara h 6 and of whole peanut protein extract were reduced upon increasing the irradiation doses (Luo et al., 2013). However, in another study, γ-irradiation alone was not associated with any change in peanut allergenicity, whereas boiling followed by γ-irradiation significantly reduced the

IgE-binding capacity of peanut (Kasera et al., 2012).

18.5.5. Multiple treatments

The effects of ultrasounds, enzyme concentration and enzyme treatment time on the concentrations and IgE-binding capacity of two major allergenic proteins (Ara h 1 and Ara h 2) of roasted peanut kernels have been studied (Li et al., 2013). The ultrasound treatment followed by protease digestion of peanuts significantly decreased the concentrations of Ara h 1 and Ara h 2. The sequential treatment of peanuts by ultrasonication-trypsin-α-chymotrypsin resulted in maximum reductions of Ara h 1/Ara h 2 concentrations, and lowest IgE-binding. Instant controlled pressure drop combining heat and steam pressure (temperature up to 170 °C with a pressure of 6 bar for 3 min) was associated with a decreased IgE-binding capacity of peanut extracts, with a higher effect on roasted peanut proteins than on raw peanuts (Cuadrado et al., 2011).

18.5.6. Peanut oil

Peanut oil is a common ingredient of some foods and cosmetics. While it is possible to minimise overt contact with peanuts, peanut oil is more difficult to detect and avoid.

Case reports of allergic reactions in infants fed infant formulae containing peanut oil (Fries, 1982; Moneret-Vautrin et al., 1991), as well as a flare up of dermatitis induced by oral challenge with peanut oil in infants with atopic dermatitis (Moneret-Vautrin et al., 1994), aroused the suspicion that residual allergenic proteins could be contained in peanut oil.

The protein content of crude peanut oil is in the range of 100-300 μg/mL, about 100 times higher than in fully refined peanut oils, which are subjected to physical and chemical methods of purification, including degumming, refining, bleaching, and deodorisation (Crevel et al., 2000). However, refined peanut oil may contain sufficient peanut allergenic proteins to elicit a reaction in highly sensitive individuals (Olszewski et al., 1998). One of these proteins was recognised by IgE antibodies from a population of 11 peanut allergic patients, four of whom reacted to commercially available refined peanut oils from the European market during a DBPCFC. The allergen had a molecular weight of 18 kDa and an isoelectric point of 4.5 similar, to those of the major peanut allergen Ara h 2. In addition, the two oleosins Ara h 10 and Ara h 11 identified in 2010 may play a role in the allergenicity of peanut oil, although no data are available regarding their contribution to the occurrence of allergic reactions to crude or fully refined peanut oil.

Peanut allergic individuals are usually cautioned to avoid crude peanut oil because of traces of peanut protein in the oil. However, the risk of severe adverse reactions to highly refined peanut oils seems to be low, although it cannot be ruled out in every highly sensitive peanut allergic individual.

18.6. Detection of allergens and allergenic ingredients in food

18.6.1. Immunological methods

18.6.1.1. ELISA

Many ELISA methods for the detection and quantification of peanut in foods are commercially available (Fielder et al., 2010; Zeleny and Schimmel, 2010). Some detect total soluble proteins or a mixture of proteins, whereas others are designed to target a specific peanut allergen (Ara h 1 or Ara h 2) (Schmitt et al., 2004). Available ELISA methods differ in the extraction buffer (usually from neutral to slightly alkaline), the sample treatment, the format (sandwich or competitive ELISA), the antibodies used (monoclonal or polyclonal, different host animals), the detection system (enzyme, substrate, secondary antibody) and the calibrant (whole peanut extract or a specific peanut allergen). Such differences lead to high between-kit variations in the absence of certified reference materials (Westphal et al., 2004; Scaravelli et al., 2009; Khuda et al., 2012a). For example, five ELISA kits were used for the detection of peanuts in incurred sugar cookies, which detected concentrations of

peanut proteins ranging from 11 to 101.8 % of the incurred levels, depending on the kit (Khuda et al., 2012b). A commercial rapid sandwich ELISA based on polyclonal antibodies with a LOD of 1.5 mg/kg, covering a range of 2.5-20 mg/kg, received an AOAC certificate (Immer et al., 2004). The reported LODs for ELISA kits available on the market range from 0.1 mg/kg for Ara h 1, to 0.5 mg/kg for Ara h 2 and 2.5 mg/kg for peanut proteins. The LOQs vary in the range of 1-20 and 1-15 mg/kg for Ara h 1 and Ara h 2, respectively, and of 3.3-90 mg/kg for peanut proteins (Fielder et al., 2010).

The ELISA methods suffer from matrix effects, especially for the detection of peanut allergens in chocolate, from which recovery is problematic (Koch et al., 2003; Poms et al., 2003), as confirmed in a comparison study of four commercial ELISA systems (Hurst et al., 2002). Thermal processing also negatively affects the detection of peanut allergens by commercial ELISA kits, owing to heat-induced changes in the solubility and immunoreactivity of the target proteins (Koch et al., 2003; Park et al., 2005; Poms et al., 2005; Whitaker et al., 2005). Raw peanuts exhibited 3-4 times higher responses than oil-roasted peanuts (Koch et al., 2003). Five ELISA kits were evaluated for detecting and quantifying peanut allergens in biscuits and dark chocolate in an inter-laboratory study (Poms et al., 2005). Although all kits performed well in the 5-10 mg/kg range, they were dependent on the type of processing and working conditions. Similar results were obtained in another inter-laboratory study evaluating the performance of three ELISA kits on different spiked foods, with a LOD of 5 mg/kg and good sensitivity and specificity (Park et al., 2005). Two commercial ELISA kits for the quantification of proteins in peanut flours, which were subjected to either moist or dry-heat treatments, underestimated the amount of proteins in samples heated at high temperature, in particular the ELISA kit targeting the thermolabile Ara h 1 (Fu and Maks, 2013). Boiling of the incurred peanut flour sample or autoclaving resulted in a decrease of 50 % in the amount of protein extracted, whereas dry-heat treatments induced a decrease in protein solubility as well as binding affinity, but at much higher temperature (> 176 °C).

A new ELISA format based on antibody-dendrimer-conjugated magnetic microparticles for the detection of Ara h 3/4 has been described (Speroni et al., 2010). Allergens captured by the magnetic particles are harvested on a magnet, washed, and quantified with a LOD of 0.2 mg peanuts/kg food.

Multi-allergen immunoassays have been developed for the detection of several allergenic proteins including peanut. One assay was applied to chocolate samples with a LOD < 1 mg/kg (Ben Rejeb et al., 2005).

The peanut test material IRMM-481, which contains five peanut varieties from different geographic origins exposed to five different heat treatments, is used as certified reference material for peanuts (Trucksess et al., 2004; Westphal et al., 2004). All kits should report the calibration method and specify which allergenic protein is the target. In case of protein detection, whether the method targets the total protein or the soluble protein, the relative method of detection should be specified. Conversion factors to calculate the amount of peanut from protein concentrations are only approximately known.

18.6.1.2. Dipsticks and lateral flow devices

A number of fast qualitative methods (dipsticks and LFDs) to detect peanuts for screening purposes are commercially available. Two dipstick-type sandwich ELISAs allow detection of about 10 ng/mL of peanut and hazelnut, corresponding to 1 mg of protein/kg of food (Stephan et al., 2002).

LFDs are based on immune-chromatographic principles and can be in the sandwich or the competitive format. A competitive liposome-based lateral flow assay for detecting Ara h 1 had a calculated LOD of 0.45 µg/mL and a visually determined detection range from 1 to 10 µg/mL (Wen et al., 2005). Two commercial peanut LFDs were tested on cookies in an inter-laboratory trial (van Hengel et al., 2006), with a performance comparable to the ELISA kit (LOD 5 mg/kg). Two commercial LFDs for peanuts also showed comparable and satisfactory specificity and a sensitivity at a level of 3.5 mg/kg in chocolate and cookies (Röder et al., 2009). The buffer used for extraction appears to play a major role

on peanut protein detectability by LFDs, particularly when analysing highly processed foods (e.g. dark roasted peanuts). Some buffers are incompatible with LFD performance because of extraction inefficiency or signal inhibition (Rudolf et al., 2012).

18.6.1.3. Biosensors

An electrochemical impedance biosensor for the detection of peanut allergen Ara h 1 has been developed using a gold substrate on which an antibody film has been immobilised (Huang et al., 2008). The LOD was estimated to be < 0.3 nM. A nanobead enhanced optical fiber SPR biosensor was also prepared for the detection of Ara h 1 and compared to a label-free prism based SPR assay and to a commercial ELISA assay (Pollet et al., 2011). Antibody-linked nanobeads greatly amplify the fiber optic SPR signals from 9 µg/mL to 0.09 µg/mL. The nanobeads enhanced assay had a LOD of 0.1 µg/mL, comparable to the ELISA kit.

18.6.2. Mass Spectrometry

MS for the detection of peanut allergens is most often used with the "bottom up" stategy, according to which the extracted protein is digested with enzymes (trypsin in most cases) and several peptides are selected as specific markers for the allergen, separated by HPLC and identified by MS/MS. MS was also used as a confirmatory method for the presence of a specific allergen, such as Ara h 1, in a model food matrix using HPLC/MS/MS (Shefcheck and Musser, 2004). The method was applied for the detection of Ara h 1 in ice cream samples, allowing detection levels as low as 10 mg/kg of the protein. The method was improved and applied to dark chocolate (Shefcheck et al., 2006). Two peptides were chosen as biomarkers of Ara h 1. The pre-extraction digestion led to better results than the post-extraction digestion. The LOD could be reduced to 2 mg/kg by using a QpQ and multiple reaction monitoring (MRM).

Another confirmatory method is the nano-electrospray Q-TOF MS/MS combined with capillary LC, which allowed the detection of a high number of peptides derived from the three peanut allergens Ara h 1, Ara h 2 and Ara h 3 in raw and processed peanuts (Chassaigne et al., 2007). Five peptides, which were stable to roasting, were selected as markers for the three proteins. Roasting affected the LOD of the method for the peptide ions measured in the multiple ion monitoring (MIM) mode. The absolute LOD was set at 7 ng of the protein used for tryptic digestion for raw peanuts, and at 10 ng for mild-roasted peanut extract, whereas the absolute LOD was 40 ng of protein for strong-roasted peanut.

A similar but quantitative method based on LC-ESI-QqQ-MS/MS for the detection of Ara h 2 and Ara h 3/4 was also developed (Careri et al., 2007a). Four peptides were chosen as specific biomarkers for the two proteins. When applied to spiked rice-crispy and chocolate snacks, the method showed a LOD for Ara h 2 of 5 mg/kg and for Ara h 3/4 of 1 mg/kg.

One paper (Pedreschi et al., 2012) discusses the difficulties encountered when detecting Ara h 1, Ara h 2 and Ara h 3 by MS in different food matrices and the ambiguities observed in some publications. The authors analysed a well characterised processed food matrix (incurred cookies with IRMM-481f) by MS. After enrichment using a commercial kit and digestion, two biomarker peptides from Ara h 3/4 were selected by shotgun proteomics and analysed by nano-LC-ESI-Q-TOF-MS/MS via SRM. The LOD was about 10 mg peanut/kg matrix.

18.6.2.1. Multiplex MS methods

A LC-LIT-MS/MS method for the simultaneous detection and quantification of five allergens including Ara h 3/4 in a single short run is available (Bignardi et al., 2010). Sensitivity was significantly improved for all allergens by performing a preliminary clean up step using size-exclusion chromatography before the enzymatic digestion of the proteins. The method is based on the detection of selected specific marker peptides for every target protein. The LOD was 0.1 mg/kg for biscuits and 7 mg/kg for chocolate, with corresponding LOQs of 0.3 mg/kg and 25 mg/kg, respectively (Bignardi et al., 2013).

A multi-method for the detection of seven allergens, including peanut, based on LC and QpQ-MS/MS in MRM mode is available (Heick et al., 2011a). On the basis of selected marker peptides for every allergen it was possible to detect the seven allergens also in incurred food samples with a LOD of 10 mg/kg for peanut.

18.6.3. Immunological methods coupled to mass spectrometry

A non-competitive sandwich ELISA combined with inductively coupled plasma-MS (ICP-MS) was constructed (Careri et al., 2007a) using polyclonal antibodies as capture reagents and monoclonal antibodies anti-Ara h 1 and anti-Ara h 3/4 for identification (Ab I). Rabbit anti-mouse polyclonal antibodies labelled with europium (Ab II) were used for detection. The LOD for peanut in food was 2 mg/kg.

An antibody magnetic support was developed for enriched extraction of the Ara h 3/4 allergen from food. After a microwave-assisted tryptic digestion of the protein, LC-ESI-IT-MS/MS was used to identify the specific Ara h 3/4 peptide biomarkers. The LOD and LOQ obtained on breakfast cereals were 3 and 10 mg peanuts/kg matrix, respectively (Careri et al., 2008).

18.6.4. DNA-based methods

Real-time PCR methods based on the DNA sequence of the peanut allergen gene Ara h 2 were developed using the TaqMan technology (Hird et al., 2003; Stephan and Vieths, 2004). Seven methods for DNA extraction were examined by Hird with an internal positive control (IPC) kit to have an indication of the amount of PCR inhibitors co-extracted with the DNA. The Hird's assay was used to detect peanut in spiked commercial foods and in biscuits baked with 2 mg/kg of roasted peanut powder prepared for the Central Science Laboratory Food Analysis Proficiency Assessment Scheme (FAPAS) food allergen program. The Stephan and Vieths' assay is specific and suitable to detect peanut in processed foods with an LOD of < 10 mg/kg.

Commercial PCR kits are also available in the format of real-time PCR, PCR-ELISA and an end-point PCR followed by gel electrophoresis, with a LOD of 10 mg/kg.

Three real-time PCR assays were developed targeting the Ara h 3 gene of peanut (Scaravelli et al., 2008), which are capable of detecting 2.5 pg peanut DNA, corresponding to less than one copy of genomic DNA. The method is quantitative and, when applied to model food samples with a precise peanut content, was able to detect 10 mg/kg peanut. A new version of this method based on single-tube nested PCR was proposed (Bergerová et al., 2011), which is more sensitive when applied to DNA extracted from peanut leaves (LOD of 0.375 pg and LOQ of 0.76 pg DNA), but less sensitive when applied to raw or roasted peanuts (LOD of 31.25 pg DNA).

18.6.4.1. DNA biosensors

An electrochemical DNA biosensor was developed for detecting Ara h 1 (Sun et al., 2012). A stem-loop probe was linked to a gold electrode. Hybridisation to the complementary DNA gave rise to electron-transfer efficiency changes between probe and electrode, as proved by electrochemical impedance spectroscopy (EIS). The detection limit was 0.35 fM. When applied to a peanut milk beverage, the LOD was 3.2×10^{-13} M.

18.6.4.2. Comparison between ELISA and PCR technologies for detecting peanuts in food products

The performance of ELISA and PCR technologies for detecting peanut in food products have been compared in a number of studies (Stephan and Vieths, 2004; Watanabe et al., 2006). Results were generally qualitative owing to the lack of a common reference material. One study (Scaravelli et al., 2009) reported the comparison between two ELISA kits and three real-time PCR methods and all data were normalised to the IRMM-481 peanut test material. Results were similar with both methods, despite a high variability observed between the two ELISA kits and the lower variability among the PCR methods. The ELISA and PCR methods were tested in the analysis of a model food matrix

(cookies) to which known amounts of peanut were added before processing. The roasting processes greatly reduced the detectability of both methods according to the baking time.

18.7. Minimal (observed) eliciting doses

Case reports of allergic reactions in peanut allergic patients after accidental ingestion of foods containing peanuts show that even traces of peanut proteins can trigger severe allergic reactions in these subjects. Data from the US Peanut and Tree Nut Allergy Registry show that most reactions to peanut occurring in restaurants were triggered by foods which contained peanut as an ingredient that could not be identified by patients (e.g. in sauces, dressings, egg rolls). The most common source of exposure was desserts (43 %), followed by entrees (35 %) and appetisers (13 %) (Furlong et al., 2001).

Different types of studies (i.e. diagnostic series, threshold-finding studies and immunotherapy trials) have reported on MED following challenge studies in adults and children combined (Oppenheimer et al., 1992; Leung et al., 2003; Lewis et al., 2005; Anagnostou et al., 2009), mostly in adults (Atkins et al., 1985; Hourihane et al., 1997; Nelson et al., 1997; Patriarca et al., 2006) (Wensing et al., 2002b), and mostly in children (Flinterman et al., 2006a; Clark et al., 2008; Clark et al., 2009; Blumchen et al., 2010; Nicolaou et al., 2010; Taylor et al., 2010; Wainstein et al., 2010; Blom et al., 2013). Studies are variable in size, challenge protocol used and type of food tested (Taylor et al., 2013). The total number of patients showing objective symptoms during the oral challenge in a given study ranged from one to 283. The lowest MOEDs also varied widely among studies, ranging from 0.1 to 1,637 mg of total peanut protein (Remington, 2013).

Four studies (Hourihane et al., 1997; Wensing et al., 2002b; Lewis et al., 2005; Flinterman et al., 2006a) were specifically designed to assess LOAEL doses and provide accurate information on the doses tested (Taylor et al., 2009b).

Fourteen adult subjects proven by challenge to be allergic to peanut were randomised to receive varying doses of peanut protein administered as peanut flour in a DBPCFC (Hourihane et al., 1997). The challenge started with a dose of 10 µg of peanut protein (21.63 µg of flour), and increased stepwise thereafter to 20 µg, 50 µg, 100 µg, 250 µg, 500 µg, 1 mg, 2 mg, 5 mg, 10 mg, 20 mg, up to a maximum dose of 50 mg (108.15 mg of flour). One subject had a systemic reaction to 5 mg of peanut protein, and two subjects had mild objective reactions to 2 mg and 50 mg of peanut protein, respectively. Five subjects had mild subjective reactions (one to 5 mg and four to 50 mg). All subjects with convincing objective reactions had short-lived subjective reactions to preceding doses, as low as 100 µg in two cases. Five subjects did not react to any dose up to 50 mg.

In another DBPCFC, 26 adult patients with a convincing history of peanut-related symptoms, a specific IgE level ≥ 0.7 kU/L, or a positive ≥ SPT of 2+ to peanut were challenged with varying doses of peanut protein provided as roasted peanut meal (Wensing et al., 2002b). Ten doses of peanut protein (30 µg, 100 µg, 300 µg, 1 mg, 3 mg, 10 mg, 30 mg, 100 mg, 300 mg, and 1 g) were tested in two separate challenges. The first challenge consisted of the 7 lowest doses (30 µg-30 mg). Patients who did not react during this challenge were asked to participate in a second challenge with 2 overlapping doses (10 and 30 mg) and 3 higher doses (100 mg, 300 mg, and 1 g). All patients reported oral symptoms (n = 26), of which 14 reported prior subjective gastrointestinal symptoms (n = 14) and other symptoms were observed in five subjects. Reactions started within 30 minutes after ingestion of peanut, but in two patients additional symptoms were delayed by one to two hours. Doses eliciting allergic reactions ranged from a dose of 100 µg up to 1 g of peanut protein. Fifty percent of the study population had an allergic reaction after ingestion of 3 mg of peanut protein. Patients with severe symptoms had lower threshold doses compared with those patients with mild symptoms.

Forty peanut allergic patients > 6 years of age were recruited who had a convincing clinical history of an allergic reaction to peanut in the last 3 years before challenge and a SPT for peanut of ≥ 6 mm, in the presence of a negative control (saline), and at least a 3 mm weal to histamine 1:10 w/v (Berg et al., 2008). In a DBPCFC, subjects received doses of peanut protein of 1, 2, 5, 10, 20, 50, 100, 250, 500

mg, and 1, 2, 4 g as roasted and partially defatted peanut flour. Doses were given between 15 and 30 minutes apart. Eliciting doses varied between 1mg and 2 g of peanut protein.

A total of 27 children > 3.5 years sensitised to peanut and on a peanut elimination diet were evaluated by specific IgE measurements, SPT, and DBPCFC (Flinterman et al., 2006a). Nine doses of defatted light roasted peanut flour (10 μg, 100 μg, 500 μg, 1 mg, 10 mg, 100 mg, 300 mg, 1 g, and 3 g), which contain about 50 % of peanut protein, were tested at intervals between 15 and 30 minutes. All children tolerated a dose of 1 mg peanut flour, which corresponds to 2 mg peanut. The lowest eliciting dose was 10 mg (n = 2), causing OAS. The eliciting dose for subjective symptoms ranged from 10 mg to 3 g of peanut flour, and was significantly lower than that for objective symptoms (from 100 mg to 3 g).

Minimal doses reported to elicit objective symptoms in peanut allergic individuals are variable depending on the study population, challenge protocol and food matrix tested. The lowest reported MOED in peanut allergic patients undergoing DBPCFC was 100 μg of peanut protein, with a NOAEL of 30 μg. Doses of peanut protein inducing OAS in other studies were above that level. However, few data are available on the doses that may trigger allergic reactions in highly sensitive patients, who are often excluded from challenge tests but tend to react to lower doses than patients with mild symptoms.

18.8. Conclusion

Peanut is a common cause of allergic reactions, which can be severe or even fatal. Prevalence of well documented peanut allergy in Europe varies between 0.1 to 1.8 % depending on the age and country of origin. The available data do not allow concluding on whether the prevalence of peanut allergy has changed in the last years in Europe. The major peanut allergens are well characterised. Roasting may increase the IgE-binding capacity of peanut allergens, whereas boiling may decrease it or leave it unchanged. ELISA assays are sometimes unsuitable for the detection of peanut allergens in processed foods. MS and PCR technologies can be used as alternative or complementary methods. The lowest reported MOED in peanut allergic patients undergoing DBPCFC was 100 μg of peanut protein, with a NOAEL of 30 μg. However, few data are available on the doses which may trigger allergic reactions in highly sensitive patients, who are often excluded from challenge tests but tend to react to lower doses than patients with mild symptoms.

19. Allergy to soy

19.1. Background

Soy (soybean) (*Glycine max)* is an edible legume belonging to the *Fabaceae* family. The seed contains around 20 % oil and 38 %-40 % protein. Consumption of soy, widespread in Asia and the USA, has increased in Europe during the past years particularly. In vegetarian cuisine soy is consumed as soy oil, soy flour, soymilk, soy drinks, soy flakes or as fermented soybean products such as Miso, Okara, soy sauce (Tamari, Shoyu), tempeh or tofu. Soy products are also used in the food industry for technological reasons as texturizers, emulsifiers and protein fillers. As soy is a good and cheap protein source, it may be part of a wide variety of processed foods such as meat products, sausages, bakery goods, chocolate or breakfast cereals (Ballmer-Weber and Vieths, 2008).

Soy is widely consumed also by children. Soy-based formulas were introduced in infant nutrition more than 100 years ago (Katz et al., 2014) and are currently used for the treatment of cow's milk allergy (CMA), lactose and galactose intolerance, among other conditions. However, soy and soy protein-based formulas (SPFs) can induce IgE and non IgE-mediated food allergy.

The clinical manifestations of soy allergy are similar to those of CMA, ranging from enterocolitis and food protein-induced enterocolitis syndrome (FPIES) (Sicherer, 2005), which are generally not associated with detectable specific IgE antibodies, to atopic dermatitis and IgE-mediated systemic reactions (anaphylaxis).

19.2. Epidemiology

19.2.1. Prevalence

19.2.1.1. Europe

There are 15 studies conducted in Denmark, Germany, Hungary, Iceland, Sweden, The Netherlands and the United Kingdom between 1994 to 2008, which report on the prevalence of soy allergy in unselected European populations (University of Portsmouth, 2013). Ten studies aimed to assess both IgE and non-IgE mediated allergy whereas five focused on IgE-mediated allergy only. All ages were included.

The highest prevalence (0.8-1.2 %) of self-reported soy allergy has been recorded among 4 and 8 year old children in Sweden (Ostblom et al., 2008a; Ostblom et al., 2008b). Self-reported prevalence in 1 and 2 year old children in Sweden (Ostblom et al., 2008a) and in other European countries at all ages were ≤ 0.6 % (Young et al., 1994; Brugman et al., 1998; Emmett et al., 1999; Kristjansson et al., 1999; Schafer et al., 2001).

Sensitisation rates assessed by positive SPTs among adults were 7.3-8.3 % in Hungary (Bakos et al., 2006) and 1.7 in Germany (Schafer et al., 2001), but only 0.3 and 0.2 % among UK children 4 (Arshad et al., 2001) and 8 (Roberts et al., 2005) years of age. Rates of sensitisation based on IgE levels were between 2.1 % and 3.7 % in adults and children in the three geographical areas (Sweden, Hungary and Greenland) for which studies were available (Bjornsson et al., 1996; Krause et al., 2002; Bakos et al., 2006; Ostblom et al., 2008a). When a convincing history was combined with sensitisation, prevalence of soy allergy was zero in 18 month olds (Kristjansson et al., 1999) and 1.6 % in 4 year olds (Ostblom et al., 2008b) in Sweden.

The only study which assessed soy allergy using either OFC (in subjects < 3 years) or DBPCFCs found a zero prevalence in a large sample (1 272) of Danish children and adults (Osterballe et al., 2005; Osterballe et al., 2009).

19.2.1.2. Outside Europe

In the US, prevalence of self-reported soy allergy was 2.7 % in children up to three years of age (Bock, 1987) and ranged between 0.1 % and 1.8 % in adults (Vierk et al., 2007; Greenhawt et al., 2009). Soy allergy was reported by < 0.3 % of the children and adults in other parts of the World, including Canada. No studies assessing prevalence of soy allergy using food challenges are available.

19.2.2. Natural history

Most soy allergic subjects outgrow their allergy. In a retrospective analysis of data in 133 children with soy allergy (88 % of which with concomitant peanut allergy) recruited at a median age of one year and followed up for a median of five years predicted a resolution of soy allergy in 25 % of children at four years, in 45 % at six years, and in about 70 % at 10 years. Absolute soy specific IgE levels were useful predictors of outgrowing soy allergy (Savage et al., 2010). By age 6 years, subjects with a peak soy-specific IgE level < 10 kUA/L had > 50 % chance of outgrowing their allergy, whereas peak levels > 50 kUA/L suggested < 20 % chance of tolerance development. Although soy allergy usually manifests early in life, the study identified a subset of patients in which allergy symptoms started after tolerating soy in their diet. It has been hypothesised that such late onset of soy allergy may be related to either birch pollen cross-reactivity or persistent peanut allergy, as indicated by high peanut-specific IgE levels at their last follow-up (Savage et al., 2010).

The prevalence of soy sensitisation progressively increased from 2 % at 2 years to 7 % at 10 years of age in the German Multi-Centre Allergy Study, where 1314 children were followed up from birth to 13 years (Matricardi et al., 2008). In patients with soy-induced FPIES, tolerance usually develops within three years of life (Nowak-Wegrzyn and Muraro, 2009), although the rate of tolerance development varies between studies and populations. Occasionally, FPIES may persist into the

teenage years. Earlier reports suggested that, within two years of age, 20 % of soy-induced FPIES resolves (Sicherer, 2005). However, a study in 23 Korean infants with FPIES found that 92 % of them tolerated soy at age 10 months (Hwang et al., 2009).

19.2.3. Time trends

There are no studies available, which allow investigating time trends in soy allergy.

19.2.4. Severe reactions/anaphylaxis

Symptoms of soy allergy are generally mild. No severe allergic reactions to soy were reported by a research group in 13 years of experience with DBPCFCs (Sicherer et al., 2000a). However, severe gastrointestinal symptoms upon consumption of SPFs in infants and children and anaphylaxis following oral exposure to soy have also been reported. During a period of four years (1993-1996), a Swedish group (Foucard and Malmheden Yman, 1999) reported 61 cases of severe anaphylactic reactions from a national register. Peanut, tree nuts and soy were deemed to have caused 45/61 reactions. All four children who died from soy anaphylaxis were suffering from asthma and severe peanut allergy. Severe reactions occurred after initially mild symptoms and an almost symptom free interval of about one hour. The foods responsible for allergic reactions in soy allergic patients were ice cream and hamburger (Host and Halken, 1990), and kebab and soy sauce (Schrander et al., 1993). Peanut allergic subjects who reacted to kebab and hamburger were highly sensitised to peanut and had soy-specific IgE. However the nature of the study does not allow firm conclusions regarding the true trigger for these fatal reactions and hidden peanut exposure as trigger cannot be ruled out. Anaphylaxis and exercise-induced anaphylaxis to soy have also been reported by others (Pumphrey and Stanworth, 1996; Sicherer et al., 2000b; Adachi et al., 2009).

In a study on allergic reactions during in-patient OFCs, three (7 %) soy challenges required administration of epinephrine (Jarvinen and Chatchatee, 2009). Higher frequency of severe reactions (25 %), including throat or chest tightness, has been reported in patients with soy and birch pollen allergy during DBPCFCs with soy (Mittag et al., 2004b).

19.2.5. Factors affecting prevalence of soy allergy

Prevalence of soy allergy appears to be higher among subjects with atopic dermatitis than in the general population. In a study conducted in the US, 21 out of 165 children with atopic dermatitis had a positive SPT to soy (13 %) and three (1.8 %) reacted to soy in a DBPCFC (Kattan et al., 2011). Two Italian studies (Giampietro et al., 1992; Magnolfi et al., 1996) report a positive RAST in 22 % and a positive SPT in 23 % of the 1075 food allergic and atopic children investigated, of which only 3 % and 6 % reacted in a DBPCFC or OFCs, respectively, representing 1.1 % of children referred for atopic disease. A higher prevalence of soy allergy has also been reported in delayed onset enterocolitis and enteropathy syndromes (Kattan et al., 2011), and in birch pollen and peanut allergic subjects due to cross-reactivities with soy allergens.

19.3. Identified allergens

Soybean contains approximately 38 % protein. At least 16 IgE-binding protein fractions of soy have been identified in the Allergome database. However, only eight soybean allergens appear in the IUIS database (Table 20).

The main storage proteins in soybean are glycinin (11S) and β-conglycinin (7S), which account for about 70 % of the total seed protein. β-Conglycinin is a trimeric glycoprotein of MW 180 kDa, which consists of three sub-units, α, α'and β, all N-glycosylated (Vu Huu and Shibasaki, 1978). Only the α-subunit is allergenic, although the α'- and β-subunits have 90.14 % and 76.2 % homology with it, respectively. Glycinin is a hexamer of MW 360 kDa. Each subunit is composed of an acidic and a basic poly-peptide linked by a disulphide bond (Staswick et al., 1981). The five subunits form three groups according to the combination of acid and basic peptides (Maruyama et al., 2004). Subunits Gy1 and Gy5 are considered main epitopes for this protein (Schiller et al., 2014).

5186 **Table 20:** Soy (*Glycine max*) allergens

Allergen	Protein	Molecular weight[a]	Superfamily/Family
Gly m 1	hydrophobic protein	7	hydrophobic seed protein
Gly m 2	defensin	8	defensin
Gly m 3	profilin	14	profilin
Gly m 4	PR-10 protein	17	Bet v 1 related protein
Gly m 5	β-conglycinin (7S globulin, vicilin)		cupin
	Subunit α	67	
	Subunit α'	71	
	Subunit β	50	
Gly m 6	Glycinin (11S globulin, legumin)		cupin
	Subunit Gy1	53.6	
	Subunit Gy2	52.4	
	Subunit Gy3	52.2	
	Subunit Gy4	61.2	
	Subunit Gy5	55.4	
Gly m 7	Seed biotinylated protein	76.2[b]	
Gly m 8	2S albumin	28	prolamin

5187 [a] MW (SDS-PAGE); [b] kDa

5188 Other soy proteins have been characterised and proposed as allergens, including the thiol-protease Gly
5189 m Bd 30k (Ogawa et al., 1991; Helm et al., 1998; Helm et al., 2000), and the Kunitz trypsin inhibitor
5190 (Moroz and Yang, 1980; Gu et al., 2001).

5191 Several authors report on *in vitro* IgE-binding studies in patients suffering from peanut or soy allergy.
5192 IgE-binding to Gly m 1 has been reported in > 90 % of patients (Djurtoft et al., 1991), to Gly m 4 in
5193 86 % (Baur et al., 1996), and to Gly m 3 in 69 % (Rihs et al., 1999). Later studies reported IgE to Gly
5194 m 4 in 70 % to 100 % of soy allergic patients (Mittag et al., 2004b; Ballmer-Weber et al., 2007;
5195 Fukutomi et al., 2012). IgE to Gly m 5 and 6 was detected in 5-67 % and 5-58 % of patients,
5196 respectively (Holzhauser et al., 2009; Ito et al., 2011; Fukutomi et al., 2012). The frequency of IgE to
5197 Gly m 5 and Gly m 6 was lower in adults than children (5 % vs. 67 % for Gly m 5 and 5 % vs. 58 %
5198 for Gly m 6, respectively) (Ito et al., 2011; Fukutomi et al., 2012). Children with primary, more severe
5199 soybean allergy are usually sensitised to Gly m 5 and Gly m 6 (Fukutomi et al., 2012). However, high
5200 levels of IgE against Gly m 5 and 6 were related to mild symptoms in adults, and higher levels of Gly
5201 m 4 were related to soy milk allergy (Klemans et al., 2013).

5202 Soy components were also studied in relation to the severity of soy allergy. IgE to Gly m 5 and
5203 Gly m 6, which contains linear epitopes, was identified as a potential diagnostic marker for severe soy
5204 allergy (Holzhauser et al., 2009), whereas high levels of IgE to Gly m 4, which contains a
5205 conformational epitope, were detected in patients with anaphylactic reactions to soy drinks (van
5206 Zuuren et al., 2010; Kosma et al., 2011). The use of soy-specific components for the diagnosis of soy
5207 allergy was investigated in case-control studies where controls were not suspected of being soy
5208 allergic (Ito et al., 2011; Vissers et al., 2011; De Swert et al., 2012; Fukutomi et al., 2012) and in a
5209 soy-allergic patients only (Mittag et al., 2004b; Ballmer-Weber et al., 2007) (Holzhauser et al., 2009;
5210 van Zuuren et al., 2010; Kosma et al., 2011). IgE to Gly m 8 had the best accuracy in diagnosing adult
5211 soy allergy, IgE to Gly m 5 and 6 was related to mild symptoms, and Gly m 4 to soy milk allergy
5212 (Klemans et al., 2013).

5213 ### 19.4. Cross-reactivities

5214 Serological cross-reactivities against other legumes in soy allergic individuals have been described in
5215 relation to peanut (70-90 %), green pea (~ 80 %), lima bean (~ 50 %), string bean (~ 40 %) (Bernhisel-
5216 Broadbent and Sampson, 1989; Bernhisel-Broadbent et al., 1989) and wheat flour in soybean
5217 sensitised bakers' (Baur et al., 1996), although these do not correlate with clinical cross-reactivities.

Immediate type allergic reactions in patients with birch pollen allergy after consuming soy protein-containing food can result from cross-reactivity between Bet v 1 specific IgE and the homologous PR-10 protein SAM 22 Gly m 4 (Kleine-Tebbe et al., 2002; Holzhauser et al., 2009). In a study of 50 Bet v 1 allergic individuals (Treudler et al., 2008), eight reactions to soy protein were reported in subjects with high IgE levels against Gly m 4.

Clinical symptoms in peanut allergic patients after soy intake are likely to result from cross-reactivity between Ara h 3 and Gly m 6 (11S globulin) (Beardslee et al., 2000). Peanut allergic children (with or without anaphylaxis) had significantly higher IgE binding to Ara h 1-3 (peanut allergens) and Gly m 5-6 (soy allergens) than asymptomatic children sensitised to peanut (Hong et al., 2012).

Clinical cross-reactivity between peanut and soy is rare despite the high degree of cross-sensitisation based on IgE-binding and SPTs (Sicherer et al., 2000b; Kattan et al., 2011). Clinical co-reactivity to soy was reported in 1 %-6.5 % of peanut allergic individuals in placebo controlled studies (Burks et al., 1998). Of 140 peanut allergic patients, 7 % were allergic to soy as determined from a combination of clinical history, serum IgE levels, SPT, and OFCs in another study (Green et al., 2007). Soy intake does not appear to be a risk factor for peanut allergy (Koplin et al., 2008).

Co-sensitisation to soy is common in patients with CMA, but clinical co-allergy is rare (Zeiger et al., 1999). Co-sensitisation without clinical reactivity to soy milk was noted in 17 % of patients with CMA (Osterballe et al., 2009). Several studies suggest that the majority of subjects with IgE-mediated CMA tolerate soy or soy formula, and that clinical reactions in subjects who do not tolerate soy are mainly non-IgE mediated (EFSA, 2004). The soybean Gly m Gy4 and Gly m 5 subunit α cross-react with casein (Rozenfeld et al., 2002; Curciarello et al., 2014). Out of 10 children with a positive milk challenge, six also had a positive soy challenge. There was a challenge order effect, which needs to be considered when designing and reporting food challenge studies (Niggemann and Beyer, 2007).

19.5. Possible effects of food processing on allergenicity and derived products

The effects of different processes on the allergenic potential of soy products, including lecithins and soybean oil, have been reviewed (Besler et al., 2001). Storage, heat treatments, fermentation and high pressure processing (HPP) affect the IgE-binding activity of sera obtained from peanut and soy allergic patients.

19.5.1. Heat treatments

Most exposures to heat between 80-120 ºC for 60 minutes lead to a reduction in IgE-binding (Burks et al., 1991a; Burks et al., 1992a; L'Hocine and Boye, 2007). Combinations of heat and steam pressure, such as instant controlled pressure drop (DIC), were shown to decrease the IgE-binding to legumes, including soy proteins, proportionally to the increase in steam pressure and duration of treatment (Cuadrado et al., 2011). Conversely, heat treatment and storage was reported to increase allergenicity of soybean hull through the formation of two neoallergens (Codina et al., 1998), and thus the conditions and duration of thermal treatments may affect the allergenicity of soy products in different ways.

19.5.2. Fermentation

Natural or induced fermentation in soybean meals significantly reduced IgE-binding up to 89 %, in particular if the resulting proteins were < 20 kDa (Song et al., 2008). Yoghurts showed the lowest antigenic activity, followed by miso and tempeh. The lowest IgE-binding was observed with liquid fermentation of soybean flour (Frias et al., 2008). The extent of hydrolysis of soybean formulae (powder vs. liquid) may affect the outcome of challenge studies in children with enterocolitis. Out of the 43 children challenged with soy formula in one study (Burks et al., 1994), 14 (33 %) reacted to a powdered soy formula and 13 reacted to a liquid formula. Allergenicity was retained in a soy sauce, a fermented product containing both wheat and soy (Hefle et al., 2005).

19.5.3. High Hydrostatic Pressure

The application of HHP treatments (100-30 MPa for 15 min) to soy "whey", a by-product from the preparation of tofu, reduced the immunoreactivity of soy proteins towards antibodies against Gly m 1 (Peñas et al., 2006b). HHP treatment of soy seeds led to lower immunoreactivity of the resulting soy sprouts, probably owing to the increased susceptibility to enzymatic hydrolysis during germination (Peñas et al., 2011). The influence of HHP treatments on IgE-binding capacity of soy allergens has also been studied in soybean protein isolates (SPI) for infant formula (Li et al., 2012). The processing conditions (300 MPa for 15 min) significantly reduced immunoreactivity by 48.6 % compared to the untreated SPI, which was linked to structural modifications of the proteins.

19.5.4. Soy derived products

19.5.4.1. Soy lecithin

Soy lecithins are used as stabilisers and emulsifiers in a wide range of foods, drugs and other industrial products. Soy lecithins are mostly obtained by hexane extraction during the manufacturing of soy oil. Crude lecithins are separated from the oils by degumming and their composition is variable. Lecithins are complex mixtures composed mainly by phospholipids, glycolipids and fatty acids (phospholipid complex), but they also contain residual proteins in variable amounts depending on the manufacturing process. Proteins present in lecithins may trigger allergic reactions in sensitive individuals (Palm et al., 1999).

Residual proteins have been determined in commercial lecithins in the range of 100-1 400 mg/kg (Gu et al., 2001; Martin-Hernandez et al., 2005). Soy lecithin was shown to contain a number of IgE-binding proteins (Gu et al., 2001), among which a methionine-rich protein (12 kDa) belonging to the 2S albumin family, the Kunitz trypsin inhibitor (20 kDa) and a protein of 39 kDa, attributed to the acidic subunits of glycinin (Müller et al., 1998). The SDS-PAGE protein pattern of the standard soy lecithin was very similar to that of soy flour (Martin-Hernandez et al., 2005). The MWs of the main proteins in soy lecithins and soy flour determined by MALDI-MS ranged from 10.5 to 52.2 kDa and were identified by ESI-MS/MS to belong to the 11S globulin fraction, corresponding to glycinin A acid subunits (35 kDa), glycinin B basic subunits (18-20 kDa) and glycinin A5 subunit (10 kDa). The seed maturation protein P34 (32 kDa) from the 7S globulin fraction of soy proteins was also identified. An IgE-binding protein (16kDa) and weak bands (< 14 kDa) were also observed (Paschke et al., 2001).

19.5.4.2. Soybean oil

Soybean oil is used in cooking and food formulations. The presence of protein in soy oil depends on the degree of refining, as for other seed oils. Both cold-pressed and fully refined oils have been shown to contain proteins (0.35-0.78 mg/kg) (Hidalgo and Zamora, 2006). Although most publications suggest that refined oils do not induce allergic reactions in sensitive individuals (Bush et al., 1985; Crevel et al., 2000), an adverse reaction to soy oil in an infant has been reported (Moneret-Vautrin et al., 2002b). IgE-binding proteins with MWs of 53 and 58 kDa were identified in three unrefined soybean oils (Paschke et al., 2001). A 56 kDa allergenic protein was also found in cold-pressed and deodorised soybean oils (Errahali et al., 2002), which was later (Errahali et al., 2004) identified as soybean β-amilase (7S globulin), together with the 20 kDa allergen Kunitz-trypsin-inhibitor. The protein profile of the cold-pressed soy oil was similar to that of soy flour, with seven bands in a wide molecular range (94-14 kDa) (Martin-Hernandez et al., 2008). The soy lecithin seed maturation protein P34 from the 7S globulin fraction (35 kDa) and β-amylase (56 kDa) were identified.

19.6. Detection allergens in food

Many methods are available to detect allergens in soy products. A critical aspect is the extraction of proteins from soy lecithins and soy oils. Extraction with hexane-isopropanol-water was found most suitable to extract protein from lecithin (Martin-Hernandez et al., 2005) and acetone-hexane from oil (Martin-Hernandez et al., 2008).

19.6.1. Immunological methods

19.6.1.1. ELISA

Several ELISA methods for detection of soybean allergens are commercially available (Gatti and Ferrett, 2010). These are based on antibodies raised against native soybean proteins, against a single protein such as Gly m Bd 30 K/P34, β-conglycinin, glycinin, the Kunitz trypsin inhibitor (KTI) or the Bowman-Birk inhibitor (BBI), or against denatured/renatured soybean proteins.

ELISA methods for the detection of soy proteins in processed foods were thoroughly reviewed (Koppelman et al., 2004). In order to improve sensitivity, a competitive ELISA assay based on polyclonal antibodies which used preliminary extraction with a buffer at pH 12 was applied to soy ingredients and soy-containing foods processed in different ways. The LOD was 0.4 mg/kg and the LOQ was 1 mg/kg.

Polyclonal and monoclonal antibodies have been raised against β-conglycinin. Two competitive ELISA quantification of β-conglycinin in processed foods and seeds are available. One is based on a specific rabbit anti-β-conglycinin polyclonal antibody (Moriyama et al., 2005) and the second on a monoclonal antibody obtained by using a conjugated chicken ovalbumin with a synthetic peptide that corresponded to one epitope sequence of β-conglycinin as the immunogen (You et al., 2008). The LOD of the latter was 2.0 ng/mL. A sandwich ELISA for the determination of β-conglycinin in food has also been developed, with a LOD of 1.63 ng/mL (Hei et al., 2012).

A competitive ELISA based on the monoclonal antibody 4B2 against glycinin exhibited high-sensitivity, with a LOD of 0.3 ng/mL of glycinin (Ma et al., 2010).

A sandwich ELISA for the detection and quantification of the soluble soybean protein in processed foods was developed using polyclonal antibodies raised against the protein P34 (Gly m Bd 30K) as a soybean marker protein (Morishita et al., 2008). The method was highly specific, with a LOD of 0.47 ng/mL (equivalent to 0.19 mg/kg in foods) and a LOQ of 0.94 ng/mL (equivalent to 0.38 mg/kg in foods). Polyclonal antibodies against the recombinant P34 fusion protein were used for an indirect ELISA able to determine the P34 content of soybean products (Liu et al., 2012a), which is deemed to be very specific and accurate, but no LOD has been reported (the lowest concentration tested was around 2.5 ng/mL, as deduced from the calibration curve).

The detection of soy proteins by commercial ELISA kits is variable and strongly influenced by processing. A competitive ELISA targeting renatured soy proteins and a sandwich ELISA determining the trypsin inhibitor in the food sample showed high sensitivity (LOD 2µg/mL and < 1µg/mL, respectively) when applied to soy proteins undergoing hydrolysis and glycation during food processing (L'Hocine et al., 2007). However, both methods showed drawbacks related either to interferences with the food matrix and specificity (cross-reactivity with chickpeas) or to accuracy, which hampered the detection of soy proteins in processed foods. Indeed, ELISA kits do not perform well in heat-treated foods, where glycated proteins are formed by the Maillard reaction (Platteau et al., 2011b). Antibodies against modified protein extracts are more suitable to detect soy allergens in processed foods than antibodies raised against the native protein (Cucu et al., 2012a). If antibodies are raised against a single native allergen, this should be stable during processing conditions.

The performance of seven different assays for the detection of soy was compared on several commercial food products (Pedersen et al., 2008). The difficulties of detecting soy proteins in processed foods was evidenced for all immunological methods, whereas the detection of DNA with a soy-specific real time-PCR offered the advantages of a good sensitivity (LOD 10 mg/kg) and a high specificity. In particular, a sandwich ELISA showed a very good sensitivity (LOD 0.05 mg/kg), but only towards native proteins; a competitive ELISA recognised denatured/renatured proteins, although with a lower sensitivity (LOD 20 mg/kg); enzyme-allergosorbent test (EAST) inhibition and histamine release (HR) tests were also utilised with a good sensitivity (LOD = 0.8-12 mg/kg and 0.2 mg/kg,

respectively), although they were very variable depending on patient sera and donor basophils, as well as potentially cross-reactive with other legumes.

19.6.1.2. Immunosensors

An optical biosensor (BIACORE) was used to develop a biosensor immunoassay (BIA) based on polyclonal antibodies for the simultaneous detection of soy, pea, and soluble wheat proteins in milk powder (Haasnoot et al., 2001). The LODs were < 0.1 % of plant protein relative to the total milk protein content. An automated fluorescent microsphere-based flow cytometric triplex inhibition immunoassay was developed for the same purpose (Haasnoot and du Pre, 2007). It is faster than the BIA and allows the simultaneous analysis of several samples with the same LOD.

A direct homogeneous aggregation immunoassay involving the use of gold nanoparticles (AuNPs) adsorbed to polyclonal anti-soy protein antibodies and light scattering detection has been described for soy protein determination in food samples (Sánchez-Martinez et al., 2009). When the method was applied to fruit juice and "non-milk yoghourt" samples, the results were similar to those obtained with a commercial ELISA kit, but the time for analysis was shorter and the LOD was about 10 times lower (65 ng/mL). A heterogeneous competitive fluoroimmunoassay with antibody capture for the determination of soy protein involving nile blue-doped silica nanoparticles (NPs) bound to anti-soy protein antibodies was found to be very sensitive, with a LOD of 0.05 mg/L (Godoy-Navajas et al., 2011).

19.6.2. Mass spectrometry

Although soy proteins could be analysed by RP-HPLC (Mujoo et al., 2003), the advent of LC coupled to MS allowed to determine the presence of allergens with high specificity and good sensitivity, and to measure multiple proteins simultaneously.

Two quantitative proteomic methods, spectral counting and LC-MS/MS were used to calculate the relative and absolute quantities, respectively, of eight soybean allergens in 20 soy varieties (Houston et al., 2011). The total proteins extracted were digested with trypsin and the peptides analysed by LC-MS/MS in the MRM mode. Absolute quantitation was carried out by spiking the peptide mixture with isotope labelled synthetic peptide standards, previously designed as markers for each allergen, according to the protein absolute quantification (AQUA) strategy. The concentration of the eight allergens in soy seeds ranged approximately from 0.5 to 5.7 µg/mg of soy protein. The impact of food processing on these specific peptides was investigated in another study (Cucu et al., 2012b), which aimed at identifying soybean-derived tryptic markers stable to processing (e.g. denaturation, Maillard reaction, oxidation) using MALDI-TOF/MS and MS/MS. Although several peptides were modified by the treatments, the most stable to processing were one from Gy1 glycinin (Gly m 6) and one from the α'-chain of β-conglycinin (Gly m 5). The study was not designed to provide LODs, but to provide the basis for a future quantitative method.

Two methods for the detection of soybean proteins in skimmed milk powder (SMP) have been developed for control purposes. One, based on nano-LC-MS/MS (Luykx et al., 2007) could detect 1-5 % of plant proteins in SMP (mainly glycinin and β-conglycinin), but was restricted only to the insoluble plant proteins in the borate buffer used for enrichment. The second was untargeted and analysed peptide mixtures resulting from the trypsin digestion of the entire SMP samples by a comparative RP nano-LC/Q-TOF MS, in combination with data dependent LC-MS/MS (Cordewener et al., 2009). No detection limits were provided.

A screening method for the simultaneous detection of seven allergens, including soy, based on LC-QpQ-MS, showed a LOD of 24 mg/kg for soy (Heick et al., 2011a).

19.6.3. DNA-based methods

End-point and real-time PCR for the detection of soybean in food products are available as alternative/complementary to ELISA. Most PCR tests are based on the amplification of the gene of soy lectin, and few on the gene of the soybean allergen Gly m Bd 30K DNA (Torp et al., 2006).

One study (Gryson et al., 2008) was aimed at detecting soy in bread following the addition of various soy ingredients (i.e. full-fat soybean flour, defatted soybean flour, toasted soy, soy protein isolate and soy fibre). Although DNA was partially degraded during the baking process of bread, the detection of soy by end-point PCR was still possible in the full-fat and defatted soybean flour (practical LOD 0.2 %) and in the soy protein isolate (practical LOD 1 %), whereas no amplification was possible for the soybean fibre and toasted flour.

An optimised end-point PCR protocol targeting the soybean lectin gene was able to detect soy DNA in 0.1 % and 0.5 % of hydrated textured protein, corresponding to 0.01 % and 0.06 % (w⁄w) of soybean protein in unprocessed and heat-processed pork meats, respectively (Soares et al., 2010). The absolute LOD reached a level of 10 pg of soybean DNA.

Two methods based on end-point and real time-PCR techniques were compared for detecting soy protein in commercial processed products by amplification of the lectin gene (Espineira et al., 2010). Both assays were specific, but the real time-PCR was more sensitive. The absolute LOD of end-point and real time-PCR was 100 pg and 10 pg of DNA for raw soy, 0.06 % and 0.05 % for soybean powder added to canned fish, and 100 and 10 mg/kg for soy flour contained in corn flour, respectively. A commercially available real time-PCR method for detection and quantification of soy in boiled sausages was validated in a ring trial (Siegel et al., 2012). The method was reproducible, allowing detecting a spike level of 10 mg/kg.

For a quantitative real time-PCR assay targeting the genomic regions of the soy allergens Gly mBd 28K and GlymBd 30K, the LOD was determined as 3.2 pg of genomic soy DNA, corresponding to 2.8 copies; the LOQ was 6.4 pg of DNA, corresponding to 5.7 copies for both copies (Platteau et al., 2011a)

A duplex real time-PCR method allowing the simultaneous detection of lupin and soy in processed (bakery and vegetarian) food products targeted DNA sequences coding for a mitochondrial gene which, being present in multiple copies per cell, increases the probability of obtaining positive results (Gomez Galan et al., 2011). The PCR platform is specific and sensitive, allowing the detection of lupin and soy at a level of 2.5 mg/kg food matrix.

A multiplex PCR by using Ligation-dependent probes targeting soy among other allergens was able to detect 13.6 ng of soy DNA (Mustorp et al., 2011). Two quantitative multiplex real time-PCR systems simultaneously determining DNA of eight allergenic foods, including soy, exhibited good specificity and sensitivity in the range of 0.01 % (LOD 10 mg/kg) (Köppel et al., 2010).

19.7. Minimal (observed) eliciting doses

Five clinical studies have assessed MEDs in soy allergic patients using food challenges with increasing doses of soy protein. In four studies, challenges were conducted for diagnostic purposes (Magnolfi et al., 1996; Zeiger et al., 1999; Fiocchi et al., 2003b; Rolinck-Werninghaus et al., 2012) and the fifth was a threshold-finding study (Ballmer-Weber et al., 2007).

In an Italian study (Magnolfi et al., 1996), 131 children aged one month to 18 years with clinical history of soy allergy and a positive SPT to soy were challenged with powdered soy formula in fruit juice using a DBPCFC design and rice or corn flour as placebo. Up to 200 mL of soy formula (13 %, 1.8 soy protein/100 mL) were administered at increasing doses (one drop, 1 mL, 5 mL, 10 mL, 50 mL and 134 mL) every 20 min. Alternatively, up to 40 capsules containing soy flour (88 mg soy protein/capsule) were administered every 20 min at increasing doses (1, 2, 3, 5, 10 and 19 capsules).

Children with no symptoms were given 200 mL of soy milk for the following days. Clinical reactions to the challenge were observed in eight (6 %) of the children. Immediate reactions (3-15 min) were observed in five children, of which two reacted to the first dose of 88 mg soy protein. Delayed (gastrointestinal) reactions were noted in three children (at 4 hours, 3 and 7 days of ingestion).

In another Italian study (Fiocchi et al., 2003b), 18 children with CMA who developed clinical reactions to a soy-based formula after a 2–18 months treatment were recruited and challenged with a soy formula in a diagnostic DBPCFC. None of the children had history of analphylaxis to soy. Doubling doses of 12, 24, 48 and 96 mL of soy milk were used, unless symptoms occurred. There were seven cases of immediate symptoms and 11 delayed reactions occurring between 2 and 48 h following the DBPCFC with soy milk. All delayed reactions were observed with the maximum cumulative dose used (180 mL), whereas immediate symptoms were already observed at the lowest dose tested in one subject, and at cumulative doses of 36 mL and 84 mL in three subjects each.

In a study conducted in the US (Zeiger et al., 1999), eight children (age ≤ 3.5 years) with CMA and history of soy allergy were challenged for diagnostic purposes (confirmation of soy allergy) by DBPCFC (n = 8) or OFC (n = 2) with 6 to 7 doubling doses of soy milk (starting from one drop to 5 mL depending on the child sensitivity) given at 10-15 min intervals up to 100 mL. Children with convincing history of anaphylaxis and a high level of soy IgE (> 10 U/mL) (n = 2) were excluded from the challenge. The minimal cumulative dose eliciting an allergic reaction was 29 mL of soy milk.

In a multicenter trial conducted in Germany, Italy and Denmark (Ballmer-Weber et al., 2007), 30 patients with a history of soy allergy (age range 1-69 years) underwent a titrated DBPCFC with nine increasing doses containing 0.002, 0.008, 0.148, 0.296, 1.183, 2.367, 4.734, 9.47, and 31.8 g of soy flour in a chocolate bar, respectively, administered at intervals of 15 min until objective allergic symptoms or ingestion of the whole meal occurred. Five patients were included on the basis of a convincing history of anaphylaxis to soy. Twelve patients experienced subjective symptoms (e.g. OAS, nausea, gastrointestinal pain or thoracic tightness), whereas objective symptoms (e.g. blistering of the oral mucosa, rhinoconjunctivitis, urticaria, flush, diarrhoea, decrease in blood pressure) occurred in 11. Since none of the patients reacted to the first dose, the NOAEL was 2 mg of soy flour (1.1 mg of soy protein). The LOAEL for subjective symptoms was 10 mg of soy flour (5.3 mg of soy protein) and the LOAEL for objective symptoms 454 mg of soy flour (240.6 mg of soy protein).

The aim of the last study (Rolinck-Werninghaus et al., 2012) was to evaluate the relationship between eliciting allergen doses, IgE levels and predictive factors, and the outcome of food challenges in children. Oral food challenges were performed in 317 children (median age 1.1 years; age range 0.3-16.1) with a suspected history of soy allergy, i.e. objective clinical symptoms in conjunction with soy-specific IgE. Seven increasing doses were administered at 30-min intervals using a semi-log scale. The first and last doses of soy protein were 4 mg and 3.6 g (0.1 and 100 mL of soy milk), respectively. The severity of objective clinical symptoms was graded following a five-level grading system, from grade I (skin symptoms and/or gastrointestinal tract symptoms with no respiratory, cardiovascular, neurological symptoms) to grade V (skin symptoms and/or gastrointestinal tract symptoms plus respiratory symptoms plus cardiovascular symptoms). Objective symptoms occurred at all doses of soy tested (Grade I for doses 4 mg; 11 mg; 36 mg; 110 mg and 360 mg of soy protein), but the majority of patients had symptoms only after the higher doses were given (grades II and III at 1.1 g of soy protein; grades I to IV at 3.6 g of soy protein). The MED in this study was 4 mg of soy protein, the lowest dose tested.

Minimal doses reported to elicit symptoms in soy allergic individuals are variable depending on the study population, challenge protocol and food matrix tested. The lowest MED reported in soy allergic patients undergoing DBPCFC was 4 mg of soy protein and the lowest MOED 88 mg of soy protein, with a NOAEL of 2 mg. However, few data are available on the doses which may trigger allergic reactions in patients with anaphylactic reactions to soy, which were often excluded from challenge tests, or on the doses which may trigger non-IgE mediated, late and mostly gastrointestinal reactions,

which are difficult to assess and has not been done prospectively. It is also unclear whether these patients may react to small amounts of allergen over a prolonged period of exposure.

19.8. Conclusion

Severe and/or fatal anaphylaxis reactions to soy and soy containing foods seem to be rare. Higher rates of anaphylactic reactions to soy protein have been reported among peanut allergic patients. The prevalence of clinically confirmed soy allergy in unselected populations in Europe appears to be low, although available studies are scarce. Serological and clinical cross-reactions have been described between soy and other legumes, with the pollen allergen Bet 1 v, and with bovine casein. Thermal processing, HHP treatments and fermentation have been shown to reduce the IgE-binding capacity of soy proteins, depending on the conditions and duration of the processes. The detection of soy proteins by ELISA is variable and strongly influenced by processing, while methods based on DNA are more robust and present good sensitivity and specificity. Quantitative determination of soy allergenic proteins by MS is possible, but not yet suitable for the analysis of large numbers of samples. The lowest MED reported in soy allergic patients undergoing DBPCFC was 4 mg of soy protein and the lowest MOED 88 mg of soy protein, with a NOAEL of 2 mg. However, few data are available on the doses which may trigger allergic reactions in patients with anaphylactic reactions to soy, which were often excluded from challenge tests, or on the doses which may trigger non-IgE mediated, late and mostly gastrointestinal reactions, which are difficult to assess and has not been done prospectively.

20. Allergy to fish

20.1. Background

Fish are water-living non-mammalian vertebrates, breathing with permanent gills, with finger-less fins. In the regulatory literature, the terms finned fish or finfish are often used to distinguish fish from shellfish (crustaceans and molluscs).

Fish is a common food in all European countries. However, fish intake varies considerably between different regions, depending on local traditions and supplies. Traditionally, consumption has been highest in coastal areas, but this pattern may have become less pronounced. Fish consumption also appears to vary greatly between families and individuals (Welch et al., 2002; Wennberg et al., 2012).

Fish allergy was demonstrated in a classical study early in the history of allergology (Prausnitz and Küstner, 1921) and fish is considered one of the eight most common allergenic foods, which are collectively considered to be responsible for about 90 % of food allergic reactions (Hebling et al., 2012). The route of exposure appears to determine whether food allergy or respiratory allergy to fish develops. Food allergy to fish is thought to be induced and triggered mainly via the peroral-gastrointestinal route (Untersmayr et al., 2007). In some fish-processing workplaces, respiratory allergy to fish has been a considerable problem because of inhaled allergen (Douglas et al., 1995; Rodríguez et al., 1997; Jeebhay et al., 2000).

This section addresses IgE-mediated food allergy to fish only. However, two important differential diagnoses should be mentioned, namely scombroid poisoning (histamine poisoning) and allergic reactions to the fish parasite *Anisakis simplex* (Sharp and Lopata, 2013). Scombroid poisoning can be caused by some fish species if stored under suboptimal conditions, owing to the conversion of histidine to histamine by bacterial enzymes (Prester, 2011; Demoncheaux et al., 2012). Allergic reactions caused by *Anisakis simplex* in infested fish (EFSA Panel on Biological Hazards (BIOHAZ), 2010; Pravettoni et al., 2012) can be very severe and clinically similar to fish allergy. Up to 35 % of allergic reactions experienced after ingestion of fish in Spain have been reported to be caused by *Anisakis* (Anibarro et al., 2007). Allergy owing to *Anisakis* and scombroid poisoning will not be further discussed in this Opinion.

20.2. Epidemiology

20.2.1. Prevalence

Data on the prevalence of well-documented fish allergy in the general population are scarce. The majority of prevalence estimates have been gathered using questionnaire-based methods (self-reported, clinical history, diagnosis by a clinician), although sensitisation rates (SPT, specific IgE) have also been assessed in some studies. Comparisons between studies are difficult owing to differences in the methodologies used and age ranges assessed.

20.2.1.1. Europe

Prevalence of self-reported fish allergy ranged from 3.5-7 % in Finnish children ≤ 4 years of age (Kajosaari, 1982; Pyrhonen et al., 2009), although only 1 % reported a clinician-diagnosed fish allergy (Pyrhonen et al., 2009). Prevalence of self-reported allergy to fish in children was lower in other Northern European countries with high fish consumption, like Iceland (1.5-2.2 %) (Kristjansson et al., 1999), Norway (1.5 %) (Eggesbo et al., 1999) or Sweden (1.2-3.2 %) (Eggesbo et al., 1999; Kristjansson et al., 1999). Self-reported allergy to cod in children ranged from 0.3 % in the UK (Venter et al., 2006a) to 1.6 % in Sweden (Ostblom et al., 2008b). In children > 4 years old and adolescents, prevalence of self-reported allergy ranged from 0.3 % and 2.3 % in Turkey (Orhan et al., 2009; Mustafayev et al., 2012), Greece (Zannikos et al., 2008), the UK (Pereira et al., 2005), Sweden (Ostblom et al., 2008a) and the Netherlands (Brugman et al., 1998) and was highest in France (4 %) (Touraine et al., 2002) and Spain (6.9 %) (Martínez-Gimeno et al., 2000). The scarce data available for adults come from Southern countries, where a prevalence between 0.4 % (Turkey) (Gelincik et al., 2008) and 1.9 % (Greece) (Sakellariou et al., 2008) has been reported.

In the European Community Respiratory Health Survey (Burney et al., 2010), prevalence and country distribution of sensitisation to 24 allergenic foods were determined in sera collected around the year 2000 in 4522 young adult individuals of the general population in 13 countries. The average prevalence of sensitisation to any food was 16.2 %. The prevalence of sensitisation to fish (0.2 %) was the lowest among the 24 foods tested, and was considerably lower than the prevalence of sensitisation to crustaceans (shrimp, 5.4 %). The highest prevalence was reported in Germany (0.9 %), followed by Spain (0.5 %), Norway and Sweden (both with 0.3 %). Sensitisation rates (positive SPT) to cod in children 1-6 years of age in the UK were up to 1 % (Arshad et al., 2001; Roberts et al., 2005; Venter et al., 2006a), and up to 1.4 % to any fish in adolescents (Pereira et al., 2005).

The few studies available using DBPCFC to confirm a clinical history of fish allergy consistently show a zero prevalence of fish allergy (Denmark (Osterballe et al., 2005); Turkey (Gelincik et al., 2008) except in 6-year old Finnish children, where it was up to 1 % (Kajosaari, 1982).

20.2.1.2. Outside Europe

Prevalence of fish allergy using questionnaire-based methods in countries with Western lifestyle outside Europe is generally below 1 % and no studies are available using DBPCFC to confirm a clinical history of fish allergy (University of Portsmouth, 2013).

20.2.2. Natural history

In contrast to clinical allergies to milk, egg, wheat and soy, which are typically outgrown despite frequently persistent positive SPT, clinical allergy to fish is often “life-long” (Bock, 1982; Eigenmann and Sampson, 1998; Priftis et al., 2008). However, fish allergy may sometimes resolve (Solensky, 2003; Pite et al., 2012), as reported for 3.5 % of fish allergic patients in one American study (Sicherer et al., 2004). Thus, fish-allergic patients should be re-evaluated from time to time.

20.2.3. Time trends

Few studies are available to examine time-trends for fish allergy. The prevalence of self-reported allergy to fish in Finnish children 1-3 years of age was assessed in 1980 (Kajosaari, 1982) and in 2001

(Pyrhonen et al., 2009). Prevalence of self-reported fish allergy slightly decreased from 7.5-% to 3.5 % in one-year olds, from 6 % to 5 % in two-year olds and from 5 % to 3.6 % in three-year olds within that time frame. In 1980, 4.5 % of children four years old reported allergy to fish, but only 1 % of children 6 years old in 2001. In the UK, 0.7 % of a 4-year old cohort and 0.5 % of a 3-year old cohort had a positive SPT in 1993 (Arshad et al., 2001) and 2001 (Venter et al., 2008), respectively.

There are no more recent data available to identify any time trends in fish allergy.

20.2.4. Severe reactions/anaphylaxis

Food allergic reactions to fish can be severe and sometimes fatal. Fish meat is one of the foods most commonly provoking severe anaphylaxis (Sampson, 2000; Lopata and Lehrer, 2009). There are also a number of reports on anaphylactic reactions to caviar and roe from various fishes (Untersmayr et al., 2002; Makinen-Kiljunen et al., 2003; Flais et al., 2004; Kondo et al., 2005; Escudero et al., 2007; Perez-Gordo et al., 2008; Chen et al., 2009; Gonzalez-De-Olano et al., 2011).

20.2.5. Factors affecting the prevalence of fish allergy

Fish allergy often manifests in young children, but it can also manifest at any age. In one study of 79 patients with clinical fish allergy (Pascual et al., 1992), the age of onset was 0-6 months in 24 %, 7-12 months in 51 %, 13-18 months in 8 %, 19-24 months in 6 %, and > 24 months in 11 % of subjects. Age distribution in a patient study can be biased for several reasons, but these data are in conformity with the perception that fish allergy tends to develop in the first year of life, although somewhat later than allergy to cows' milk and hens' egg.

20.3. Identified allergens

Fish allergens included in the IUIS database are shown in Table 21.

Table 21: Fish (*Animalia chordata*) allergens

Biochemical name	Allergen	Common name	Scientific name	Source	Molecular weight[a]
β-Parvalbumin	Clu h 1	Atlantic herring	*Clupea harengus*	Fish meat	12[1]
	Cyp c 1	Carp	*Cyprinus carpio*		
	Gad c 1	Codfish	*Gadus callarias*		
	Gad m 1	Atlantic cod	*Gadus morhua*		
	Lat c 1	Barramundi	*Lates calcarifer*		
	Lep w 1	Whiff	*Lepidorhombus whiffiagonis*		
	Onc m 1	Rainbow trout	*Oncorhynchus mykiss*		
	Sal s 1	Atlantic salmon	*Salmo salar*		
	Sar s 1	Pacific pilchard	*Sardinops sagax*		
	Seb m 1	Ocean perch	*Sebastes marinus*		
	Thu a 1	Yellowfin tuna	*Thunnus albacares*		
	Xip g 1	Swordfish	*Xiphias gladius*		
Tropomyosin	Ore m 4	Mozambique tilapia	*Oreochromis mossambicus*	Fish meat	33[b]
β-Enolase	Gad m 2	Atlantic cod	*Gadus morhua*	Fish meat	47.3[b]
	Sal s 2	Atlantic salmon	*Salmo salar*		47.3[b]
	Thu a 2	Yellowfin tuna	*Thunnus albacares*		50
Aldolase A	Gad m 3	Atlantic cod	*Gadus morhua*	Fish meat	40
	Sal s 3	Atlantic salmon	*Salmo salar*		40
	Thu a 3	Yellowfin tuna	*Thunnus albacares*		40
Vitellogenin (β' component)	Onc k 5	Chum salmon	*Oncorhynchus keta*	Fish roe	18[b]

[1] Approximate – slight variation exists between species; [a] MW (SDS-PAGE); [b] kDa

Parvalbumin is a major fish allergen, which is found in all fish species (panallergen). However, fish also contains a number of other allergens, some of which have been recently characterised and identified. For example, Baltic codfish contains other allergens than the parvalbumin Gad c 1 (Aukrust et al., 1978a; Aukrust et al., 1978b; Dory et al., 1998). A total of 18 IgE-binding bands in freshly prepared codfish extract were identified by immunoblotting (Hansen et al., 1996). In one study, only one of eight tuna fish allergic patients had IgE-binding to parvalbumin (Yamada et al., 1999).

Cod parvalbumin is widely used as a general test allergen for sensitisation to fish, and IgE to cod is widely used as a marker of sensitisation to fish (de Martino et al., 1990). However, for patients with allergy to a single or a limited number of fish species, test allergens should be chosen according to the patient's history to avoid 'false negative' results (Kuehn et al., 2013).

While fish muscle and fish skin appear to share allergens, fish roe contains allergens not found in muscle or skin. Fish roe allergic individuals will often tolerate fish (Makinen-Kiljunen et al., 2003; Escudero et al., 2007; Chen et al., 2009).

20.3.1. Fish muscle and skin

20.3.1.1. Parvalbumins

Parvalbumin was first described in codfish (Aas and Jebsen, 1967; Elsayed and Apold, 1983) as one of the first allergens characterised at the molecular level. Parvalbumin is a vertebrate-specific, mainly cytosolic, globular acidic (pI 3.9-5.5), Ca^{++}-binding small protein (106–113 residues, MW ~ 12 kDa) of the EF-hand superfamily, and is expressed in fast-twitch muscles and, to some extent, in certain other cells and organs (Arif, 2009). Two phylogenetic lineages of parvalbumin, α and β, differ in isoelectric point (pI > 5 and pI < 5 for α and β parvalbumin, respectively) and features of amino acid sequence, but share a similar tertiary structure. Both have 30-residue long sub-domains, each containing a central loop flanked by short amphipathic α-helices (Nakayama et al., 1992). Allergenicity of fish is related to the presence of β-parvalbumins. The high structural stability of the Ca^{++}-loaded form confers relative resistance to cooking and digestion in the gastrointestinal tract. Allergenicity of parvalbumins is greatly reduced by calcium depletion (Bugajska-Schretter et al., 2000) owing to conformational changes in the Ca++-binding region, which is an IgE-binding epitope (Declercq et al., 1991). Some allergenic determinants in parvalbumin appear to be sequential, which may explain the low tendency for remission of fish allergy. Biologically active parvalbumin has been demonstrated in serum samples as early as 10 min after ingestion, peaking after 1-2 hours, suggesting some pre-gastric absorption (Untersmayr et al., 2007).

Parvalbumins have been reported to be the major and only fish allergen for 95 % of patients suffering from IgE-mediated fish allergy (Swoboda et al., 2002). Parvalbumins differ among fish species and belong to the second (after tropomyosin) largest animal food allergen family, with at least 18 parvalbumins described as allergens and a large number of isoallergens. Isoallergens per definition show at least 67 % sequence identity, whereas isoforms with pairwise sequence identity above 90 % are referred to as 'microheterogenous isoforms' (Chapman et al., 2007). Since even microheterogenous isoforms of some allergens may induce very different responses by human T and B cells (Wagner et al., 2008) and microheterogenous isoforms are common in parvalbumin (Lapteva et al., 2013), allergic immune responses may be elicited by a wide repertoire of molecular forms of the same allergen (Lapteva et al., 2013). Certain species of fish (e.g. African catfish) display up to eleven parvalbumin isoforms (Huriaux et al., 2002). Further, parvalbumins have a predisposition for intrinsic disorder (Permyakov et al., 2008) which may contribute to their allergenicity (Xue et al., 2011).

There is evidence that the allergenicity of different fish species may differ to some extent, with e.g. hake and cod reportedly being among the more allergenic, and albacore tuna being among the less allergenic (Bernhisel-Broadbent et al., 1992; Pascual et al., 1992; Pascual et al., 2008). This is in part due to the different levels of expression of parvalbumin in different fish species (Kuehn et al., 2009). Further, parvalbumin content differs in various locations within the whole fish, decreasing in the

anterior to posterior direction (Lee et al., 2012), and white fish muscle expresses higher parvalbumin levels than dark fish muscle (Lim et al., 2005; Kobayashi et al., 2006).

20.3.1.2. Collagen

Collagen is ubiquitously found as an extracellular matrix protein in animals. Native collagen is composed of three homo or hetero α-chains twisted together to form a triple helix, and is insoluble in water at low temperature. If collagen is denatured, each α-chain is released from the triple helix, and the denatured form of collagen, i.e. gelatine, is water-soluble. Fish skin from several fish species such as cod, pollock, tuna and salmon is used for the preparation of fish gelatine (Taylor et al., 2004). Some muscle tissue is likely to adhere to the skin used for collagen preparation (Koppelman et al., 2012). Isinglass is derived from the swim bladder of certain fish and consists predominantly of collagen.

Although fish collagen has been proposed to be an allergen based on IgE-binding studies and two clinical case reports (Sakaguchi et al., 1999; Sakaguchi et al., 2000; Hamada et al., 2001; Kuehn et al., 2009; Liu et al., 2012b), data from two DBPCFCs studies in fish-allergic patients (Andre et al., 2003; Hansen et al., 2004) suggest that its clinical importance is very limited. Thus, whereas fish collagen is a sensitiser, its ability to trigger allergic reactions is uncertain, in contrast to mammalian collagen, which can cause severe allergic reactions. Mammalian and fish collagens do not crossreact (Hamada et al., 2001).

20.3.1.3. Tropomyosin

Tropomyosin is a major allergen in crustaceans and molluscs, but has only been described as an allergen in one fish i.e. tilapia (*Oreochromis mossambicus*) (Liu et al., 2013).

20.3.1.4. Enolase and aldolase

β-enolase and aldolase are enzymes which have been described as allergens of clinical relevance in e.g. codfish, salmon and tuna (Hajeb and Selamat, 2012; Liu et al., 2012b; Kuehn et al., 2013; Sharp and Lopata, 2013; Tomm et al., 2013).

20.3.2. Fish roe allergens

Some clinical reports on anaphylactic reactions and local symptoms to caviar and roe are well documented, but no published DBPCFC studies on fish roe or caviar are available. The reports consistently suggest that roe allergens are different from fish meat allergens because fish roe allergic patients were often not allergic to fish meat. Several authors have identified vitellogenin (fragments) as allergens in fish roe (Untersmayr et al., 2002; Perez-Gordo et al., 2008; Shimizu et al., 2009). In one case, the presumed allergen (based on immunoblotting) showed homology with α-S1-casein from cow's milk (Chen et al., 2009).

20.4. Cross-reactivities

20.4.1. Cross-reactivity among fish species

20.4.1.1. Fish meat and skin allergens

Parvalbumin is responsible for most of the extensive cross-reactivity among fish species. However, owing to the broad repertoire of molecular forms of parvalbumin and the small role of other allergens, patterns of serological and clinical cross-reactivity are difficult to predict (Hansen et al., 1997; Helbling et al., 1999; Van Do et al., 2005). Extensive serological and clinical cross-reactivity has been observed among closely related as well as among more distant fish species (Bernhisel-Broadbent et al., 1992; Pascual et al., 1992; Hamada et al., 2003). It has been reported that about 50 % of individuals allergic to one type of fish will react to a second fish species, and that up to 40 % of patients sensitised to one or more species of fish do not present symptoms when consuming some other species (Torres Borrego et al., 2003). Fishes in the *Scombroideae* family, which includes tuna, appear to be the best tolerated.

Sera from eight patients clinically allergic to codfish showed cross-reactivity with cod, mackerel, herring and plaice. Clinical cross-reactivity was verified by DBPCFC (Hansen et al., 1997). Extensive cross-reactivity among 17 fish species as determined by SPT, RAST, and clinical history was also observed in fish allergic patients (de Martino et al., 1990). SPT, serological studies and DBPCFC in nine subjects with clinical symptoms attributed to fish allergy confirmed the broad serological and clinical cross-reactivity among fishes, but also showed that individuals with high specific IgE values to some fish species can have low or undetectable levels of specific IgE to other fishes (Helbling et al., 1999).

Bernhisel-Broadbent Bernhisel-Broadbent et al. (1992) studied clinical cross-reactivity to 10 fish species in 11 patients, each of whom was challenged with four to six fish species. Oral challenges were positive to one fish only in seven patients, to two fishes in one patient, and to three fishes in two patients, suggesting that most fish allergic patients are able to eat one or more fish species without symptoms. However, cross-reactivity among fishes is so broad and unpredictable that fish allergic subjects should be advised to avoid all fish species until a fish species has been proven safe by food challenge (Helbling et al., 1999).

The variation in cross-reactivity among individuals can be explained by differences between IgE-binding parvalbumin epitopes in different fish species, combined with different allergen and epitope preferences by different individuals. There are only two case reports describing cross-reactivity between fish species (bluefin tuna and marlin; pangasius and tilapia) without parvalbumin being involved (Kondo et al., 2006; Ebo et al., 2010a). Collagen is assumed to play a role in cross-sensitisation between fishes (Kuehn et al., 2013), but there are no studies specifically addressing this question. Cases with apparent monosensitisation to one fish species or group of fish have been described, e.g. to swordfish, to tuna, to pollock, to codfish, to tropical sole, and to salmonid fishes (Mata et al., 1994; Kelso et al., 1996; Galland et al., 1998; Asero et al., 1999; Yamada et al., 1999; Kuehn et al., 2011), suggesting that some allergens may be species specific (e.g. specific for yellowfin tuna as compared to albacore tuna) (Yamada et al., 1999).

20.4.1.2. Fish roe

Different patterns of serological cross-reactivity against roe from different fish species (e.g. salmon, cod, trout, hake, herring, pollock) have been observed in various studies, consistent with the fact that different individuals show different allergen and epitope preferences (Makinen-Kiljunen et al., 2003; Escudero et al., 2007; Shimizu et al., 2009). However, broad cross-reactivity between roe from different species appears to be common (Shimizu et al., 2009).

20.4.2. Cross-reactivity between fish and other species

20.4.2.1. Fish meat and skin allergens

Allergenicity in fish is found with β-parvalbumins, while in frog and chicken it is associated with α-parvalbumins. However, both forms of parvalbumin appear to be present in all species mentioned. Some antibodies react with both α- and β-parvalbumins, and rare cases of cross-allergy between fish and chicken (Gonzalez-de-Olano et al., 2012) and between fish and frog (Hamada et al., 2004; Hilger et al., 2004) have been reported, claimed to be caused by cross-reactivity between fish β-parvalbumin and chicken and frog α-parvalbumins, respectively.

There is no IgE cross-reactivity between fish and mammalian collagens (Hamada et al., 2001), and no cross-reactivity between fish and bovine or porcine gelatines has been demonstrated (Sakaguchi (Sakaguchi et al., 1999; Andre et al., 2003).

There is no information on whether tilapia fish tropomyosin cross-reacts with tropomyosins of other species.

5750 20.4.2.2. Fish roe allergens

5751 IgE cross-reactivity between salmon roe and the phylogenetically distant sea urchin roe has been
5752 reported (Kondo et al., 2011). Vitellogenin, identified as an allergen in fish roe, is also an allergen in
5753 chicken's egg (Gal d 6), but there is no IgE cross-reactivity between fish roe and chicken's egg
5754 (Koyama et al., 2006; Kondo et al., 2011).

5755 **20.5. Possible effects of food processing on allergenicity**

5756 **20.5.1. Heat and other food treatments**

5757 Parvalbumin is resistant to boiling and other high temperature processing. It has "sequential" epitopes
5758 which keep their IgE-binding capacity and allergenicity after heating at 100 ^{o}C for 10 min, and after
5759 digestion with proteolytic enzymes or denaturation with chemicals (Elsayed and Aas, 1971; Elsayed
5760 and Apold, 1983). The Ca^{++}-binding region is an IgE-epitope (Declercq et al., 1991) and is highly
5761 stabilised by calcium binding (Bugajska-Schretter et al., 2000).

5762 Using sera from fish allergic patients, IgE-binding to fresh and processed (smoked, salted/sugar-cured,
5763 canned, lye-treated and fermented) cod, haddock, salmon, trout, tuna, mackerel and herring, and to
5764 hydrolysates based on salmon and whiting, was investigated using immunoblot and inhibition ELISA.
5765 The various treatments often, but not consistently, reduced IgE-binding, whereas some treatments and
5766 some sera also showed increased IgE-binding (Sletten et al., 2010).

5767 Bigeye tuna collagen was found to be very thermostable as to its IgE-binding capacity (Hamada et al.,
5768 2001). Even when denatured to gelatine by heating in a boiling water bath for 120 minutes, the bigeye
5769 tuna collagen retained 90 % of its original binding capacity for specific IgE.

5770 A number of other fish allergens are temperature-sensitive, e.g. some enzymes. Although IgE-binding
5771 proteins were observed for cooked or canned tuna, the biologic function was absent when tested in the
5772 histamine release assay. This may explain why cooked or canned fish (e.g. salmon, tuna) may be
5773 tolerated by individuals who react to undercooked or raw fish (Bernhisel-Broadbent et al., 1992). It
5774 should be noted that some patients appear to react to cooked fish but not to raw fish (Prausnitz and
5775 Küstner, 1921).

5776 Glycosylation of parvalbumin appears to increase IgE binding without affecting digestibility, and thus
5777 food processing under certain conditions may increase the allergenicity of parvalbumin (de Jongh et
5778 al., 2013).

5779 In conclusion, heat treatment during food preparation and some other types of traditional food
5780 processing may reduce IgE-binding capacity in some cases, but do not represent a reliable method to
5781 render fish less allergenic.

5782 **20.5.2. Highly processed and novel fish-based products**

5783 20.5.2.1. Surimi

5784 Surimi is a product made of minced and thoroughly washed fish meat which is cooked only briefly at
5785 low temperature (Musmand et al., 1996). It has numerous applications in food industry. It can be made
5786 from one (e.g. cod, Alaskan pollock, mackerel) or more fish species and retains much of its
5787 allergenicity after processing (Helbling et al., 1992; Mata et al., 1994; Musmand et al., 1996), 1992).
5788 In one study (Mata et al., 1994) a 63 kDa protein in codfish was the single allergenic protein detected
5789 in surimi, whereas the 13 kDa parvalbumin was presumably washed out during surimi preparation.
5790 Allergy to surimi has been verified by DBPCFC in a patient who reacted to 1 g of surimi (Musmand et
5791 al., 1996).

20.5.2.2. Ice-structuring proteins

Ice-structuring proteins (ISP) are naturally occurring proteins that bind to ice and structure ice crystal formation. Their function is to help protecting organisms in cold habitats from ice crystal damage. ISP can be isolated from fish living in or near Arctic waters, they have been produced using recombinant baker's yeast, and are a novel food ingredient with a number of commercial applications in the food industry. ISP preparations did not bind specific IgE to fish, and other evidence for allergenicity has not been found (Baderschneider et al., 2002; Bindslev-Jensen et al., 2003; Crevel et al., 2007).

20.5.2.3. Fish oils

Fish oils might contain fish allergens. However, no analytical studies are available and only one clinical study has been published. Six subjects (23 to 64 years, three female) who reported fish allergy (throat constriction, urticaria and angioedema) and had a positive SPT to at least three of six common fish species showed negative SPT to undiluted, unfiltered liquid extracted from softgel fish oil supplement capsules of two different brands (Mark et al., 2008). An oral challenge with one 1 000 mg capsule of each supplement (one hour apart) did not induce subjective or objective symptoms.

20.5.2.4. Fish gelatine and isinglass

Fish gelatine is derived from the skin of several fish species. After thorough washings to remove remaining muscle tissue, bones, salts and off-flavours, the skin is subjected to heating, acidic extraction and acidic and/or enzymatic hydrolysis. Fish gelatine is mostly used by dairy, confectionery, and pharmaceutical industries. Both fish gelatine and isinglass are widely used as fining agents in the production of beverages, such as wine and beer. Isinglass is derived from the swim bladders of fish by washing and cleaning, conditioning in hot water, removing muscle layers and blood vessels, and treating with hydrogen peroxide.

Fish gelatine and isinglass generally contain 80-95 % of collagen and related peptides. Depending on the degree of hydrolysis, they may contain molecules ranging from native collagens (MWs > 117 kDa) to short peptides (MWs < 40 kDa). Isinglass particles can be removed from the wine or beer by sedimentation and/or filtration. Low levels of parvalbumin have been reported in isinglass but not in gelatine (Weber et al., 2009b).

Fish gelatine-specific IgE antibodies have been identified in fish allergic patients (Sakaguchi et al., 2000). No adverse reactions were observed in two independent DBPCFC studies (Andre et al., 2003; Hansen et al., 2004) with gelatine derived from tuna and codfish. Neither research group observed allergic reactions of clinical relevance in a total of 33 fish allergic patients tested with a cumulative dose of 5 g fish gelatine (three patients) or with 14.6 g of fish gelatine (30 patients), respectively, although very few of the patients tested had specific IgE to collagen.

20.6. Detection of allergens and allergenic ingredients in food

Fish parvalbumins are abundant and stable proteins in fish meat. However, the measurement of fish parvalbumin concentrations in foods is complicated by the fact that parvalbumins show differences in different fish species and consequently IgG antibodies raised against them will show different binding patterns (Lee et al., 2011).

Immunological methods (mainly ELISA), mass spectrometry and PCR techniques have been used to detect parvalbumin in foods.

20.6.1. ELISA

A specific sandwich ELISA for the quantitative determination of fish using a polyclonal rabbit anti-cod parvalbumin antibody for capture and detection (Faeste and Plassen, 2008) was reported, with a LOD of 0.01 mg parvalbumin/kg food (or 5 mg fish/kg food). The recovery was very variable, ranging from > 50 % for nine fish species down to < 1 % for some others.

Purified parvalbumins from several fish species were used to develop a competitive indirect ELISA based on commercial PARV-19 anti-parvalbumin antibodies raised against frog muscle parvalbumin. The method allowed to detect all the parvalbumins investigated within a range of 0.1-0.5 mg/L (Weber et al., 2009b). ELISA methods to detect the presence of parvalbumin in fish gelatine and isinglass have been described (Lifrani et al., 2009; Weber et al., 2010; Koppelman et al., 2012) and used to detect fining agent residues in wine.

A sandwich ELISA for the determination of fish protein in processed foods used a polyclonal antibody raised against Pacific mackerel parvalbumin (Shibahara et al., 2013). The LOD was estimated to be 0.23 mg fish protein/kg food and the LOQ was 0.70 mg fish protein/kg food. The method was validated in inter-laboratory tests with a good recovery (69.4-84.8 %) and sufficient sensitivity and specificity. It could measure fish protein in 18 of the 21 processed foods tested, but not in fermented foods, where parvalbumin can be highly degraded to peptides.

Different types of antibodies have been used to develop ELISAs which show varying specificities for different fish species. Among three anti-parvalbumin IgG antibodies, a polyclonal anti-cod parvalbumin antibody, and the commercially available monoclonal anti-frog and monoclonal anti-carp antibodies, the polyclonal anti-cod parvalbumin antibody showed reactivity to the widest range of fish species (Lee et al., 2011). In general, polyclonal antibodies are more suitable than monoclonal antibodies to detect different fish species in processed foods.

ELISA methods seem to better recognise conformational epitopes than linear epitopes. Parvalbumin being a Ca^{+2} binding protein, Ca^{+2} depletion in the assay buffer may considerably change the conformation of the protein, thus decreasing the sensitivity of ELISA assays.

Polyclonal antibodies have also been raised against fish collagen and a sensitive indirect ELISA for the detection of fish gelatine and isinglass has been described (Weber et al., 2010). The LOD was $\leq$ 0.11 mg/mL.

20.6.2. Mass spectrometry

A method based on mass spectrometry for the rapid and direct detection of fish parvalbumin in food products has been described (Carrera et al., 2012). Parvalbumin is extracted, purified and digested by trypsin in High Intensity Focused Ultrasound (HIFU) equipment. Nineteen selected peptide biomarkers are separated by LC and monitored by Selected MS/MS Ion Monitoring (SMIM) in a linear ion trap mass spectrometer. The method was applied to several processed foods and allowed the identification of parvalbumin unequivocally, although no quantification has been provided.

20.6.3. PCR

PCR-based assays have been developed to detect fish DNA from different species. DNA is present in all tissues, stable at high temperature, and allows differentiation of closely related fish species.

A comparative study of methods for the extraction of DNA from fish muscle which utilise different principles of separation reported high variability in the extraction efficiency (Cawthorn et al., 2011). One method consistently extracted DNA with the highest yield from all fish species tested, but DNA purity was satisfactory for only 50 % of the extracts. Conversely, the method with the lowest yield provided the highest DNA purity.

Parvalbumin DNA of Pacific mackerel (*Scomber japonicus*) has been detected in food by conventional PCR (Choi and Hong, 2007). Parvalbumin DNA has been detected in different tissues of sturgeon species (*Acipenser*) by reverse-transcription (RT)-PCR (Rehbein and Lopata, 2011). Conventional PCR methods have also been set for the specific detection of salmonoid fish (Ishizaki et al., 2012) and Atlantic herring (Rencova et al., 2013) in processed foods, with LODs of 0.02 fg DNA/µL (corresponding to 10 DNA copies) and of 10 pg DNA/µL, respectively.

A real-time PCR assay (Sun et al., 2009) detects parvalbumin DNA from several fish species with a LOD of 5 pg DNA, but it is not species specific. An assay which identifies eight fish species in food was developed by using PCR for amplification of fish parvalbumin introns and the multianalyte profiling (xMAP^{TM}) technology with probes targeting species-specific sequences (Hildebrandt, 2010). The LODs for the eight fish species ranged from 0.01 % to 0.04 %. The assay showed no cross-reactivity with other species.

20.7. Minimal (observed) eliciting doses

In a DBPCFC (Hansen and Bindslev-Jensen, 1992), the minimum amount of codfish needed to elicit a reaction (starting at 5 mg and going up to 5 g) was 6 mg. The lowest eliciting doses of fish in DBPCFCs from various investigators ranged between 5 mg (cod, herring) and 500 mg (mackerel) or 600 mg (plaice) (Taylor et al., 2002). In a DBPCFC (Untersmayr et al., 2007), adverse reactions to codfish protein with cumulative doses ranging between 1.11 mg and 3.11 mg of fish protein for fish preparations digested at pH 3.0 were reported.

The Panel notes that MEDs reported in DBPCFCs range from 5mg to 600mg of fish depending on the study and the fish species tested, and from 1.11 mg to 3.11 mg of fish protein. Few data are available on the doses which may trigger allergic reactions in highly sensitive patients, who are often excluded from challenge tests but tend to react to lower doses than patients with mild symptoms.

20.8. Conclusion

Fish is widely consumed in all European countries and is among the foods most commonly triggering IgE-mediated allergic reactions, which can be severe and occasionally fatal. Fish meat is one of the foods most commonly triggering severe anaphylaxis. Prevalence of well documented fish allergy in the general population is well below 1 %. The major fish allergens are well characterised and heat-resistant. Parvalbumin is responsible for most of the extensive and unpredictable cross-reactivity among fish species. ELISA and MS, as well as PCR techniques, have been used successfully to detect parvalbumins and DNA belonging to different fish species in foods. The minimal doses observed to elicit a clinical reaction were 5 mg of fish and 1.1 mg of fish protein. Few data are available on the doses which may trigger allergic reactions in highly sensitive patients.

21. Allergy to crustaceans

21.1. Background

Crustaceans are common food in all European countries. Few accurate consumption data are available, but seafood intake in general is considered to vary considerably between different regions, depending on local traditions and supplies. Similar to fish, the route of exposure for crustaceans appears to determine whether food allergy, skin allergy or respiratory allergy develops. In some food processing workplaces, respiratory allergy to crustaceans has been a considerable problem owing to inhaled allergen (Lopata and Jeebhay, 2013).

Decapod crustaceans (e.g. shrimp, prawn, crab and lobster) are of main interest as allergenic foods. However, some non-decapod crustaceans like krill, mantis shrimp and barnacles have recently been reported to be allergenic and may become more important because of food trends. Krill is mainly consumed as unrefined oil in Europe, whereas in e.g. Russia, Japan and Korea, krill is used also in various processed foodstuffs.

21.2. Epidemiology

21.2.1. Prevalence

21.2.1.1. Europe

Studies reporting on the prevalence of allergy to crustaceans in the general (unselected) European population are scarce.

In the few studies available, the prevalence of self-reported crustacean-related adverse reactions to food in children ranged from 0.1 % and 0.3 % in Greece (Zannikos et al., 2008) and the UK (Pereira et al., 2005) to 5.5 % in France (Touraine et al., 2002). Figures reported from the Netherlands (Brugman et al., 1998), Sweden and Iceland (Kristjansson et al., 1999) were within that range (0.7-1.5 %). Prevalence of self-reported allergy to shrimps was 0.5 % in 2-14 year old Finch children (Rancé et al., 2005).

In adults, estimated sensitisation rates to crab in Germany (Schafer et al., 2001) based on positive SPTs were similar to those reported in Hungary (Bakos et al., 2006) based on specific IgE testing (1.9 % and 1.8 %, respectively).

Prevalence rates of allergy to crustaceans based on clinical history and positive SPT in the German general population were much lower (0.2 %) (Zuberbier et al., 2004). Only one study conducted in Denmark reported challenge proven prevalence data for shrimp allergy, which ranged from zero in subjects < 22 years to 0.3 % in subjects > 22 years (Osterballe et al., 2005).

21.2.1.2. Outside Europe

Most prevalence data available from Western countries outside Europe have been collected using questionnaire-based methods (self-reported, physician's diagnosis) and do not relate to crustaceans specifically but rather to "seafood" or "shellfish". In Canada, rates of total self-reported allergic reactions to shellfish among children were about 0.5 %, and 0.1 % when diagnosis was made by a clinician (Ben-Shoshan et al., 2010). Self-reported allergic reactions to shellfish in adults varied in the US, ranging from 1.7 % (Vierk et al., 2007) to 9 % (Greenhawt et al., 2009). In Australia, self-reported allergic reactions to shrimp were 3.3 % (Woods et al., 2002).

Higher rates of self-reported allergic reactions were observed in some Asian countries, both for adults (24.5 %; China) (Sai et al., 2011) and children (8.7 % and 11.6 %, respectively; Philippines) (Connett et al., 2012). However, the only study which used OFC to confirm diagnosis reported a prevalence of clinical allergy to crab and shrimp of 0.2 % and 0.9 %, respectively, among 3-7 year olds in Thailand (Lao-araya and Trakultivakorn, 2011).

21.2.2. Natural history

There are no data available regarding the natural history of crustacean allergy, apart from a report suggesting that shrimp sensitisation decreases with age (Ayuso et al., 2010).

21.2.3. Time trends

The only information available on time trends comes from China and relates to the prevalence of sensitisation to shrimp in infants and young children, which was zero and 0.3 % in 1999 and 2009, respectively (Hu et al., 2010).

The data available are insufficient to conclude on time trends regarding the prevalence of allergy to crustaceans in Europe.

21.2.4. Severe reactions/anaphylaxis

Crustacean allergy was early recognised to cause severe allergic reactions and occasionally fatal anaphylaxis (Yunginger et al., 1988; Bock et al., 2001). In a multicentre study of anaphylactic reactions to food (Moneret-Vautrin and Kanny, 1995), crustaceans accounted for 11 % (9/81) of cases. Crustaceans were incriminated on the basis of clinical history, SPT and serum specific IgE in 17 % of 60 cases of severe, near-fatal reactions in another study (Andre et al., 1994).

21.2.5. Factors affecting prevalence of crustacean allergy

Allergy to crustaceans mostly affects the adult population (Crespo and Rodriguez, 2003; Skypala, 2011). Nevertheless, shellfish (crustaceans and molluscs) appears to be responsible for a majority of emergency department visits for food allergy also in children ≥ 6 years of age in the US, and represents a significant cause of allergic reactions in children one to six years of age (Ayuso et al., 2009).

Crustacean allergic children show higher levels of specific IgE to shrimp allergens and a broader epitope repertoire than adults, indicating a higher IgE reactivity (Ayuso et al., 2010). It has been suggested that children tend to react more to raw crustaceans and adults to boiled crustaceans (Ayuso et al., 2010), and that children more frequently react to allergens like sarcoplasmic calcium-binding protein (SCBP) and myosin light chain (MLC) than adults (Ayuso et al., 2008; Ayuso et al., 2009).

Sensitisation to crustaceans appears to be influenced by sensitisation to molluscs and non-molluscan invertebrates, like mites, cockroaches and the fish parasite *Anisakis*, and allergy to crustaceans may sometimes be secondary to allergy to cross-reactive organisms (Ayuso et al., 2008).

21.3. Identified allergens

21.3.1. Decapod crustaceans

Decapod crustaceans are of main interest as allergenic foods. The Allergome database lists 375 crustacean allergens (isoallergens included), whereas only 30 allergens (plus 33 isoallergens) are listed in the IUIS database (Table 22).

Crustaceans contain many IgE-binding proteins. Raw black tiger prawn and king prawn showed 14 and 11 IgE-binding proteins, respectively (Sahabudin et al., 2011), while giant freshwater prawn also had 11 (Yadzir et al., 2012). Some of these proteins, e.g. sarcoplasmic calcium-binding protein (SCBP), were found able to activate basophils even more than tropomyosin (Ayuso et al., 2009). Although the clinical relevance of most IgE-binding proteins is uncertain, some crustacean allergic individuals only show IgE-binding to non-tropomyosin allergens (Abramovitch et al., 2013).

Several major allergens have been described in crustaceans , including tropomyosin, arginine kinase, sarcoplasmic calcium-binding protein and myosin light chain 1 and light chain 2 (Ayuso et al., 2008; Ayuso et al., 2009; Bauermeister et al., 2011; Sahabudin et al., 2011).

5997 **Table 22:** Crustacean (*Animalia arthropoda*) allergens

Biochemical name	Allergen	Common name	Scientific name	Molecular weight[a,1]
Tropomyosin	Cha f 1	Crab	*Charybdis feriatus*	34
	Cra c 1	Common Shrimp	*Crangon crangon*	38[b]
	Hom a 1	American Lobster	*Homarus americanus*	-
	Lit v 1	European White Shrimp	*Litopenaeus vannamei*	36
	Mac r 1	Giant Freshwater Prawn	*Macrobrachium Rosenbergii*	37[b]
	Met e 1	Greasyback Shrimp	*Metapenaeus ensis*	-
	Pan b 1	Northern Red Shrimp	*Pandalus borealis*	37[b]
	Pan s 1	Spiny Lobster	*Panulirus stimpsoni*	34
	Pen a 1	Brown Shrimp	*Panulirus stimpsoni*	36
	Pen i 1	Indian Shrimp	*Penaeus indicus*	34
	Pen m 1	Black Tiger Prawn	*Penaeus monodon*	38
	Por p 1	Blue Swimmer Crab	*Portunus pelagicus*	39[b]
Arginine kinase	Cra c 2	Common Shrimp	*Crangon crangon*	45[b]
	Lit v 2	European White Shrimp	*Litopenaeus vannamei*	
	Pen m 2	Black Tiger Prawn	*Penaeus monodon*	40
Myosin light chain 2	Hom a 3	American Lobster	*Homarus americanus*	23
	Lit v 3	European White Shrimp	*Litopenaeus vannamei*	20
	Pen m 3	Black Tiger Prawn	*Penaeus monodon*	
Sarcoplasmic calcium-binding protein, SCBP	Cra c 4	Common Shrimp	*Crangon crangon*	25
	Lit v 4	European White Shrimp	*Litopenaeus vannamei*	20
	Pen m 4	Black Tiger Prawn	*Penaeus monodon*	-
	Pon l 4	Narrow Clawed Crayfish	*Pontastacus leptodactylus*	24[b]
Myosin light chain 1	Art fr 5	Brine Shrimp	*Artemia franciscana*	17.5
	Cra c 5	Common Shrimp	*Crangon crangon*	17.5
Troponin C	Cra c 6	Common Shrimp	*Crangon crangon*	21
	Hom a 6	American Lobster	*Homarus americanus*	20
	Pen m 6	Black Tiger Prawn	*Penaeus monodon*	-
Troponin l	Pon l 7	Narrow Clawed Crayfish	*Pontastacus leptodactylus*	30[b]
Triosephosphate isomerase	Arc s 8	Shrimp	*Archaeopotamobius siberiensis*	28[b]
	Cra c 8	Common Shrimp	*Crangon crangon*	28

5998 [1] Approximate – some variation exist between species; [a] MW (SDS-PAGE); [b] kDa

5999 21.3.1.1. Tropomyosin

6000 Tropomyosin is a well-characterised, major crustacean allergen, which shows high sequence
6001 homology (up to 98 %) among crustaceans (Leung and Chu, 1998). Tropomyosin was the first
6002 allergen (Pen a 1) identified in shrimp (Hoffman et al., 1981), its IgE-binding epitopes have been
6003 identified, and at least 80 % of shrimp allergic subjects react to tropomyosin (EFSA, 2004; Zheng et
6004 al., 2011). Monosensitisation to tropomyosin appears to be frequent. In one study, 12 of 31 subjects
6005 exhibited detectable specific IgE exclusively to tropomyosin (Bauermeister et al., 2011).

6006 21.3.1.2. Arginine kinase

6007 Arginine kinase (France et al., 1997) is an enzyme that plays a key role in energy metabolism in
6008 invertebrates (García-Orozco et al., 2007; Yu et al., 2011). It is a panallergen (Binder et al., 2001), a
6009 major allergen in at least some crustaceans, and has also been identified in other invertebrates, such as
6010 moth and cockroach (Ayuso et al., 2008).

6011 21.3.1.3. Sarcoplasmic calcium-binding protein

6012 The water-soluble SCBP has been identified as a shrimp allergen (Shiomi et al., 2008; Ayuso et al.,
6013 2009; Chen et al., 2013). SCBP functions as an EF-hand calcium-binding protein in invertebrates,
6014 analogous to parvalbumin in fish. Like parvalbumin, SCBP shows high polymorphism. All isotypes
6015 and subunits of SCBP show IgE-binding capacity (Chen et al., 2013). In some studies SCBP is a major

allergen (Ayuso et al., 2009), and some shrimp allergic individuals are exclusively sensitised to SCBP (Bauermeister et al., 2011).

21.3.1.4. Myosin light chains

Myosin light chains (MLC) are components of the macromolecular complexes, which constitute myosins. The 177-amino acid muscle protein myosin light chain (MLC) is a major allergen in shrimp (Ayuso et al., 2008) and has also been identified in other invertebrates. There seems to be independent groups of allergenic MLC (Bauermeister et al., 2011), as the sequence identity between two MLC proteins studied (light chain 1 and light chain 2) is only 13 % (Ayuso et al., 2008; Bauermeister et al., 2011). MLC is an EF-hand calcium-binding protein. In one study, the recombinant protein was recognised by serum IgE from 17 out of the 19 shrimp-allergic individuals tested, and was almost the only allergen recognised by some shrimp-allergic patients (Ayuso et al., 2008).

21.3.1.5. Other crustacean allergens

Troponin C is a novel IgE-binding protein in crustaceans (Bauermeister et al., 2011), which was also identified in the cockroach (Bla g 6). Troponin 1 is an allergen also in crayfish, a major allergen of the fish parasite *Anisakis* (Ani s 1), and an allergen in the cockroach. Triosephosphate isomerase is a novel crustacean allergen (Bauermeister et al., 2011), but members of this protein family had already been reported as IgE-binding proteins in fish, midges and various plants.

21.3.2. Non-decapod crustaceans

The small shrimp-like krill species Pacific krill (*Euphausia pacifica*) and Antarctic Krill (*Euphasia superba*) have the allergens Eup p 1 and Eup s 1 listed in the Allergome database, both with one variant. These tropomyosins show extensive IgE-binding cross-reactivity with shrimp, crab and lobster tropomyosins (Nakano et al., 2008). Krill tropomyosins and mantis shrimp tropomyosin have 82.3-89.8 % and > 90 % sequence identity with decapod tropomyosins, respectively (Motoyama et al., 2008). Tropomyosin is also the main allergen in acorn barnacle (*Balanus rostratus*) and goose barnacle (*Capitulum (Pollicipes) mitella*). These non-decapod crustaceans belong to the class *Thecostraca*, which is taxonomically remote from the decapods, but cross-react with decapod tropomyosin (Suma et al., 2007).

21.4. Cross-reactivities

At least four crustacean allergens are, like the main fish allergen parvalbumin, EF-hand calcium-binding proteins, namely SCBP, myosin light chain (MLC), troponin C, and troponin 1. Some homologues of these crustacean proteins are allergens in e.g. cockroaches and the fish parasite *Anisakis* (Bla g 6, Bla g 8, Ani s 1), and in plants. Cross-reactivity between EF-hand proteins is limited to phylogenetically closely related species, suggesting that different families of calcium-binding allergens possess specific epitopes (Ayuso et al., 2009).

21.4.1. Cross-reactivity among crustaceans

In a crustacean allergic individual, the probability of reacting to another crustacean species has been estimated to be 75 % (Torres Borrego et al., 2003). Although tropomyosin is the allergen most frequently involved in cross-reactions among crustaceans (Kamath et al., 2013), SCBP shows high sequence identity among crustaceans and also contributes to serological cross-reactivity (Ayuso et al., 2009; Mita et al., 2013). Cross-reactivities among crustaceans are, however, not always observed, possibly because of selective IgE-binding to species-specific epitopes of major allergens, or to minor allergens (e.g. haemocyanin) which may be species specific (Piboonpocanun et al., 2011; Abramovitch et al., 2013).

21.4.2. Cross-reactivity between crustaceans and molluscs

Tropomyosin is important for cross-reactions between crustaceans and molluscs, but tropomyosin sequence identity between the two is markedly lower than within crustaceans or within classes of

molluscs, which may explain why cross-reactivity between crustaceans and molluscs is more limited than within either crustaceans or classes of molluscs (EFSA, 2005a; Lu et al., 2007; Tsabouri et al., 2012; Kamath et al., 2013). The IgE-binding regions of Pen a 1 partly or completely overlap with those of Pen i 1 from the shrimp *P. indicus*, Tur c 1 from the snail *T. cornutus* and Cra g 1 from the oyster *C. gigas*, supporting the notion that tropomyosin is a major cause of serological and clinical cross-reactivity between crustaceans and molluscs (Lehrer and McCants, 1987; Reese et al., 1999; Ayuso et al., 2002a). SBCP shows only 14 % identity between shrimp and scallops and does not appear to be involved in cross-reactivity between crustaceans and molluscs (Ayuso et al., 2009), whereas some other non-tropomyosin allergens may play a role (Boquete et al., 2011).

Cross-reactivity between crustaceans and molluscs is often restricted to a few species. For example, there are several reports of individuals clinically reacting to squid and shrimp (Carrillo et al., 1992) while tolerating other crustaceans and molluscs. A similar situation is observed with regard to serological cross-reactivity. Serological and clinical cross-reactivities between crustaceans (e.g. shrimp, lobster and crab) and the mollusc squid (e.g. *Todarodes pacificus*, *Loligo vulgaris*), and between crustaceans and oyster, e.g. *Crassostrea gigas* appear to be frequent (EFSA, 2005a).

The extent to which mollusc allergy may be secondary to crustacean allergy, or vice-versa, is uncertain. Out of 38 patients with shellfish allergy, 25 were sensitised to crustaceans and molluscs, 12 to crustaceans only, and one to molluscs only (Laffond Yges, 1996). Further, out of 24 shellfish allergic children, 23 were allergic to crustaceans, while 10 were allergic to molluscs (Crespo et al., 1995a). Using sera from nine crustacean allergic individuals, IgE-binding to tropomyosin in the muscle extract of all 10 molluscs tested was observed (Leung and Chu, 1998). These findings suggest that some patients reacting to molluscs could be primarily sensitised to crustaceans, and vice-versa, although some cross-inhibition studies suggest dual sensitisation (van Ree et al., 1996b; Goetz and Whisman, 2000).

All the mentioned clinical cross-reactivities between crustaceans and molluscs, however, are based on case histories, sometimes including elimination diets, and not on DBPCFC.

21.4.3. Cross-reactivity between crustaceans and non-molluscan invertebrates

Sensitisation to shrimp tropomyosin may induce allergy to mite and cockroach (Reese et al., 1999), whereas IgE reactivity to shrimp has been observed in unexposed populations allergic to mite and/or cockroaches (Fernandes et al., 2003). Serological cross-reactivity between crustaceans, mollusc, mite and cockroach tropomyosins may cause difficulties in the diagnosis of e.g. shrimp allergy (Shafique et al., 2012).

Clinically relevant cross-reactivity between crustacean and house dust mite allergens has been described as the “mite-crustacean-mollusc-syndrome” (Witteman et al., 1994; Kütting and Brehler, 2001). Primary sensitisation is most often against mite. However, allergy to mites or cockroaches subsequent to sensitisation to crustaceans has also been described (van Ree et al., 1996b; Ayuso et al., 2002a). Shrimp tropomyosin Pen a 1 IgE-binding regions show high sequence homology with corresponding regions of Per a 7 (cockroach) and Der p 10 (mite) (60-100 %) (Ayuso et al., 2002a). Immunotherapy with mite allergen has been reported to increase the risk for anaphylactic reactions to crustaceans (van Ree et al., 1996b; Pajno et al., 2002).

Cases of clinical cross-reactivity between crustaceans (shrimp), molluscs (oysters in the case cited) and the fish parasite *Anisakis* (Pascual et al., 1997; Gonzalez Galan et al., 2002) are supported by IgE-binding studies (Martínez et al., 1997; Pascual et al., 1997; Asturias et al., 2000) and by tropomyosin sequence homology data (Ayuso et al., 2002a; Ivanciuc et al., 2002). *Anisakis* also shares other allergenic molecules with crustaceans e.g. troponin 1, which may explain cases of apparent cross-reactivity between crustaceans and molluscs, and between them and *Anisakis*-infested fish (Torres Borrego et al., 2003). Shrimp tropomyosin also cross-reacts with the phylogenetically distant sea urchin roe used in e.g. sushi (Pascal et al., 2012).

The involvement of non-tropomyosin allergens in cross-allergy between shellfish and mites is suggested by a number of case reports. Serum from a man with primary sensitisation to house dust mites and selective allergy to lobster showed no IgE-binding to tropomyosin, but recognised four proteins in lobster and two and three allergens in two different mite species (Iparraguirre et al., 2009). The panallergen arginine kinase (Der p 20 and Pen m 2 in mite and shrimp, respectively) show 78 % amino acid sequence homology and appear to be involved in cross-reactivity between crustaceans, molluscs, and mites (Boquete et al., 2011). Myosin light chain 1 (MLC 1) may also be involved in cross-reactivity between crustaceans and cockroach and possibly mites (Ayuso et al., 2008).

21.4.4. Cross-reactivity between crustaceans and vertebrates

In vertebrates, tropomyosin is considered to be non-allergenic (Leung et al., 1996; Restani et al., 1997), with the exception of the recent description of tropomyosin from the fish tilapia (*Oreochromis mossambicus*) as an allergen (Liu et al., 2013). Extracts of salmon, tuna, trout, pollock and mackerel failed to significantly inhibit a shrimp RAST (O'Neil et al., 1993), indicating that unique IgE epitopes are present among crustacean tropomyosins, which may explain the general absence of cross-reactivity between fish and crustaceans. Similar considerations can be made for the other crustacean allergens, e.g. EF-hand calcium-binding muscle proteins (Ayuso et al., 2008).

21.5. Effect of food processing on allergenicity

21.5.1. Heat treatment

The allergenicity of crustacean allergens may be unchanged, increased or decreased after heat treatment depending on the allergen. One study in giant freshwater prawn showed that, out of the 11 IgE-binding proteins observed in the raw shrimp extract, only 5 could be identified after cooking (Yadzir et al., 2012).

Crustacean tropomyosin re-folds after heating (Usui et al., 2013) and is heat-resistant (Shanti et al., 1993; Leung et al., 1994; Crespo et al., 1995b; Samson et al., 2004). Whereas tropomyosin increases its IgE-binding capacity after boiling (Liu et al., 2010a; Shriver et al., 2011; Kamath et al., 2013), extracts from boiled shrimp showed reduced IgE-binding, which points to a role of other heat-sensitive allergens in IgE-binding to the extract. Heating markedly increased IgE-binding of extracts from blue swimmer crab and black tiger prawn (Abramovitch et al., 2013). The Maillard reaction has been reported to increase the allergenicity of scallop tropomyosin (Nakamura et al., 2005). How these findings reflect on clinical allergenicity is unknown.

SCBP has been found stable during thermal and acid/alkali treatment (Chen et al., 2013). In addition, MLC binds IgE in both raw and cooked shrimp extracts (Ayuso et al., 2008). One potentially important heat-sensitive allergen is arginine kinase (Yu et al., 2003; García-Orozco et al., 2007).

21.5.2. Other treatments

Proteinase digestion reduced the IgE-binding capacity of prawn, shrimp and crab tropomyosins. The effect of boiling, of combined ultrasounds and boiling, and of high pressure steaming on the digestibility of crab tropomyosin under simulated gastric and intestinal conditions has also been investigated (Liu et al., 2010c; Liu et al., 2010b; Yu et al., 2011). High pressure steaming was most efficient in accelerating digestion and correspondingly reducing IgG/IgE antibody binding.

Pulsed ultraviolet light (PUV), a novel technology most commonly used for microbial inactivation, has been reported to reduce the allergenicity of some foods. PUV-treated shrimp extracts showed reduced IgE-binding to tropomyosin (Shriver et al., 2011), and this effect was maintained in extracts undergoing gastric and intestinal digestion in models intended to mimic real-life conditions (Yang et al., 2012).

Krill is mainly consumed as unrefined oil, which may contain allergenic proteins. Tropomyosin was found in samples of krill oil, but not in oil from the small crustacean-like zooplankton *Calanus*

finmarchius (found in North Atlantic Ocean, which is similar to krill found in the South Atlantic) (Vang et al., 2013).

21.6. Detection of allergens and allergenic ingredients in food

21.6.1. Immunological methods

All ELISA methods described for the detection of crustacean allergens targeted tropomyosin, the most important allergen present in crustaceans and molluscs. While some immunological methods have been developed to detect crustaceans and molluscs and are not able to differentiate between these two types of shellfish, others are specific for crustaceans or even for single crustacean species (mostly biosensors). Monoclonal antibodies are preferred for targeting a single species, whereas polyclonal antibodies are more useful for detecting the entire group of crustaceans and/or molluscs.

21.6.1.1. ELISA

Methods of detection specific for crustaceans

The first method developed was a mAb sandwich ELISA for the quantification of the major shrimp allergen tropomyosin Pen a 1 (brown shrimp) (*Penaeus aztecus*) (Jeoung et al., 1997). The method is sensitive (LOD 1ng/mL), reproducible and non cross-reactive with oyster, cockroach or house dust mites. It is suitable to detect Pen a 1-like molecules in extracts from other crustacean species, such as crab and lobster, but it was not tested for the detection of other shellfish in cooked foods.

A number of sandwich ELISA assays using polyclonal antibodies have been developed. One against Western King prawn (*Penaeus latisulcatus*) tropomyosin is able to detect both cooked and raw crustaceans in foods (Fuller et al., 2006). The method did not show cross-reactivity with molluscs, fish or mammalian meat. The LOD was about 1 mg/kg (prawn, lobster).

Another sandwich ELISA assay based on a polyclonal anti-tropomyosin capture antibody raised against shrimp (*Pandalus borealis*) and the biotinylated conjugate of the same antibody for detection has been validated using spiked samples and commercially available food products (Werner et al., 2007). It is specific for crustaceans, though cross-reacting to some extent with cockroach. The LOD is 1mg/kg.

One sandwich ELISA which used monoclonal and polyclonal antibodies against black tiger prawn tropomyosin (Seiki et al., 2007) was specific for the Decapoda group, apart from minor cross-reactivities with other crustacean and molluscs. This method has a good accuracy and precision, with a LOD of 0.71 ng/mL, corresponding to 0.29 mg of crustacean protein/kg food sample. A similar sandwich ELISA using a monoclonal antibody against the same tropomyosin showed no cross-reactivity with molluscs. The LOD was 0.16 mg/kg (Shibahara et al., 2007).

Few commercial test kits are available for the detection of soluble crustacean tropomyosins in foods. A rapid and sensitive ELISA test kit for the detection of crustacean residues in food samples has been commercialised as screening method, with a LOQ for tropomyosin of 0.05 mg/kg by using a microwell reader (Schubert-Ullrich et al., 2009).

Methods of detection for crustaceans and molluscs

While the above mentioned ELISA methods are specific for crustaceans, others detect tropomyosin in crustaceans and molluscs. A commercial ELISA assay based on a tropomyosin specific monoclonal antibody was tested to detect crustaceans and molluscs, as well as to investigate the impact of heating on the detection (Abdel Rahman et al., 2013). Tropomyosin was detected in all crustacean species, but only partially in molluscs. Heating of shellfish increased recognition of multiple tropomyosin variants in both crustaceans and molluscs. The effect was attributed to the modification of the protein by the

Maillard reaction. A potentially specific antibody targeting the N-terminal region of tropomyosin was identified to enable the differentiation between crustaceans and molluscs.

A sandwich ELISA based on the monoclonal antibody CE7B2 obtained against an IgE epitope, which is shared by several shellfish tropomyosins, was developed in order to detect tropomyosin in both crustaceans and molluscs (Zhang et al., 2014). The mAb CE7B2 reacts to intact tropomyosin, but also recognises fragmented peptides with a specific IgE epitope sequence, which is shared by a number of shellfish tropomyosins. The LOD is 0.09 ng/mL for kuruma prawn and 0.64 ng/mL for molluscs and house dust mite samples.

A lateral flow test for crustaceans and molluscs (including crab, lobster, brown shrimp, tiger prawn, langoustine, crayfish, scallop, oyster, mussel, cockle, and squid) has been marketed with a LOD around 5 mg/kg (Schubert-Ullrich et al., 2009).

21.6.1.2. Protein chip

A sandwich protein chip assay, which used rabbit antisera as the capture reagent and a biotin-labelled mAb as detector reagent, was developed to quantify shrimp allergens in food matrices (Zhenxing et al., 2010). The resulting antigen–antibody complexes were visualised in the presence of streptavidin labelled with Cy3, which produced a fluorescence signal suitable for quantification. The LOD was 0.054 mg tropomyosin/kg and the LOQ 0.096 mg tropomyosin/kg. The protein chip was cross-reactive with allergens from other crustaceans.

21.6.1.3. Biosensors

A rapid method based on a quartz crystal microbalance immunosensor, which uses a polyclonal antibody specific to shrimp allergens, was able to detect shrimp allergens with a LOD of 0.333 µg/mL (Xiulan et al., 2010). The electrode was modified based on self-assembly with 1,6-hexanedithiol (HDT) and nanogold.

In a cell-based electrochemical biosensor for the quantification of shrimp tropomyosin (Pen a 1) (Jiang et al., 2013), rat basophilic leukemia (RBL-2H3) mast cells encapsulated in type I collagen were immobilised on a self-assembled L-cysteine/gold nanoparticle(AuNPsCys)-modified gold electrode and pre-sensitised by specific anti-shrimp tropomyosin IgE. In the presence of the antigen, mast cells exhibit morphological changes which indicate degranulation, thus inducing dose-dependent impedance signals which can be detected by EIS. The impedance value increased with the concentration of purified tropomyosin, with a LOD of 0.15 µg/mL.

21.6.2. Mass spectrometry

Two methods for the characterisation and quantification of tropomyosin and arginine kinase from snow crab using isotopic labelled mass spectrometry (LC-MS/MS) are available (Abdel Rahman et al., 2010; Abdel Rahman et al., 2011). A comprehensive proteomic strategy (allergenomics) for characterising and quantifying allergenic proteins in crustaceans (northern shrimp) has also been described by the same authors (Abdel Rahman et al., 2013). Tropomyosin, arginine kinase and sarcoplasmic calcium-binding protein were targeted for quantification. The marker peptides for each protein were selected and synthesised in the light and heavy form and used in the development of the AQUA LC-MS/MS (MRM mode) approach. The peptide mixture could be analysed with a LOD < 0.25 nM. These methods are very selective, reproducible and accurate, and were applied to measure the level of these allergens in air samples, but not in foods.

21.6.3. DNA-based methods

DNA-based methods can discriminate among crustaceans by targeting specific nucleotidic sequences, while commercially available ELISA kits targeting tropomyosin are generally not able to differentiate between shrimp and crab species owing to the high homology of the tropomyosins.

Detection and species identification of crustacean DNA was achieved with a PCR restriction fragment length polymorphism (PCR-RFLP) method (Brzezinski, 2005). A fragment of the 16S rRNA gene in crustacean species was amplified by PCR and digested with differential restriction endonucleases to determine the species to which the DNA belongs. The specificity of the method was demonstrated by analysing shrimp, crab, lobster and crawfish. The LOD was < 0.1 % for shrimp in a raw meat mixture.

A shrimp end point-PCR method with post-amplification digestion and a crab end point-PCR method that specifically amplifies a fragment of the 16S rRNA gene allowed differentiating between shrimp and crab (Taguchi et al., 2011). The sensitivity and specificity of these PCR methods were verified by using incurred foods and commercial food products. Both methods could detect 5 pg of DNA extracted from the target species and 50 ng of genomic DNA extracted from incurred foods containing 10 mg/kg total protein of shrimp or crab.

A fast (40 min) real-time PCR for crustacean detection in differently processed foods has been developed using a locked nucleic acid probe (LNA) which, on account of its high affinity, allows specific recognition of even short DNA sequences (Herrero et al., 2012). No cross-reactivity was observed with molluscs or fishes, but it did not distinguish among crustacean species. The method was able to recognise 1.25 pg of crustaceans in highly processed foods.

Two real-time PCR assays aimed to detect penaeid shrimp and blue crab targeting mitochondrial genes, which could provide more sensitive assays owing to the high copy number (Eischeid et al., 2013). The assays were tested using shrimp and crab meat spiked into several types of foods at levels ranging from 0.1 to 106 mg/kg and analysed either raw or cooked. Cooking methods used to simulate thermal processing of foods had little effect on the assay performance. LODs were between 0.1 and 1 mg/kg.

21.7. Minimal (observed) eliciting doses

There is little information on the lowest doses of any crustacean causing a clinical allergic reaction upon ingestion. In two DBPCFCs, one patient reacted to 14 g of shrimp (Bernstein et al., 1982) and four reacted to 32 mg of shrimp extract, corresponding to 16 g of shrimps (four shrimps of medium size) (Daul et al., 1988).

21.8. Conclusion

Crustaceans are a common trigger of food-allergic reactions, which are sometimes severe. The most important major allergen, tropomyosin, is well characterised. Tropomyosin and other crustacean allergens are heat-resistant. Prevalence of crustacean allergy in unselected populations in Europe has been estimated to be 0.2-0.3 %, although available studies of clinically confirmed crustacean allergy are scarce. Immunological methods such as ELISA, protein chips and biosensors, as well as mass spectrometry and DNA-based methods have been developed for the detection of crustacean allergens in processed foods. The lowest doses of crustaceans reported to elicit an allergic reaction in the only two DBPCFC studies available are 14 g of shrimp and 32 mg of shrimp extract, respectively.

22. Allergy to molluscs

22.1. Background

The *Phylum Mollusca* is second only to the *Phylum Arthropoda (*which includes the class *Crustacea*) in the number and diversity of species (> 100 000) (Levinton, 2001; Hickman et al., 2004). Molluscs live in salt water, fresh water and on land, range in size from less than one millimetre to nearly 20 meters (giant octopus), and may weigh up to 900 kg (giant squid, *Architeuthis*). Molluscs are commonly classified into eight classes, of which three are of particular importance as food, namely gastropods, bivalves and cephalopods. The largest class, *Gastropoda*, counts more than 70 000 species (Hickman et al., 2004). A non-exhaustive list of mollusc species relevant in relation to food allergy is given in Table 23.

6290 **Table 23:** Taxonomic classification of relevant molluscs (*Phyllum Molusca*) in the context of food
6291 allergy [1]

Class	Major organisms	Common name	Scientific name
Gastropoda	Abalones	Small abalone	*Haliotis diversicolor*
		Red abalone	*Haliotis rufescens*
			Haliotis rubra
		Abalone	*Haliotis midae*
		Northern disk abalone	*Haliotis discus hannai*
	Limpets	Limpet	*Patella piperata*
			Patella vulgata
		Grand keyhole limpet	*Fisurella maxima Sowerby*
	Land (terrestrial) snails	Land snail	*Euparipha pisana*
			Limax agrestis
			Eobania vermiculata
			Cernualla virgata
			Helix aperta
			Helix terrestre
			Helix pomatia
			Helix aspersa aspersa
			Helix aspersa maxima
			Helix lucorum
	Marine snails	Turban shell	*Turbo cornutus*
	Whelks	Whelk	*Hemifusus ternatana*
			Buccinum undatum
			Neptunea arthritica
Bivalvia	Clams	Clam	*Lutraria philipinarum*
			Tapes decussates
			Tapes japonica
		Razor clam	*Tagelus plebius*
	Oysters	Pacific oyster	*Crassostrea gigas*
		Eastern oyster	*Crassostrea virginica*
	Mussels	Green mussel	*Perna viridis*
		Blue mussel	*Mytilus edulis*
		Mussel	*Mytilus galloprovincialis*
	Scallops	Scallop	*Chlamys opercularis*
			Chlamys nipponensis
			Patinopecten yessoensis
	Cockles	Cockle	*Cardium edule*
Cephalopoda	Squids	Squid	*Toradodes pacificus*
			Loligo edulis
			Loligo vulgaris,
			Loligo japonica,
			Loligo forbesi
			Loligo opalescens
			Loligo pealei
	Octopuses		*Octopus luteus*
			Octopus vulgaris
	Cuttlefishes		*Sepia madokai*
			Sepia latimanus
			Sepia officinalis

6292 [1] Adapted from Hickman et al. (2004) and Taylor (2008)

6293 Molluscs are often grouped together with crustaceans under the term "shellfish" in the literature
6294 dealing with food allergy and food consumption data. However, data on allergy to "shellfish" do not
6295 provide information about the allergenicity of molluscs and thus have not been considered in this
6296 section.

Molluscs are a common food in most European countries, although consumption data are sparse. Whereas their use as added ingredients appears to be limited, they can be found in some processed foods, like soups and sauces, and in products like surimi.

22.2. Epidemiology

22.2.1. Prevalence

Data on the prevalence of mollusc allergy should be interpreted with particular caution for a number of reasons. First, adverse reactions to molluscs caused by infectious agents or toxins (e.g. algal toxins in blue mussels), in particular gastroenteritis-like symptoms (Myrmel et al., 2004; Hungerford, 2005), may lead to overestimation of the prevalence of mollusc allergy in studies using questionnaire-based methods. Second, the serological cross-reactivity between molluscs and crustaceans, mites, insects and helminths, may lead to overestimation of sensitisation to molluscs. Third, mollusc species often do not cross-react with each other, and thus the absence of a reaction to the one or few molluscs species used for testing in clinical studies does not exclude sensitisation or clinical allergy to other mollusc species, leading to an underestimation of the prevalence of mollusc allergy in these studies.

No prevalence studies using food challenges to confirm allergy to molluscs are available.

22.2.1.1. Europe

Data on the prevalence of mollusc allergy in unselected European populations are scarce.

In a questionnaire-based survey among children (2716 responders) in France (Rancé et al., 2005), two children (0.8 % of cases) reported allergy to mussels, one to snails and one to oysters (0.4 % of cases each), giving a prevalence of self-reported mollusc allergy of about 0.15 % (4/2716). In another French study (Touraine et al., 2002), 1.5 % of 5-17 year olds reported an allergy to oysters. In Denmark, 0.4 % of 22 year olds (n=843) reported allergy to octopus, with 0.1 % confirmed by food challenge (Osterballe et al., 2009). One study (Zuberbier et al., 2004) was based on positive SPT and a convincing clinical history and reported zero prevalence of mussel allergy in adults (n = 4093) in Germany.

Prevalence data of mollusc allergy in food allergic patients are more abundant, but are only indicative of the relative importance of molluscs as a trigger of allergic reactions to food. In Gran Canaria, Spain, 33 (27.5 %) out of 120 food allergic subjects reported adverse reactions to squid (second most common allergenic food after shrimp), 12 (10 %) to oyster, 10 (8 %) to clam, and 10 (8 %) to mussel (Castillo et al., 1996). Also in Spain, molluscs caused 1.6 % of 608 allergic reactions in 355 children based on clinical history, SPT and specific IgE (Crespo et al., 1995a).

Among 163 severe food allergic reactions reported by allergologists in France in 2001, six (3.8 %) were caused by molluscs (Moneret-Vautrin et al., 2002a). In a questionnaire-based study among 1139 subjects with food hypersensitivity in Baltic countries, 6.2 % indicated allergic reactions to clam, 3.2 % to oyster and 1.4 % to snail, but < 50 % of the subjects had ever eaten clam, oyster or snail (Eriksson et al., 2004).

22.2.1.2. Outside Europe

In a random cross-sectional telephone survey on the prevalence of seafood allergy in the United States (Sicherer et al., 2004), 14 948 individuals completed the survey. Sixty-seven persons reported reactions to scallops, clams, oysters, or mussels, representing about 0.4 % of the study population (67/14 948) and 20 % of all doctor-diagnosed or “convincing” seafood allergy.

In Thailand, self-reported mollusc allergy was 0.2 % in 3-7 year olds (Lao-araya and Trakultivakorn, 2011). In Taiwan, mollusc allergy defined by a clinician’s diagnosis varied from 0.1 % in under 3 year olds to 1.5 % in adults (Wu et al., 2012).

22.2.2. Natural history

There are no data available regarding the natural history of mollusc allergy.

22.2.3. Time trends

There are no studies available, which allow investigating time trends in mollusc allergy.

22.2.4. Severe reactions/anaphylaxis

Anaphylactic reactions and death have been reported in mollusc-allergic patients, including cases of food-dependent exercise-induced anaphylaxis (EFSA, 2005a). Of the 107 fatal or near-fatal reactions to food reported by the Allergy Vigilance Network for 2002 mainly in France, five were to snails (4.7 % of all reactions) (Moneret-Vautrin et al., 2004). In a report on 67 consecutive cases of anaphylaxis from an immunology/allergy centre in Singapore (Thong et al., 2005), 30 cases were triggered by food and 11 of these (36.7 %) by molluscs (limpet and abalone).

22.2.5. Factors affecting the prevalence of mollusc allergy

A number of case reports and patient series suggest that allergic reactions to molluscs most commonly occur in school age children and young adults (EFSA, 2005a), and thus may tend to develop later than the common childhood allergies This may be explained in part by the later introduction of molluscs into the diet, and by the fact that cross-reactive respiratory allergies e.g. to mites tend to develop relatively late.

22.3. Identified mollusc allergens

Whereas the Allergome database records 155 entries under molluscs allergens, only three allergens are listed in the IUIS database (Table 24), which illustrates the relative lack of systematic studies relative to mollusc allergens.

Table 24: Mollusc (*Animalia Mollusca*) allergens[1]

Biochemical name	Allergen	Common name	Scientific name	Molecular weight (kDa)[a, 3]
Tropomyosin	Buc u 1	Common whelk	*Buccinum undatum*	36-38
	Chl n 1	Japanese scallop	*Chlamys nipponensis*	
	Cra g 1	Oyster	*Crassostrea gigas*	
	Ens m 1	Razor clam	*Ensis macha*	
	Hal d 1	Abalone	*Haliotis discus*	
	Hal m 2	Abalone	*Haliotis midae*	
	Hel as 1[2]	Garden snail	*Helix aspersa*	
	Hal r 1	Abalone	*Haliotis rufescens*	
	Mim n 1	Scallop	*Mimachlamys (Chlamys) nobilis*	
	Oct v 1	Octopus	*Octopus vulgaris*	
	Per v 1	Mussel	*Perna viridis*	
	Pin a 1	Fan shell	*Pinna atropurpurea*	
	Tod p 1[2]	Japanese flying squid	*Todarodes pacificus*	
	Tur c 1	Turban shell	*Turbo cornutus*	
N.A.	Hal m 1[2]	Abalone	*Haliotis midae*	49

N.A. = Not assigned; [1] The list is not comprehensive; [2] Allergens listed in the IUIS database; [a] MW (SDS-PAGE); [3] Slight variation between species

Tropomyosin is considered to be the most important mollusc allergen (Chu et al., 2000; Motoyama et al., 2006; Emoto et al., 2009). The muscle protein tropomyosin is a highly conserved panallergen among invertebrate animal species including molluscs, crustaceans, arachnids (e.g. mites), and insects (e.g. cockroaches) (Reese et al., 1999). Tropomyosin has also been described as an allergen in one fish, i.e. tilapia (*Oreochromis mossambicus*) (Liu et al., 2013). The carboxyl-terminal region of

tropomyosins is highly conserved across molluscan species, whereas other parts of the molecule are more variable. This is also reflected at the epitope level, with some epitopes being shared and cross-reactive among mollusc species whereas others are more or less species specific (Chu et al., 2000).

Tropomyosins are allergens in many mollusc species (Table 23). However, in some species, tropomyosin appears to be a minor allergen, e.g. in land snail (Asturias et al., 2002) and non-tropomyosin allergens are present in most, if not all, food-relevant molluscs (Taylor, 2008). Non-tropomyosin mollusc allergens include hemocyanin (Koshte et al., 1989; Mistrello et al., 1992), myosin heavy chain (Martins et al., 2005), arginine kinase (Shen et al., 2012) and amylase (Azofra and Lombardero, 2003). Myosins have been reported to be a major allergen in snail (Martins et al., 2005). However, little information is yet available on the clinical importance of mollusc non-tropomyosin allergens.

22.4. Cross-reactivities

Vertebrate tropomyosins, that generally are not allergenic, show between 50 %-60 % amino acid sequence identity with all invertebrate tropomyosins. All molluscan tropomyosins show identity ranging from 68 % to 88 %, and even higher within the individual mollusc classes: 91-100 % among cephalopods, 70-100 % among bivalves, and 85-97 % among gastropods. The amino acid sequence identities between crustacean and mollusc tropomyosins range from 56-68 %. Mite and cockroach show 56-66 % sequence identity with mollusc tropomyosins, similar to crustaceans (Motoyama et al., 2006; Taylor, 2008; Emoto et al., 2009). This, and the yet ill-defined role of non-tropomyosin allergens in cross-reactivity, makes the serological and clinical picture of cross-reactivity in relation to molluscs' complex.

22.4.1. Cross-reactivity among molluscs

Some individuals appear to react to all common molluscs, whereas others react to few or one species only. Although clinical cross-reactivity among molluscs is limited and tends to fall into a number of loosely defined clusters that, to a limited extent, reflect the taxonomic classification, it is often unpredictable (EFSA, 2005a). Among 67 individuals reacting to scallops, clams, oysters, or mussels, 34 (51 %) reacted to one, 13 (19 %) to two, 5 (8 %) to three, and 15 (22 %) to all four species (Sicherer et al., 2004). Case reports have been published on isolated allergy to octopus (Caiado et al., 2009), snail (San Miguel-Moncin M et al., 2007), razor shell clam (Martín-García et al., 2007) and clam (Rodríguez-Del Rio et al., 2009). In the three first cases, there was evidence that the triggering allergen was not tropomyosin.

22.4.2. Cross-reactivity between molluscs and crustaceans

See section 21.4.2 on crustaceans.

22.4.3. Cross-reactivity between molluscs and non-crustacean invertebrates

A number of examples of simultaneous clinical and serological reactivity to molluscs, insects, arachnids and nematodes with IgE-binding to tropomyosin suggest that tropomyosin is an important allergen triggering clinical cross-reactivity among invertebrates. The house dust mite allergens Der p 10, Lep d 10 and Der f 10, and the cockroach (*Periplaneta americana* and *Blatella germanica*) allergens Per a 7 and Bla g 1, are tropomyosins (EFSA, 2004, 2005a).

Clinically relevant cross-reactivity between snail, limpet, mussel and house dust mite has been described as the "mite-crustacean-mollusc-syndrome" (Kütting and Brehler, 2001; EFSA, 2005a). Primary sensitisation is most often against mite. However, allergies to mites or cockroaches subsequent to sensitisation to molluscs (e.g. snail) have been reported (van Ree et al., 1996b; Ayuso et al., 2002a; Martins et al., 2005). Tropomyosin (Der p 10) may play a role in snail-mite cross-reactivity (Ayuso et al., 2002b; Ayuso et al., 2002a), but non-tropomyosin allergens are also involved, e.g. Der p 4 (amylase), Der p 5, Der p 7, and hemocyanin (Mistrello et al., 1992; Bessot et al., 2010), and these allergens appear to be of importance in cross-reactivity between molluscs, cockroach and other insects

(van Ree et al., 1996b; Guilloux et al., 1998). Immunotherapy with mite allergen has been reported to increase the risk of anaphylactic reactions to snails (van Ree et al., 1996b; Pajno et al., 2002).

Similar to crustaceans, clinical cross-reactivity between molluscs and the fish parasite *Anisakis* has been observed (Gonzalez Galan et al., 2002). Individuals reacting clinically to fish because of *Anisakis* infestation may also react to molluscs, which would appear as fish-mollusc cross-reactivity.

22.4.4. Cross-reactivity between mollusc and vertebrates

Vertebrate tropomyosins appear to be non-allergenic (Leung et al., 1996; EFSA, 2004, 2005a), with the exception of tropomyosin from the fish tilapia (*Oreochromis mossambicus*) (Liu et al., 2013). Cross-reactivities for tilapia tropomyosin have not yet been reported. Invertebrate myosins, a major snail allergen, did not cross-react with chicken, pig, rabbit, cow or horse myosins (Martins et al., 2005).

22.5. Effects of food processing on allergenicity

Tropomyosin is heat-resistant, whereas some non-tropomyosin mollusc allergens may be destroyed by heating (Yadzir et al., 2010; Shen et al., 2012). Mollusc overall allergenicity is not reliably reduced by heat treatment. In some cases, heating may increase the allergenicity of molluscs (EFSA, 2004, 2005a). One study on scallop tropomyosin (Nakamura et al., 2005) identified the Maillard reaction as one mechanism by which the IgE-binding capacity may be increased after heating.

22.6. Detection of allergens and allergenic ingredients in food

Only few (mainly immunological) methods for the detection of mollusc allergens, primarily tropomyosin, have been reported. However, tropomyosin is a major cross-reactive allergen among crustaceans and molluscs, and thus immunological methods of detection may not be able to discriminate between the two groups of shellfish. Only methods specific for the detection of molluscs allergens are described here. No MS methods for the detection of mollusc allergens have been reported. PCR methods have been used mostly for the identification and authentication of different mollusc species. No limits of detection have been reported.

22.6.1. Immunological methods

22.6.1.1. ELISA

A sandwich ELISA based on a monoclonal antibody obtained using the Japanese flying squid (*Todarodes pacificus)* tropomyosin as immunogen has been described (Shibahara et al., 2010). The method is specific for cephalopods and does not recognise other molluscs and crustaceans. The LOD was 0.24 mg/kg.

22.6.1.2. Rapid methods

A specific immunostick assay based on monoclonal antibodies against abalone (*Haliotis midae*) enabled differentiation between several abalone species (Lopata et al., 2002), although it showed less reactivity to heat treated abalone. No binding was observed for other mollusc or crustacean species analysed. No limit of detection has been reported.

22.6.2. PCR methods

Various PCR methods have been used for the identification of molluscs in food products, mostly for traceability and authentication. In particular, forensically informative nucleotide sequencing (FINS), multiplex PCR and single-strand conformation polymorphism (PCR-SSCP) have been used to identify abalone (Aranceta-Garza et al., 2011; Chan et al., 2012). FINS and restriction fragment length polymorphism (PCR-RFLP) have been used for the identification of cephalopod species (Chapela et al., 2003). However, no data are reported on limits of detection and quantification.

22.7. Minimal (observed) eliciting doses

Specific data on doses of mollusc triggering allergic reactions are rare. Exercise-induced anaphylaxis has been reported after ingestion of 100 g of canned oysters (Maulitz et al., 1979) and fatal anaphylaxis after consumption of three snails (Wu and Williams, 2004). In a DBPCFC, the cumulative dose of dried snail causing 20 % decrease in forced expiratory volume (FEV1), a measure of systemic allergic reaction, was 120 mg and 400 mg in two children, respectively (Pajno et al., 2002).

22.8. Conclusions

Molluscs can cause severe and occasionally life-threatening food allergic reactions. Prevalence data in unselected populations are scarce and mostly limited to self-reported prevalence. The most important allergen of molluscs is tropomyosin, which has been well characterised in several mollusc species. Molluscs also contain a number of other allergens. Tropomyosin is heat-resistant and mollusc allergenicity is not reliably reduced by food processing. Only few immunological methods specific for mollusc allergens have been described. ELISA methods to detect both crustaceans and molluscs are available. There is limited information on the lowest dose of mollusc that can elicit a clinical reaction. In the only DBPCFC available, reactions were observed to cumulative doses of dried snail in the low hundred mg range.

23. Allergy to celery

23.1. Background

Celery (*Apium graveolens*) belongs to the *Apiaceae* family (or *Umbelliferae*). The celery plant is composed of a root or tuber, also called celeriac, and of an aerial part, the sticks or stalks. Celery (tubers and sticks) is consumed raw (e.g. in salads), cooked (e.g. on its own, in sauces and soups), and dried as a spice, and it is a common ingredient in processed foods.

Celery can induce allergic reactions of immediate type, from oral contact urticaria to anaphylactic shock. About 30 % of patients with OAS are allergic to celery. The first evidence for IgE celery specific antibodies in sensitised subjects was reported using SPTs (Dechamp et al., 1984; Pauli et al., 1985). Diagnostic tests like SPT with raw celery and allergen extracts have high positive predictive values, while the negative predictive values are low.

23.2. Epidemiology

23.2.1. Prevalence

23.2.1.1. Europe

Four studies published between 2001 and 2006 reported prevalence data on celery allergy in Europe in unselected populations (Schafer et al., 2001; Touraine et al., 2002; Zuberbier et al., 2004; Bakos et al., 2006).

Reported rates of positive SPTs to celery were 9.1 % in adults in Germany (Schafer et al., 2001), and 11.1 % and 3.7 % in adults and elderly people in Hungary, respectively (Bakos et al., 2006). Sensitisation rates measured by serum specific IgE levels to celery in Hungary were 2.8 % for adults and 9.2 % for the elderly (Bakos et al., 2006). The prevalence of self-reported allergy to celery was 5.5 % among 5-17 year olds in France (Touraine et al., 2002). The prevalence of celery allergy in Germany (all ages) based on positive SPT and clinical history of allergy to celery was 2.7 % (Zuberbier et al., 2004).

Allergy to celery was not confirmed with food challenges in any of the studies available reporting on prevalence in unselected populations.

6502 23.2.1.2. Outside Europe

6503 One study conducted in Taiwan reported that 1.8 % of 6-8 year olds suffer from celery allergy based
6504 on positive serum specific IgE levels and clinical history (Wan and Chiu, 2012).

6505 **23.2.2. Natural history**

6506 There are no data available regarding the natural history of celery allergy.

6507 **23.2.3. Time trends**

6508 There are no studies available, which allow investigating time trends in celery allergy.

6509 **23.2.4. Severe reactions/anaphylaxis**

6510 Celery root may trigger severe anaphylactic reactions in some of patients with celery allergy
6511 (Wuthrich et al., 1990). In one study of French patients attending a specialist allergy clinic, about
6512 30 % of 580 food allergic patients showed specific IgE to celery and 30 % of the 60 severe, near-fatal
6513 allergic reactions to food occurred between 1984-1992 appeared to be due to celery (Andre et al.,
6514 1994). Systemic and severe reactions to celery in subjects allergic to pollen (pollen-food allergy
6515 syndrome) have been reported by several authors (Schöll and Jensen-Jarolim, 2004).

6516 **23.2.5. Factors affecting prevalence of celery allergy**

6517 Patients with birch pollen allergy may develop allergic reactions to celery. In Germany, 70 % of
6518 patients with a pollen-related food allergy were reported to have a positive SPT or RAST to celery
6519 (Jankiewicz et al., 1996). In Italy, about 10 % of 262 patients with OAS to fresh fruit and vegetables
6520 had a clinical history of allergic reactions to celery, and about 3 % experienced severe symptoms to
6521 celery, such as laryngeal oedema (Ortolani et al., 1988).

6522 **23.3. Identified allergens**

6523 The major celery antigen is Api g 1. Other identified allergens in celery are Api g 2, Api g 4, and Api
6524 g 6 (Table 25). The cross-reactive carbohydrate determinants also seem to be allergenic.

6525 **Table 25:** Celery (*Apium graveolens*) allergens.

Source	Allergen	Biochemical name	Superfamily/family	Molecular weight[a]
Tuber/root	Api g 1	PR-10	Bet v 1	15
Sticks/stalk	Api g 2	ns-LTP 1	prolamin	9[b]
Sticks/stalk	Api g 3	chlorophyll a-b binding protein		-
Tuber/root	Api g 4	profilin	profilin	14
Tuber/root	Api g 5	FAD-containing oxidase		58
Tuber/root	Api g 6	ns-LTP 2	prolamin	7[b]

6526 [a] MW (SDS-PAGE): [b] kDa

6527 The panallergen profilin Api g 4, a cross-reacting protein present in several plant foods, has been
6528 shown to be involved in celery allergy (Vallier et al., 1992). The cross-reactive carbohydrate
6529 determinants, structures containing α-1,3-fucose and β-1,2-xylose bound to proteins via N-glycoside
6530 linkages, are highly immunogenic in mammals; some celery allergic patients exclusively display IgE-
6531 binding to these determinants of molecular weight > 45 kDa. However, any clinical significance of
6532 cross-reactive carbohydrate determinants-specific IgE is still a matter of debate (Aalberse, 1998;
6533 Fotisch et al., 1999).

Ganglberger et al. (Ganglberger et al., 2000) described two high molecular weight allergens of celery recognised by the sera of five patients with positive case histories, SPTs and RASTs to celery and birch. These 55 and 58 kDa proteins represent members of a protein family not described so far, as no homologous sequences were found in the databases. The 58 kDa allergen, included in the IUIS nomenclature as Api g 5, may correspond to a 60 kDa allergen identified by Heiss et al. (Heiss et al., 1996), the function of which was not determined. Bublin et al. (Bublin et al., 2003) found the complete abolition of binding of serum IgE from all 14 patients tested by chemical deglycosylation of the Api g 5 glycoprotein allergen and observed that native Api g 5 other than the deglycosylated protein completely inhibited the IgE-binding to high molecular weight allergens in protein extracts from birch pollen, mugwort pollen and celery. These results suggest that IgE directed to cross-reactive carbohydrates may be capable of eliciting allergic reactions.

23.4. Cross-reactivities

Three different structures are responsible for cross-reactions between pollen and plant foods, namely Bet v 1 and related plant proteins, profilin, and carbohydrate determinants. Cross-reactivities of celery allergens with pollen and other plant foods, which have been described in the literature, are depicted in Table 26.

Api g 1 and Bet v 1 belong to a class of intracellular PR proteins and their structure shows 40 % identity and 60 % similarity (Breiteneder et al., 1995; Schirmer et al., 2005). Api g 1 is the major allergen for patients with birch pollen/celery sensitisation (Vieths et al., 1995). Whereas two isoforms of Api g 1, Api g 1.0201 and Api g 1.0101 cross-react with Bet v1 from birch pollen, Api g 1.0201 shows a weaker IgE-binding capacity than Api g 1.0101 (Hoffmann-Sommergruber and Mills, 2009). Api g 1 also shows high identity (61.4 %) and homology (79.1 %) with the two parsley PR proteins PcPR1-1 and PcPR1-3 (Somssich et al., 1988). Both celery and parsley belong to the *Apiaceae* family.

Celery profilin, Api g 4, has high sequence identity (71-82 %) to known allergenic plant profilins, which may be responsible for allergenic cross-reactivity between celery and other plant foods or pollens (Table 26). Its IgE cross-reactivity with the minor birch pollen allergen Bet v 2, identified as a profilin (Valenta et al., 1992), explains the birch-mugwort-celery syndrome (Wuthrich et al., 1990; Bauer et al., 1996; Scheurer et al., 2000).

Table 26: Cross-reactivities of celery allergens with pollen and other plant foods

Celery allergen	Cross-reactivity	Allergen	Detected by	Reference
Api g 1	Birch	Bet v1	Sequence homology IgE	(Hoffmann-Sommergruber et al., 2000; Lüttkopf et al., 2000; Schirmer et al., 2005; Wangorsch et al., 2007)
Api g 1	Parsley	PcPR1-1 PcPR1-3	Sequence homology	(Somssich et al., 1988)
Api g 2	Peach Mugwort	Unknown	IgE	(Gadermaier et al., 2011a)
Api g 4	Birch Olive	Bet v 2 Ole e 2	Sequence homology IgE	(Valenta et al., 1992; Bauer et al., 1996; Asturias et al., 1997; Asturias et al., 1998; Scheurer et al., 2000)
Api g 4	Timothee grass Bermuda grass Sunflower Soy Peanut Pear Cherry	Phl p 11 Cyn d 12 Hel a 2 Gly m 3 Ara h 5 Pyr c 4 Pru av 4	IgE	(Scheurer et al., 2000; Scheurer et al., 2001)

Sensitisation to celery is frequently associated with birch and/or mugwort pollinosis, hence the term "birch-mugwort-celery-syndrome". Wüthrich et al. (Wuthrich et al., 1990) hypothesised that the association between celery and birch is due to a common thermolabile allergen while the common allergen between celery and mugwort is thermostable. A confirmation of this assumption is the fact that RAST with cooked celery extract were negative in patients with birch allergic rhinitis, while it remains positive in those with mugwort allergic rhinitis.

There is evidence that birch pollen and celery allergy are highly related in Central Europe (Hoffmann-Sommergruber et al., 1999), while celery allergy is most frequently related to mugwort pollen allergy in Southern Europe. Ballmer-Weber et al. (Ballmer-Weber et al., 2000) reported that all patients with positive DBPCFC for celery were sensitised to either birch (91 %) or mugwort (64 %) pollen, and that only two out of 22 patients did not show any sensitisation to birch pollen. Also in a previous study performed in Swiss patients, 8 % of celery allergic subjects were not sensitised to rBet v 1 or rBet v 2 (Wüthrich and Straumann, 1997). Api g 2 was shown to cross-react with peach and mugwort pollen and was recognised by IgE in 25 % of 786 LTP sensitive Italian subjects (Gadermaier et al., 2011b).

In one study (Lüttkopf et al., 2000), the allergens recognised by IgE from 22 patients with positive DBPCFCs to celery were identified. Cross-reactivities with pollen allergens were also assessed. Api g 1, cross-reactive carbohydrate determinants, and celery profilin were recognised by IgE of 59 %, 55 %, and 23 % of patients, respectively. IgE-binding to all three structures in a celeriac extract was inhibited by birch pollen extract, whereas mugwort pollen extract could only inhibit IgE reactivity to Api g 4 and cross-reactive carbohydrate determinants. Cross-inhibitions with extracts of birch pollen, mugwort pollen, timothy grass pollen, and lychee, demonstrated the ubiquitous presence of cross-reactive carbohydrate determinants and profilin, while Api g 1 was only cross-reactive with birch pollen. Homologues of Api g 4 and cross-reactive carbohydrate determinants were also present in tree pollen and pollens from weeds, *Graminaceae* and other plant families.

Allergies to carrot and spices, predominantly of the *Umbelliferae* family, are strongly associated to celery allergy, known as "celery-carrot-mugwort-spice syndrome". This syndrome is frequently described in the German literature (Wuthrich and Dietschi, 1985). The only studies carried out in patients with celery allergy confirmed by positive DBPCFC pointed out a sensitisation to carrot in 77 % of patients with CAP > 0.7 kU/L (Ballmer-Weber et al., 2000).

23.5. Possible effects of food processing on allergenicity

Jankiewicz et al. (Jankiewicz et al., 1997) investigated the immunochemical stability of allergens in celery roots after various treatments such as microwaving, drying, γ-irradiation, ultra high pressure and high voltage impulse, and demonstrated that the cross-reactive carbohydrate determinants are the most heat-stable allergens, followed by profilin and Api g 1. The risk of clinical reactivity to cooked celery could not be deduced from the sensitisation pattern to individual celery allergens. The majority of patients reacting to cooked celery recognise the heat-stable allergens Api g 4 and cross-reactive carbohydrate determinants, but a minority of them are exclusively sensitised to Api g 1, which is more heat-labile. Patients exclusively sensitised to Api g 1 react to higher doses of cooked celery compared to the other patients. In addition, Api g 2, a member of the lipid-transfer protein family primarily expressed in celery stalks, is thermally stable and resistant to gastrointestinal digestion (Gadermaier et al., 2011a).

EAST inhibition data also shows that Api g 1 is the most heat-labile allergen in celery, that celery profilin Api g 4 is more stable under thermal processing, and that the IgE reactivity to cross-reactive carbohydrate determinants is not affected by heating (Ballmer-Weber et al., 2002). In this study, a total of 12 patients with history of allergic reactions to raw or to raw and cooked celery were recruited. Of these, 11 (three with reported allergic reactions to raw, but not cooked, celery) underwent a DBPCFC with cooked celery root and six reacted. An increasing intensity of the heat treatment did not lead to unequivocal reduction of allergenicity. Only 10 patients agreed to undergo a DBPCFC with raw celery root and all reacted. There were no patients reacting to cooked celery root without

symptoms to the raw root. This may indicate that no neoallergens are created by the heating process, and that residual activity of the native celery allergens is responsible for the allergenic activity of the cooked vegetable. Also, a DBPCFC with celery spice, dried and pulverised celery was performed in five of the patients recruited. All patients reacted with symptoms comparable to those observed during the DBPCFC with raw extract. However, symptoms occurred at a lower provocation dose compared to raw celery, probably because of higher protein content in celery spice (about 4.5 times higher). This study suggests that, in some subjects, allergic reactions to cooked celery will take place even when high temperatures are used, and that celery spice is allergenic for individuals allergic to raw celery.

23.6. Detection of allergens and allergenic ingredients in food

Several methods for the detection of celery have been described (Stephan et al., 2004; Hupfer et al., 2007), including ELISA and PCR.

23.6.1. ELISA

ELISA methods are generally non-specific as cross-reactivity has been shown with other vegetal species. However, a sandwich-ELISA for the detection and quantification of celery proteins with monoclonal antibodies obtained against the recombinant fusion allergenic protein rApi g 1.01 has been published (Wang et al., 2011a). The method has a high specificity, except a low cross-reactivity with carrot, and a good sensitivity (LOD = 1.9 µg of celery soluble protein/g food sample; LOQ = 5.6 µg whole celery protein/g food sample). The method gave reliable results on both raw and heat processed foods.

23.6.2. PCR

PCR methods are generally more specific than ELISA. Both conventional PCR and real time PCR (Hupfer et al., 2007; Mustorp et al., 2008) methods target the gene encoding for mannitol dehydrogenase. A novel real time PCR method (Fuchs et al., 2013) allows the detection of traces of celery in complex food matrices targeting the gene coding for the *Apium graveolens* NADPH (Nicotinamide Adenine DiNucleotide Phosphate)-dependent mannose-6-phosphate reductase. It allows the detection of three varieties of celery commonly used. It is specific and sensitive (LOD = 10 pg celery DNA). The best performance concerning DNA extraction was obtained with the Wizard method, which produced no false negative results. The method is applicable to commercially available foodstuffs (e.g. noodles, sauces, sausages, soups and spice mixes). In another report (Pafundo et al., 2011), the amount of DNA recovered from celery with the GK-resin method was less variable than with other methods, although the yield was lower. By using Fast SYBR® PCR, DNA analysis was performed on raw celery and food products containing celery (LOD = 10 mg/kg). The results obtained are repeatable, reproducible and suitable for routine analysis. A duplex PCR was also carried out by the same authors by combining the primer pair 18SR as an internal control, and the primer pairs specific for celery. This method, although only qualitative, can be used to detect celery in highly processed foods.

A multiplexed real-time PCR method for the detection of DNA from 12 allergenic ingredients, including celery, is also available (Köppel et al., 2012). Two hexaplex real-time PCR systems were developed to amplify DNA simultaneously from six allergenic ingredients each. The method is specific and allows detecting 0.1 % of each analyte, but the corresponding amounts of protein on a weight basis have not been reported.

An innovative method based on optical thin film biochips for multiplex detection of eight allergenic ingredients, including celery, has also been developed (Wang et al., 2011b). Eight target fragments were amplified by two tetraplex PCR and spotted on the microarray. This method has a high throughput and allows visualising the results with the naked eye (no need of expensive instruments), but needs further development for routine use.

23.7. Minimal (observed) eliciting doses

Data from DBPCFCs conducted in 32 patients with history of an allergic reaction to celery have been published (Ballmer-Weber et al., 2000). Patients underwent SPT and specific IgE was measured in serum. In addition, DBPCFC with raw celery root was performed. Two different drinks were prepared for the test meal, i.e. an active drink with celery and a placebo. The foods were identical in colour, consistency and taste, and all ingredients except for celery were known to be tolerated by each patient. Patients were first challenged in a single-blind way with a placebo drink (5 mL), which they had to retain in their mouth for 5 min. Individuals reacting were excluded. Patients who did not react underwent a two-step DBPCFC, during which (i) they had to retain increasing amounts of the celery extract from raw celery root and placebo drinks in the mouth for one minute at 15 min intervals and (ii) if the patients did not complain about symptoms during this "spit" phase, they were asked to swallow the drinks in increasing amounts. Twenty-two patients showed symptoms to the active preparation: 11 complained about symptoms strictly localised to the oral cavity (OAS) and 11 showed systemic reactions. The minimum provocation dose to elicit symptoms was 0.7 g of celery root, corresponding to the first dose tested, whereas the minimal provocation dose to elicit a systemic reaction was 1.9 g (nausea and dyspnoea) and 5.6 g (urticaria). The eight non-responders underwent an open challenge with celery, and four of them had OAS with 5 g.

The same authors confirmed allergy to cooked celery in six out of eight patients with a positive case history (Ballmer-Weber et al., 2002) using DBPCFC with raw celery, cooked celery, and celery spice. Seven of these complained about OAS during the local mucosal challenge ("spit" phase) of raw celery at a minimum dose of 0.7 g (first dose tested), and five at a minimum dose of 0.9 g of cooked celery. Symptoms were systemic in three patients at provocation doses of 28.5 g of raw celery, and in one patient at the provocation dose of 34.5 g of cooked celery. DBPCFC with celery spice were performed in five of the patients recruited: all of them were responders. Two had OAS at the provocation dose of 0.16 g of celery spice and three had systemic symptoms during the local mucosal challenge at 0.16 g, 0.32 g and 5.85 g of celery spice.

23.8. Conclusion

Celery tuber/root is an important source of food allergens in Central Europe. Celery stalks are often consumed in Mediterranean countries. Celery tuber/root could be found as food ingredients in several pre-packed food and spice mixes, as it is widely used in the food industry owing to its aromatic flavour. The prevalence of celery allergy based on positive SPT and clinical history has been estimated to be 2.7 % in Germany. Celery root may trigger severe anaphylactic reactions in some of patients with celery allergy. Patients with birch pollen allergy may develop allergic reactions to celery and react with severe symptoms, such as laryngeal oedema. Allergenicity to cooked celery seems to be reduced, though not abolished. There are currently no specific immunochemical methods commercially available for celery detection, on account of cross-reactivity with other species. At the moment, the method of choice, suitable for quantification of both raw and cooked celery, is the detection of DNA by conventional (semi-quantitative) and real-time PCR. Only two studies reported minimum doses eliciting local symptoms (at 0.7 g) or systemic symptoms (at 1.9 g), which were similar for raw and cooked celery but corresponded to the first dose tested in the study. It cannot be excluded that some subjects would react to lower doses. Celery spice can trigger systemic symptoms also at low doses (0.16 g).

24. Allergy to lupin

24.1. Background

Lupin (genus *Lupinus*, family *Leguminosae*) is a legume, which includes over 450 species. It is widely grown as a flowering plant for animal feed and farmland management. The usual garden species are poisonous. Some species, like *Lupinus luteus* (yellow lupin, Central Europe), *Lupinus albus* (white lupin, Mediterranean countries), and *Lupinus angustifolius* (blue lupin, Australia) are used as whole seed flour, or as lupin derived drinks (lupin milks), for human and animal consumption. Lupin seeds

are a common snack in several European countries. The yellow lupin variety, because of its colour, is used as egg substitute. The above varieties are known as sweet lupins.

The nutritional value of lupin and its potential as a human food has been under consideration for about 30 years owing to its low cost, high protein quality, and the associated increased protein-efficiency ratio compared to other members of the legume family. Lupin protein contains the essential amino acids (lysine, leucine and threonine) but it is low in methionine, the addition of which improves the protein efficiency ratio. Lupin flour is an excellent source of protein (39 %-45 %, depending on the lupin species). Lupin does not contain gluten and can be used in gluten-free foods (Marss, 1996; Kanny et al., 2000). Since its introduction as an ingredient in wheat flour in the late 90's, lupin flour became a more widely consumed food ingredient. Lupin flour is used in biscuits, pasta, sauces, dietetic products sold as milk and soy substitutes. Due to its emulsifying properties, lupin concentrates are also used in meat and cold-cut industry (EFSA, 2005b).

24.2. Epidemiology

24.2.1. Prevalence

No population-based studies investigating the prevalence of primary allergy to lupin are available, and thus the prevalence of primary allergy to lupin in the general population is unknown.

Allergic reactions to lupin in Europe have emerged following its introduction in processed foods in the late 1990s. The possibility of under-reporting of allergic reactions to lupin cannot be excluded because, until recently[11], it was a hidden (undeclared) ingredient in bakery and other food products.

In 1040 consecutive patients attending an allergy clinic in the Netherlands with a suspected food allergy, 372 were skin prick tested with peanut, soy and lupin flour. A total of 135, 58 and 22 patients were SPT positive for peanut, soy and lupin flour, respectively. Nine patients sensitised to lupin flour underwent a DBPCFC, which was negative in eight cases. The estimated prevalence of lupin allergy among patients with a suspected food allergy was 0.27-0.81 %. In most cases, sensitisation was not clinically relevant and was most likely caused by cross-sensitisation to peanut (de Jong et al., 2010).

Since allergic reactions to lupin have mostly been documented in peanut allergic individuals (Moneret-Vautrin et al., 1999; Leduc et al., 2002), the clinical relevance of primary allergy to lupin has been questioned (Lindvik et al., 2008; de Jong et al., 2010). However, cases of allergic reactions following lupin consumption as a bread ingredient or as snacks were reported in subjects with no prior allergy to peanut and negative SPT for this food (Smith et al., 2004; Peeters et al., 2007; Quaresma et al., 2007). This is corroborated by specific binding of IgE from sensitised individuals to isolated lupin globulins (Klos et al., 2010). Sensitisation to lupin via inhalation has also been reported in individuals with no immunologic reactivity to other legumes (Novembre et al., 1999; Prieto et al., 2010), and for occupationally exposed adults with no allergy to peanut (Crespo et al., 2001; Parisot et al., 2001; Campbell et al., 2007). Individuals sensitised via inhalation to lupin flour may react to lupin flour after ingestion (Crespo et al., 2001; Crespo et al., 2002).

24.2.2. Natural history

There are no data available regarding the natural history of lupin allergy.

24.2.3. Time trends

The prevalence of allergy to lupin is likely to depend on local eating habits and the level of exposure through other routes. Lupin consumption appears to be increasing in several European countries, but no data are available on time trends for lupin allergy.

[11] Labelling Directive 2000/13/EC, as amended by Directive 2003/89/EC that entered into force on 25 November 2005, which applies only to pre-packaged foodstuffs.

24.2.4. Severe reactions/anaphylaxis

Severe anaphylactic reactions have been described upon oral exposure to lupin both in subjects primarily sensitised to lupin (Brennecke et al., 2007) and in legume allergic individuals, including peanut allergic subjects (Matheu et al., 1999). It is currently estimated that, with respect to the cases of anaphylaxis reported after oral exposure to lupin, the ratio between pre-existing legume allergy (mostly peanut) and *de novo* sensitisation to lupin seeds is around 1:1 (Jappe and Vieths, 2010).

24.2.5. Factors affecting prevalence of lupin allergy

The main population at risk of developing allergic reactions to lupin is peanut allergic individuals. Most reports of allergic reactions to lupin refer to patients with known allergy to peanuts attending specialist medical services (Hefle et al., 1994; Moneret-Vautrin et al., 1999; Faeste et al., 2004). A study conducted in 47 peanut-allergic children and adolescents and 46 atopic controls, 4 % of peanut allergic patients showed clinical reactions to lupin when challenged orally, whereas none of the atopic controls reacted (Shaw et al., 2008).

24.3. Identified allergens

L. angustifolius contains seed storage proteins which include two major protein types, β-conglutin (vicilin-like protein, or acid 7S globulin) and α-conglutin (legumin-like protein or 11S globulin), and two minor components, δ-conglutin (2S albumin) and γ-conglutin (basic 7S globulin). The four fractions (named on the base of their electrophoretic mobility) are glycosylated (Foss and Frökiær, 2005) (Table 27).

Table 27: Lupin (*L. angustifolius*) allergens

Superfamily/ family	Biochemical name	% of total protein	Molecular weight (kDa)	Allergen	Molecular weight[a] (kDa)
α-Conglutin[1] (legumin-like)	11S globulin	33	69 to 89	Lup-2[2]	20
β-Conglutin (vicilin-like)	7S globulin	45	19 to 60	Lup an 1	55-61
				Lup-1[2]	34.5
γ-Conglutin[1]	7S globulin	6	46		46
δ-Conglutin[1]	2S albumin	12	14		14

[1] www.allergome.org; [2] present also in *Lupinus albus*; [a] MW (SDS-PAGE)

β-Conglutin is a non-covalently associated heterogeneous trimer consisting of a number of polypeptides ranging from 16 to 70 kDa (Duranti et al., 2005). β-Conglutin from *L. angustifolius* seed was recognised by the IgE of most (8/12) lupin-allergic subjects (Goggin et al., 2008) and is considered the major lupin allergen and is the only lupin allergen (Lup an 1) reported in the IUIS allergen nomenclature. A polypeptide of the β-conglutin fraction from *L. albus* has been also identified and designated as Lup-1 (Alvarez-Alvarez et al., 2005; Guillamon et al., 2010). Lup-1 has been shown to be a major allergen in patients with allergy following lupin ingestion (Sanz et al., 2010) and is highly homologous to soy β-conglycinin and peanut Ara h 1.

In *L. angustifolius*, α-conglutin consists of four subunits, which are non-covalently linked. The subunits are in a 55-80 kDa range and contain a 20 kDa disulphide-bound moiety. A polypeptide of 20 kDa, called Lup-2, has been isolated from the α-conglutin fraction, characterised and identified as a

major allergen in *in vitro* IgE-studies (Guillamon et al., 2010). In *L. albus*, α-conglutin is a heterogeneous mixture composed of a hexamer of basic and acid trimers linked by two disulphide bridges with molecular weight in the range 47-54 kDa linked to a basic polypeptide of ca. 20 kDa (Magni et al., 2005). α-Conglutin is highly homologous to the peanut allergen Ara h 3 (Foley et al., 2011).

γ-Conglutin consists of two disulphide linked polypeptides of 30 and 17 kDa, respectively. Specific IgE-binding from lupin-allergic individuals to γ-conglutin has been described (Klos et al., 2010). α-, β- and γ-Conglutin include two cupin domains. δ-Conglutin is a monomeric protein with two disulphide linked polypeptides of 9 and 4 kDa, respectively, which is highly homologous to the peanut allergen Ara h 2.

IgE-binding proteins of lupin with MW of 43-45 kDa were shown by immunoblotting in studies involving lupin allergic patients (Moneret-Vautrin et al., 1999; Novembre et al., 1999; Parisot et al., 2001; Holden et al., 2008).

Other potential allergens with MWs of 13, 29, 34, 38, and 66 kDa were isolated from lupin seeds by chromatographic methods (Dooper et al., 2007) and were studied for IgE-binding affinities (Magni et al., 2005; Holden et al., 2008).

24.4. Cross-reactivities

Several legumes (e.g. peanut, soybean, lentils, beans, chickpeas and peas) may cross-react with lupin *in vitro* (IgE-binding) (Bernhisel-Broadbent and Sampson, 1989; Bernhisel-Broadbent et al., 1989; Ballabio et al., 2013).

In vitro cross-reactivity between lupin and other legumes has been tested mostly using serum from peanut-allergic individuals. β-Conglutin (Lup an 1) was a major allergen in patients with allergy following lupin ingestion (Sanz et al., 2010) and the major lupin allergen cross-reacted with peanut proteins, as observed in IgE-binding and SPT studies in peanut allergic individuals (Ballabio et al., 2013). The basic subunits of the 11S globulin α-conglutin may also be responsible for cross-reactivity between lupin and other leguminous plants (Ballabio et al., 2010; Sirtori et al., 2011). The high level of amino acid sequence homology between Lup-1 and Lup-2 and major allergens of some legumes explains the cross-reactivity between lupin and other legumes.

Although the amino acid sequence of the lupin γ-conglutin does not align with any known peanut protein, γ-conglutin also bound specific IgE from peanut allergic individuals (Sirtori et al., 2011), suggesting that the IgE-binding epitopes for this protein and for peanut allergens are similar. Conversely, the lupin proteins γ-conglutin (2S albumin) and 11S globulin were shown to cross-react with homologous polypeptides of other legumes (Magni et al., 2005).

Cross-reactivity between Ara h 2 and δ-conglutin and between Ara h 1 and β-conglutin were also described using sera from lupin-allergic patients (Dooper et al., 2009). Significant sequence and molecular homology between Ara h 8 of peanut and the pathogenesis related protein PR-10 of white lupin suggest that these proteins could in part be responsible for some of the reported cross-reactivities in peanut allergic individuals (Guarneri et al., 2005).

In vitro cross-reactivities between members of the legume family are of clinical relevance in about 5 % of legume allergic individuals, notably cross-reactivity to peanut (EFSA, 2005b). The risk of clinically relevant cross-reactions with peanuts in lupin allergic patients is higher than with other legumes, whereas cross-reactivity to lupin in peanut allergic patients is also of clinical relevance (Hefle et al., 1994; Moneret-Vautrin et al., 1999; Kanny et al., 2000; Faeste et al., 2004).

In a study of 44 peanut allergic subjects, 11 had positive SPTs to lupin flour and seven out of the eight subjects who underwent a DBPCFC with lupin flour reacted, indicating clinical cross-reactivity

between peanut and lupin (Moneret-Vautrin et al., 1999). In a DBPCFC, 68 % (15/23) of patients allergic to peanuts showed clinical reactions to lupin flour (Leduc et al., 2002).

Although a major lupin allergen belonging to the PR-10 is homologous to the birch pollen allergen Bet v 1 superfamily (17-22 kDa), with common secondary structures, there is no information as to the likelihood of clinical reactions to lupin in these individuals. The scarcity of clinical reports from countries with a high birch pollen sensitisation rate (e.g. Sweden) may suggest that this structural similarity is not of clinical relevance in these populations. The Panel is not aware of systematic studies, which address the relationship between lupin pollen allergies and reactions to lupin flour after ingestion.

24.5. Effects of food processing on allergenicity

A common feature of most legume allergens is their relative resistance to thermal, chemical, and proteolytic degradation (Lalles and Peltre, 1996; Mills et al., 2009). The IgE-binding capacity of lupin seeds after boiling (up to 60 minutes), autoclaving (121 °C, 1.18 atmospheres, up to 20 minutes and 138 °C, 2.56 atmospheres, up to 30 minutes), microwave heating (30 minutes), and extrusion cooking has been assessed (Alvarez-Alvarez et al., 2005). An important reduction in IgE-binding capacity was reported after autoclaving at 138 °C for 20 minutes and absence of IgE-binding after autoclaving for 30 minutes.

After harsh industrial processing involving mechanical, high-pressure homogenisation and lyophilisation and thermal (200 °C for 30 min) treatments, α-, β-, and δ-conglutin were still able to release stable IgE-binding peptides (Sirtori et al., 2010). However, the *in vitro* IgE-binding of lupin was reduced when an instantaneous controlled pressure drop was applied to lupin cotyledons (Guillamon et al., 2008). Removal of oligosaccharides from intact lupin seeds by ethanol extraction reduced the content of γ-conglutin in the lupin protein fraction (Martínez-Villaluenga et al., 2006). *In vitro* hydrolysis of the major globulins found in sweet lupin by the enzymes pepsin and trypsin appears to reduce their IgE-binding capacity (Sormus de Castro Pinto et al., 2009).

Lupin allergens are generally resistant to thermal, chemical, and proteolytic degradation. The effects of different processing methods on the allergenicity of lupin have not been systematically investigated.

24.6. Detection of allergens and allergenic ingredients in food

24.6.1. ELISA

A quantitative sandwich ELISA that uses polyclonal rabbit anti-lupin antibodies was used as a routine method to detect lupin in food products with a LOD of 1 mg lupin protein per 1 kg of food (Holden and Egaas, 2005). A kit for this ELISA test is commercially available. Another test based on monoclonal/polyclonal sandwich ELISA has also been described with a LOD of 1 mg/kg, suitable for both raw and processed proteins (Holden et al., 2007). The Kaw's assay (Kaw et al., 2008) is based on the rabbit antisera as the capture reagent and the sheep antisera as detector reagent, with a LOQ of 1mg/kg. It has been applied to model and reference food standard with reliable results. Minor cross-reactivities have been observed with soy (*Glycine max)* and black bean (*Castanospermum australe*). The extensive immunological cross-reactivities between legumes represent a problem in the development of lupin-specific immunological assays (Bernhisel-Broadbent and Sampson, 1989; Bernhisel-Broadbent et al., 1989).

24.6.2. Mass spectrometry

Protein detection by mass spectrometry has emerged as an alternative method to ELISA. A semi-quantitative study was performed on lupin trypsin digested proteins using HPLC/ESI-MS/MS (Locati et al., 2006). β-Conglutin was detected in a linear 0.025-1.5 mg/mL concentration range. The same group (Brambilla et al., 2009) developed a nanoHPLC-chip-MS/MS stable isotope label-free (SIF) method for the simultaneous characterisation and quantitation of *L. albus* seed storage proteins in four

lupin cultivars and a HPLC-chip-ion trap MS/MS for the quantitation of γ-conglutin in a lupin seed protein extract (Resta et al., 2012).

A rapid shotgun proteomic LC-ESI-MS/MS method was proposed for the simultaneous and unequivocal confirmation and quantitation of α-, β-, γ- and δ-conglutins in pasta and biscuits (Mattarozzi et al., 2012). The allergenic proteins were identified by monitoring target tryptic peptides specific and unique for the four proteins. The LOD was in the same range as shown for ELISA and PCR (around 1 mg/kg). The LOQ varied for the different proteins (4-42 mg/kg) and depending on the matrix.

24.6.3. PCR

Real-time PCR assays for the detection of lupin genomic DNA in food products have been developed with different LODs (0.1-10 mg/kg) (Demmel et al., 2008; Scarafoni et al., 2009; Gomez Galan et al., 2010; Demmel et al., 2011) on the base of sequence tags publicly available. Also, a qualitative duplex real-time PCR method for the simultaneous detection of lupin and soy mitochondrial DNA is available, with a LOD of 2.5 mg/kg in processed foods (Gomez Galan et al., 2011).

The performance of ELISA and real-time PCR methods for the detection of lupin in different food matrices (biscuits, bread, noodles and rice patties) was assessed by developing in-house one sandwich ELISA, two competitive ELISA and one real-time PCR method (Ecker and Cichna-Markl, 2012). The most sensitive method was the sandwich ELISA, with a LOD of 10 mg/kg for all matrices, both before and after heat treatment. Both ELISA and PCR methods gave different results according to the lupin cultivars (Röder et al., 2013).

24.7. Minimal (observed) eliciting doses

Available data on the lowest doses of lupin triggering clinical allergic reactions have been obtained almost exclusively in peanut allergic individuals.

In a DBPCFC, six children allergic to peanut were challenged orally with lupin flour (Moneret-Vautrin et al., 1999). Five children showed allergic reactions at doses of lupin flour ranging from 265 to 1000 mg (two children with clinical response to the labial challenge did not undergo the oral challenge). The youngest child (1.5 years) did not have a positive SPT but responded with deterioration of her atopic dermatitis. In this study, the minimal doses of allergenic food eliciting a clinical response were similar for peanut and lupin (5-965 mg and 265-1000 mg, respectively).

Twelve children with history of clinical allergic reactions to peanut were evaluated by SPT, the ImmunoCAP test, immunoblotting, and DBPCFC. In the DBPCFC, patients received lupin-enriched pasta every 30 minutes at increasing doses of 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 12.8, and 25.6 g of macaroni (the last dose at 3.5 h), totalling 12.7 g of lupin protein for children under 13, with a ninth dose of 51.2 g of pasta at 4 h for children over 13 years of age for a total of 25.6 g of lupin protein. Carrot-containing pasta was used as control. Positive clinical reactions were observed in two children at doses of 0.2 and 6.4 g of pasta, corresponding to 50 mg and 1.6 g of lupin proteins, respectively. β-Conglutin was the protein most involved in SPT positivity (Fiocchi et al., 2009).

Peeters et al. (Peeters et al., 2009) studied 39 peanut-sensitised patients by skin prick tests (SPT) and ImmunoCAP to lupin, pea, and soy. Eighty-two percent of the study population was sensitised to lupin, 55 % to pea, and 87 % to soy. Clinical reactivity was measured by DBPCFC for lupin, and by history for pea and soy. Clinical reactions to lupin, pea, or soy occurred in 35 %, 29 %, and 33 % of the study population, respectively. The MED for lupin inducing mild subjective symptoms was 0.5 mg of lupin flour, and the NOAEL was 0.1 mg of flour. The amount of protein corresponding to this amount of flour was not reported.

A case of anaphylaxis and deteriorating lung function in a peanut allergic, 13 year old girl after oral challenge with a cumulative dose of 965 mg of a crude lupin flour extract has been reported (Kanny et

al., 2000). This quantity could be present in 100 g of bread if wheat flour contains 10 % lupin, as it was allowed by some national legislation.

24.8. Conclusion

The frequency of allergic reactions to lupin in the general population is unknown. Allergic reactions to lupin have been documented in peanut allergic as well as in individuals with primary sensitisation to lupin. The possibility of under-reporting of allergy cases cannot be excluded, as until recently lupin was an unlabelled ingredient in various bakery and meat products. Lupin allergens have been identified. Lupin allergens are generally resistant to thermal, chemical, and proteolytic degradation. The effects of different processing methods on the allergenicity of lupin have not been systematically investigated. ELISA, MS and PCR methods are available to detect and quantify lupin in foods. Clinical reactions to lupin range from mild symptoms to anaphylaxis. Doses of lupin protein triggering clinical reactions in peanut allergic individuals vary widely (from 50 mg to 1.6 g). Subjective symptoms have been reported to 0.5 mg of lupin flour.

25. Allergy to sesame

25.1. Background

Sesame (*Sesamum indicum* L) is a plant originally from tropical Africa, which is now universally cultivated for its seeds. It is the most important species in the *Sesamum* genus of the *Pedialaceae* family. The seeds are used in several food products, especially in bakery products, fast-foods, processed meat, vegetarian and ethnic dishes. The oil obtained from the seeds is used for cooking and salad dressing in Oriental, Chinese and South American cuisines, and is also employed by the pharmaceutical industry as a vehicle of medications for intramuscular injection.

In some countries, sesame is one of the major causes of food allergy. In Israel, where sesame seed-based foods (halva and tehina) are included in the diet of infants and young children as a source of proteins and iron, sesame is the third common cause of IgE-mediated food allergy and the second most common cause of anaphylaxis (Dalal et al., 2002; Dalal et al., 2012).

25.2. Epidemiology

25.2.1. Prevalence

25.2.1.1. Europe

Eight studies from Europe (in France, Germany, Hungary and the United Kingdom) are available between 1999 and 2008 and all ages were studied.

Self-reported diagnosis of sesame allergy was investigated in three studies. The highest prevalence was observed in France, where 1.5 % of 5-17 year olds self-reported an adverse reaction (Touraine et al., 2002), whereas a zero prevalence was reported in the UK across all ages (Emmett et al., 1999).

Sensitisation to sesame measured by SPT was reported in four studies. In the UK the lowest sensitisation rates were reported in 7-year-old children (0.1 %) (Roberts et al., 2005), and the highest in 3 year olds (1.4 %) (Venter et al., 2008). Only one study determined specific IgE levels to sesame and found zero prevalence of sensitisation among 60-97 year olds in Hungary (Bakos et al., 2006). In Germany, a population based study reported prevalence rates based on a positive SPT plus a convincing clinical history of 1.7 % (Zuberbier et al., 2004).

In the UK, two studies challenged subjects suspected of sesame allergy and showed prevalence between 0.1 % in 6-year olds (Venter et al., 2006a) and 0.6 % in 3-year olds (Venter et al., 2008).

6961 25.2.1.2. Outside Europe

6962 In the rest of the world, self–reported sesame allergy ranged between 0.07- 0.23 % in Canada (Ben-
6963 Shoshan et al., 2010) and was 0.1 % in the US general population (Sicherer et al., 2010).

6964 In Israel, where exposure to sesame occurs earlier in life than in European countries, 0.18 % of young
6965 children up to two years of age had positive SPT with clinical history of sesame allergy (Dalal et al.,
6966 2002).

6967 One Australian study based on OFC reported a prevalence of food allergy to sesame of 0.7 % in
6968 children12-15 months old (Osborne et al., 2011).

6969 **25.2.2. Natural history**

6970 Sesame allergy appears to be persistent similar to allergy to fish or peanuts (Agne et al., 2004).
6971 However, Cohen et al. (Cohen et al., 2007) reported that 20 % of 74 sesame allergic paediatric patients
6972 in Israel developed tolerance during the follow-up period of 1.8-14 years (median 6.4 years). Clinical
6973 scoring and severity of symptoms were not found to be predictive in the development of the tolerance.
6974 Similarly, in a cohort of 234 children, sesame was the third most common allergenic food after milk
6975 and egg, but unlike milk and egg allergy, sesame allergy resolved in only 30 % of patients (Aaronov et
6976 al., 2008).

6977 **25.2.3. Time trends**

6978 There were limited studies on sesame allergy, with only two studies worldwide using food challenges
6979 (in the UK and Australia), so no time trends can be reported.

6980 **25.2.4. Severe reactions/anaphylaxis**

6981 Information about documented severe reactions to sesame is scarce. In the UK, a questionnaire-based
6982 survey suggested that sesame was responsible for severe reactions. Among 280 replies received, 54 %
6983 reported reactions to sesame; 89 % of reactive subjects reported other atopic diseases and notably
6984 84 % were also nut/peanut allergic. A total of 17 % had suffered potentially life-threatening
6985 symptoms, with 65 % of severe reactions happening on first known exposure (Derby et al., 2005).
6986 Many publications on sesame allergy are case reports describing anaphylaxis or case series on
6987 anaphylaxis presenting to emergency departments (Dalal et al., 2012). Although systemic reactions
6988 occur, a single case of death owing to an allergic reaction to sesame has been reported (Pumphrey and
6989 Gowland, 2007). Anaphylactic shocks with 1 and 2 mL of sesame oil have been reported in two out of
6990 five patients with a positive DBPCFC (Morisset et al., 2003a).

6991 **25.2.5. Factors affecting prevalence of sesame allergy**

6992 Sesame allergy appears to be present more frequently during childhood, although onset maybe at any
6993 age (Dalal et al., 2012).

6994 In one study using SPT and specific IgE testing for diagnosis in children with sesame-seed allergy, a
6995 significant association was found with allergy to other seeds, especially poppy seed, in 17 % of
6996 subjects (Foong et al., 2013). Sesame-seed allergy was also significantly associated with tree-nut
6997 allergies but not with peanut allergy. Patients with sesame allergy have a high likelihood of having
6998 multiple allergies and it is recommended to test sesame allergic patients at least for tree nut and peanut
6999 allergens (Dalal et al., 2012).

7000 **25.3. Identified allergens**

7001 Sesame seeds contain 50-60 % oil and 19-25 % proteins. Most protein present in sesame seeds are
7002 storage proteins composed of globulins (67.3 %), albumins (8.9 %), prolamins (1.4 %) and glutelins
7003 (6.9 %) (Rivas R et al., 1981). The water-insoluble 11S globulins and the soluble 2S albumins are the
7004 two major storage proteins, constituting 80-90 % of the total seed proteins in sesame.

7005 Seven proteins have been identified as allergens in sesame seeds and are reported in the IUIS database
7006 (Table 28).

7007 **Table 28:** Sesame (*Sesamum indicum*) allergens

Allergen	Biochemical name	Superfamily/family	Molecular weight[a]
Ses i 1	2S albumin (sulphur-poor)	prolamin	9
Ses i 2	2S albumin (sulphur-rich)	prolamin	7
Ses i 3	7S vicilin-like globulin	cupin	45
Ses i 4	oleosin	oleosin	17
Ses i 5	oleosin	oleosin	15
Ses i 6	11S globulin	cupin	52
Ses i 7	11S globulin	cupin	57

7008 [a] MW (SDS-PAGE)

7009 The first allergen identified and sequenced in sesame seeds was a 2S albumin named Ses i 1, a seed
7010 storage protein, which was recognised by the 10 patients studied (Pastorello et al., 2001b). All patients
7011 showed high levels of sesame specific IgE and highly positive SPT with fresh seeds and commercial
7012 extracts. In contrast, only a minority of the 20 patients with systemic reactions tested in a second study
7013 recognised proteins with a molecular weight in the range of Ses i 1 (Beyer et al., 2002a). In a third
7014 study conducted in Israel, which evaluated 24 subjects with symptoms and specific IgE to sesame, 22
7015 recognised the 14 kDa 2S albumin precursor, confirming Ses i 1 as a major sesame allergen (Wolff et
7016 al., 2003). 2S albumins are typically heterodimeric proteins with small and large subunits linked by
7017 disulphide bonds. Several reacting epitopes were found on the peptide corresponding to the residues
7018 24-94 (Wolff et al., 2004). Ses i 1 has 47 % homology with the Brazil nut Ber e 1, 41 % with ricin
7019 nut Ric c 1 and 40 % with sunflower seeds (Pastorello et al., 2001b). Other authors (Fremont et al.,
7020 2002) reported homology of Ses i 1 with Sin a 1 of yellow mustard, and with Bra j 1 of oriental
7021 mustard.

7022 The two sesame allergens Ses i 2 and Ses i 3 (Beyer et al., 2002a) belong to the family of seed storage
7023 proteins. Ses i 2 is a 2S albumin and a sulphur-rich protein (Tai et al., 1999), 47 % homologous and
7024 35 % identical to Ses i 1, which is a sulphur-poor protein (Tai et al., 2001). Ses i 2 was recognised
7025 only by 30 % of the patients. It has a sequence homology of 38 % with the walnut allergen Jug r 1,
7026 40 % with the Brazil nut Ber e 1 and 34 % with the peanut allergen Ara h 1 (Beyer et al., 2002a).

7027 Ses i 3, which constitutes approximately 5 % of the total sesame protein, is a 7S vicilin-like globulin,
7028 formed by polypeptides non covalently linked (Orruño and Morgan, 2007). It was recognised by 75 %
7029 of patients and is a major allergen of sesame (Beyer et al., 2002a). Ses i 3 showed a 41 % sequence
7030 homology to the walnut allergen Jug r 2 and 36 % homology to the peanut allergen Ara h 1.

7031 Two oil body-associated proteins (oleosins), which were recognised by IgE from most sesame allergic
7032 patients (29 out of 32 patient sera), were sequenced and named Ses i 4 and Ses i 5 (Leduc et al., 2006).
7033 They represent 80-90 % of total oil body proteins and correspond to only 1-2 % of total seed proteins.
7034 Ses i 4 and Ses i 5 are highly hydrophobic and may remain residually present in oil and bind specific
7035 IgE. Anaphylactic shocks have been reported after ingestion of a few millilitres (1 and 5 mL) of
7036 sesame oil (Morisset et al., 2003a). Homology between oleosin of different species has been found for
7037 a Chinese spice shiso (*Perilla frutescens*, 75 % identity) and for carrot oleosin (64 % identity). Lower
7038 levels of identity have been observed with peanut and soybean oleosins (56 and 51 %, respectively).

7039 Two additional sesame seed allergens Ses i 6 and Ses i 7, which are 11S globulins of high-molecular
7040 weight sharing only 36 % identity, have been obtained by cloning (Beyer et al., 2007). The

recombinant proteins were screened with sera of 24 patients with sesame allergy. Thirteen patients showed a strong IgE binding to Ses i 6 and ten patients to Ses i 7. Clinical reactions were observed in these patients involving the skin (n = 19), the gastrointestinal tract (n = 11), the respiratory system (n = 6) and several organ systems (n = 12).

The stability of the allergenic proteins to gastrointestinal digestion varied widely and consistently with the reported IgE-binding data (Orruño and Morgan, 2011). The 2S albumins were highly stable to digestion by all the enzymes tested. The 7S and 11S globulins were relatively labile to pepsin, but generated stable polypeptides after digestion with trypsin and chymotrypsin.

25.4. Cross-reactivities

Few data are available on the clinical and immunological cross-reactivity of sesame seeds.

Children sensitised to sesame had a high prevalence of sensitisation to peanuts (84.8 %), hazelnut (82.9 %), egg (81.5 %), walnut (80.6 %) and almond (76.3 %) (Stutius et al., 2010). Both cross-sensitivity and clinical cross-reactivity were observed between sesame, peanut and tree nuts. Children sensitised or allergic to both peanuts and tree nuts may be more likely to be sensitised or allergic to sesame (Stutius et al., 2010).

By using a modified basophil activation test (mBAT), the sesame 11S globulin Ses i 6 showed partial immunological cross-reactivity with walnut (Wallowitz et al., 2006b; Wallowitz et al., 2007).

25.5. Effects of food processing on allergenicity

The major sesame allergen Ses i 1 was thermo-stable up to 90 °C at neutral and acid pH, showing minimal conformational alterations which were reversible on cooling, as shown by circular dichroism (CD) and Fourier transform-infrared spectroscopy (FTIS) (Moreno et al., 2005). It was also highly resistant to digestion in an *in vitro* gastrointestinal model system. However, no tests on the antigenicity/allergenicity of heated samples have been reported.

Protein extracts of sesame seeds prepared using different conditions (NaCl concentration, pH) showed different immunological responses (Achouri and Boye, 2013). The immunoreactivity was higher for isolates extracted with water and lower salt concentration (0.2 M NaCl) as compared with those extracted at higher salt concentration (0.6 M and 1 M), on account of the different solubility of the proteins extracted (Achouri et al., 2012). At higher salt concentration, salting out and aggregation could have also prevented the interaction of the epitopes with the IgG antibodies.

High pressure treatments (from 100 MPa to 500 MPa) markedly decreased the antigenicity of sesame allergens at all pH values (in particular at pH 7 and 10), probably owing to the unfolding of the proteins with loss of conformational epitopes, as monitored by FTIR (Achouri and Boye, 2013). Thermal processes, such as boiling and dry roasting, increased the antigenic response, whereas microwaving decreased it. IgE-binding capacity of sesame storage proteins was not significantly altered by the application of γ-irradiation with doses up to 10 kGy (Zoumpoulakis et al., 2012).

Subjects reacting to 100 mg up to 7 g of sesame seeds also reacted to a few milligrams of proteins in sesame oil (Morisset et al., 2003a). This may indicate the presence of lipophilic proteins (oleosins) in the lipid matrix, which may increase allergenicity.

25.6. Detection of allergens and allergenic ingredients in food

25.6.1. ELISA

Immunochemical assays for the detection of sesame allergens with a LOD < 1 mg/kg of food have been reported (Brett et al., 1998) and detection kits are commercially available (Poms et al., 2004a). An indirect competitive ELISA assay, based on polyclonal antibodies, has been developed (Husain et al., 2010). In crisp bread, crackers, cereals and snacks, the LOD was found to be 5 mg of sesame

protein/kg of food, corresponding to 28 mg sesame/kg of food, with a LOQ of 30 mg sesame protein/kg of food, corresponding to 165 mg sesame/kg of food. In fresh bread and rolls, the LOD was 11 mg of sesame protein/kg food, corresponding to 61 mg sesame/kg of food, with a LOQ of 49 mg/kg sesame protein/kg of food, corresponding to 270 mg sesame/kg of food. No cross-reactivity with other allergens was observed. It was not possible to detect sesame in sesame oil or in sesame roasted at 250 °C with this method.

A sandwich ELISA was also developed which did not show any cross-reactivity with 19 food ingredients commonly found in sesame containing foodstuffs (Redl et al., 2010). In wholegrain bread, crisp toasts and snacks the LOD was 0.5, 0.5 and 0.3 mg sesame protein/kg and the LOQ was 0.6, 0.8 and 1.4 mg sesame protein/kg, respectively. The sandwich ELISA showed significantly lower LOD and LOQ than the competitive ELISA previously described. Sesame roasted at 250°C for 10 min could not be detected. This method was not tested for the detection of allergens in sesame oil.

25.6.2. PCR

PCR test kits for detecting sesame are commercially available. Selective real-time PCR methods for the detection of sesame in food are able to detect 5 pg of purified sesame seed DNA (Brzezinski, 2007). Another method targeting the gene coding for Ses i 1 (Schoringhumer and Cichna-Markl, 2007) was able to recognise white, brown and roasted sesame, but not sesame oil, probably owing to the low concentration of DNA in oil. A good linearity was obtained down to 10 pg/µL, corresponding to an absolute amount of 50 pg or, assuming a haploid sesame genome size of 0.97 pg, 52 genomic copies. The assay did not show cross-reactivity with 17 common food ingredients.

Another quantitative and sensitive real-time PCR method for the detection of sesame in food was developed (Mustorp et al., 2008) targeting the genes encoding for the two 2S albumins, Ses i 1 and Ses i 2, which show only a limited sequence homology. The assay gave a good performance with solid foods (wheat flour, barbecue spice) at a spiking level of 0.005 % (w/w), detecting template DNA below approximately 1 molecule. It was not tested for the detection of sesame in sesame oil.

25.6.3. Multiplex DNA

Multiplex DNA-based methods based on different approaches have been developed for the simultaneous determination of several allergens, including sesame.

A duplex real-time PCR method to simultaneously detect sesame and hazelnut in food did not show cross-reactivity with 25 common food ingredients and allowed detection in spiked foods down to 0.005 % of both sesame and hazelnut (Schoringhumer et al., 2009). A method for the simultaneous detection of celery and sesame in foods by means of an end-point PCR protocol in connection with a microchip CE platform (Coïsson et al., 2010) had a LOD of 1 mg/kg DNA for sesame.

Two tetraplex qPCR for the detection of eight allergenic ingredients had a specificity and sensitivity for sesame in the range of 0.01 % (Köppel et al., 2010), whereas two quantitative hexaplex real-time PCR systems for the detection and quantification of 12 allergens in food (Köppel et al., 2012) had a LOD of 0.1 % for all analytes. Another six-plex qPCR able to detect six allergenic ingredients (Pafundo et al., 2010) had a LOD of the template sesame DNA of 0.5 pg.

A multiplex ligation-dependent probe amplification (MLPA) method for the detection of 10 different nuts and sesame (Ehlert et al., 2009)had a reported LOD in the lower mg/kg range for all allergenic ingredients. A quantitative 10-plex competitive MLPA method for the detection of 10 allergenic ingredients, including sesame, with an internal positive control (IPC) had a high sensitivity (Mustorp et al., 2011) for sesame, with a of LOD 3.8 ng DNA, corresponding to 173 gene copy number (± 93) and similar or higher sensitivity for spiked foods.

Optical thin-film biochips for multiplex visible detection of eight allergenic ingredients in food have been developed based on two tetraplex PCR systems (Wang et al., 2011b). The absolute LOD was 0.5

pg sesame DNA, and the practical LOD for sesame concentration in a blended mixture was 0.001 %, the lowest value observed up to now.

25.7. Minimal (observed) eliciting doses

In one study (Morisset et al., 2003a), haemodynamic modifications and respiratory symptoms were observed in 8 % and in 42 %, respectively, of the 12 positive oral challenges (SBPCFC or DBPCFC) to sesame seeds analysed. A cumulative reactive dose ≤ 65 mg of solid food (equivalent to 12.4 mg of sesame proteins) was found in 8 % of sesame allergic patients. The lowest eliciting dose was observed at ≤ 30 mg of sesame seeds. Five out of six DBPCFCs with sesame oil were positive, and two patients had an anaphylactic shock with 1 and 5 mL, respectively.

25.8. Conclusion

Allergy to sesame seeds is well documented, especially in countries like Israel where exposure occurs early in life. Sesame seeds contain major allergens, which can cause severe anaphylactic reactions. Both sensitivity and clinical cross-reactivity were observed between sesame and peanut and tree nut. Thermal processes, such as boiling and dry roasting, increased the IgE-binding capacity, whereas microwaving decreased it. High pressure treatments markedly decreased the IgE-binding capacity of sesame allergens at all pH values. ELISA and real-time PCR methods are available to detect sesame in foods. DBPCFC studies show that both sesame seeds and sesame oil can elicit allergic reactions in sensitised patients, with MEDs ranging from 30 mg to 10 g of sesame seed, and few millilitres (1-5 mL) of sesame oil. Few milligrams of sesame protein are enough to trigger severe symptoms.

26. Allergy to mustard

26.1. Background

The mustard plant belongs to the *Brassicaceae (Cruciferae)* family. White/yellow (*Sinapis alba* L.), black (*Brassica nigra* L.*)* and brown/oriental mustard (*Brassica juncea* L.) are the main types of mustard seeds used in cuisine and food processing. Mustard powder commercially available is usually a mixture of ground white and black mustard seeds. White and brown seeds are blended to make the English style mustard. White mustard seeds are the main ingredient in Nord-American mustard, while the brown seeds are mainly used in Europe and China. Black mustard is mostly used in Indian cuisine. Mustard oil is also widely used as an edible oil and as a flavouring agent in India.

Mustard is used on some meat dishes, like hot-dogs and hamburgers, and is very often an added ingredient in spices, sauces, salads and other foods. For example, mayonnaise as well as ketchup and curry mixtures may contain mustard. Mustard is also used in traditional remedies (Rancé et al., 2000). Mustard consumption in different countries varies according to local food habits.

26.2. Epidemiology

26.2.1. Prevalence

Prevalence data from DBPCFC for allergy to mustard are scarce owing to the difficulty of masking the strong taste of mustard. In addition, oral challenges to confirm mustard allergy have been considered an unethical health risk owing to the severity of systemic reactions reported following ingestion of mustard in allergic individuals.

Only one population-based study based on self-reported diagnosis of mustard allergy could be found in the literature (Touraine et al., 2002), where 3 % of teenagers (5-17 year olds) in France reported adverse reactions to mustard.

Data on the prevalence of mustard sensitisation, clinical mustard allergy and the incidence of severe allergic reactions to mustard in the general population are lacking.

Data obtained in patient populations are particularly abundant in France, where sensitisation rates form 1 % to 28 % have been reported in food allergic adults and children between 1983 and 2001 (Moneret-Vautrin and André, 1983; Andre et al., 1994; Rancé et al., 1999).

The prevalence of mustard allergy in clinical studies using DBPCFC or OFC varies between 23.3 % among children with a previous history of a clinical reaction to mustard (Morisset et al., 2003b), 42 % among previously sensitised children (Rancé et al., 2000; Rancé et al., 2001), and 58 % among atopic adults (Figueroa et al., 2005).

Studies testing sensitisation to mustard in patient populations based on SPT, mustard specific IgE and RAST are also available. In Spain, 18.2 % of a patient population (n = 269), who visited their allergy clinic for other reasons, had a positive SPT to mustard (Leanizbarrutia et al., 1988). Among a subpopulation of pollen SPT positive patients from the same study, 54.2 % (n = 49) were SPT positive to mustard, but only 4 (8 %) complained of symptoms associated with mustard ingestion. In another Spanish study, mustard allergy (unequivocal history with positive SPT or serum specific IgE (CAP-System) and absence of symptoms after mustard elimination from the diet) accounted for 7 % of food allergy consultations (8 of 120 subjects) in the Canary Islands (Castillo et al., 1996). In Finland, a series of 1 120 atopic and 380 non-atopic patients were SPT tested for allergy to spices including curry (Niinimäki and Hannuksela, 1981). When 71 of the curry-positive subjects were SPT tested with curry components, 23 (32.4 %; 2.2 % of all atopic subjects tested) had positive reactions to mustard. However, as in Spain, only five patients reported clinical symptoms when eating seasoned food. In another Finnish study, 58 % of the 50 subjects with a history of reaction to spices and pollen tested with SPT and RAST showed positive reaction to mustard in at least one test (Niinimaki et al., 1989).

It is to be noted that prevalence to mustard in atopic children varies: 22 of 49 subjects (44 %) in Finland (Niinimaki et al., 1995), 23 out of 83 (28 %) in southwest France (Rancé et al., 2002) and lower in other parts of France (1 %) (Moneret-Vautrin, 2001).

26.2.2. Natural history

There are no data available regarding the natural history of mustard allergy.

26.2.3. Time trends

Since only one population-based study on the prevalence of self-reported allergy to mustard is available, no time trends for mustard allergy can be derived.

26.2.4. Severe reactions/anaphylaxis

The potential severity of mustard allergy has been described by several authors. The risk of severe reactions and anaphylaxis appears to be higher in adults than in children based on results of DBPCFC (Morisset et al., 2003b; Figueroa et al., 2005). Anaphylactic reactions have been reported in 2 % of children (Rancé et al., 1998; Rancé et al., 1999) and in up to 48 % of adults with confirmed mustard allergy (Caballero et al., 2002).

Based on specific IgE, mustard was incriminated in 11 % of food allergy reactions and 3 % of the anaphylactic reactions in 580 patients (480 adults, 100 children) with a "pathological reaction" to food, 60 of which had severe, near-fatal reactions (Andre et al., 1994). In a multicentre survey of food-induced anaphylactic shocks in France, two of the 81 reported cases were identified as being caused by mustard (Moneret-Vautrin and Kanny, 1995). In a report published by Health Canada in 2009[12], 22 individual cases of allergic reactions to mustard were described in 13 international case reports, 15 of which reported anaphylactic-type reactions that required emergency medical intervention. Other severe reactions described in case reports included laryngeal oedema, generalised urticaria and bronchial asthma.

[12] http://www.hc-sc.gc.ca/fn-an/alt_formats/pdf/pubs/label-etiquet/mustard-moutarde/index-eng.pdf

26.2.5. Factors affecting prevalence of mustard allergy

The occurrence of mustard allergy symptoms was observed in children under the age of 3 years (Amlot et al., 1987; Rancé et al., 2000; Rancé et al., 2001) in France, which is one of the largest consumers in Europe and where mustard was previously present in certain commercial foods for toddlers. However, despite a low consumption of mustard in Finland and no information related to the introduction of mustard in baby foods or a significant consumption by young children in this country, 100 % positive SPT and specific IgE to mustard was reported in 14 Finnish children with atopic dermatitis and positive challenge to turnip rape, which belongs to the *Brassicaceae* family (Poikonen et al., 2009). Five of these children (36 %) had a positive oral challenge to mustard. The 2S albumin allergens present in the seeds of certain plants from the *Brassicaceae* family (mustard, oilseed rape, turnip rape) were considered to be highly cross-reactive and to play a role as sensitisers (via oral or respiratory route), particularly in children with atopic dermatitis.

Positive SPTs were reported in three children aged 12-18 months, breastfed until the age of 11 months, who had never consumed mustard (Niinimaki et al., 1989). It has been suggested that sensitisation *in utero*, during lactation and early consumption in baby foods may occur, as with peanut and sesame seed. It has been reported that the prevalence of mustard allergy increases with age in children (Guillet and Guillet, 2000).

The presence of mustard allergy in small children may be taken as an indication of primary sensitisation to mustard in at least some food allergies. The reported cross-reactivities with pollens and with other members of the *Brassicaceae* family may influence the prevalence of specific IgE and SPT positivity, lead to an overestimation of the prevalence of sensitisation to mustard, and may possibly also influence the occurrence of oral allergy syndrome-like symptoms elicited by mustard. Another factor contributing to a possible overestimation of mustard sensitisation and allergy, as determined by SPT or labial provocation challenge, is the presence of irritating substances in mustard that may cause false positive allergy-like reactions.

26.3. Identified allergens

Several mustard allergens have been identified and characterised (Table 29).

Table 29: Mustard allergens

Scientific name (common name)	Allergen	Biochemical name	Superfamily/family	Molecular Weight[a]
Sinapis alba (yellow mustard)	Sin a 1	2S albumin	prolamin	14
	Sin a 2	11S globulin	cupin	51[b]
	Sin a 3	nsLTP	prolamin	12.3[b]
	Sin a 4	profilin	profilin	13-14[b]
Brassica juncea (oriental mustard)	Bra j 1	2S albumin	prolamin	14[b]

[a] MW (SDS-PAGE); [b] kDa

Sin a 1 and Sin a 2 are the main protein components of yellow mustard seeds. Sin a 1 is a 2S seed storage albumin constituted by two disulphide-bonded subunits of 10 and 4 kDa (Menendez-Arias et al., 1988). Immunologic mapping of Sin a 1 with 10 monoclonal antibodies showed two immunodominant regions, one located in the large chain (a continuous epitope) and the other in the hypervariable region of the molecule (Menendez-Arias et al., 1990). Sin a 1 is thermostable and resistant to digestion by trypsin and other proteolytic enzymes (EFSA, 2004; Palomares et al., 2005). Sin a 1 interacts with cell membranes, facilitating its uptake in the intestine. Sin a 1 was the first food

allergen to be cloned and expressed by molecular biology techniques (Gonzalez de la Peña et al., 1993; Gonzalez De La Peña et al., 1996).

Sin a 2, an 11S globulin of the cupin superfamily, is a multimeric protein (Palomares et al., 2005; Palomares et al., 2007). The single-chain nsLTP Sin a 3 and the profilin Sin a 4 are contained in yellow mustard seeds in very low amounts (Sirvent et al., 2009).

Bra j 1 is a 2S seed storage albumin similar to Sin a 1 in structure and amino acid composition (Gonzalez de la Peña et al., 1991).

A detailed clinical characterisation of 34 patients with mustard allergy combined with component-resolved diagnosis was performed by using yellow mustard extract and the four purified mustard allergens Sin a 1, Sin a 2, rSin a 3, and rSin a 4 (Vereda et al., 2011a). A SPT was performed and the specific IgE level in serum was measured by ELISA. All patients reported a clear immediate allergic reaction with mustard within the first 30 minutes of consumption and had positive SPT to mustard extracts. Twenty-seven patients developed immediate systemic reactions after the ingestion of mustard, 28 had symptoms with other plant foods and 24 were allergic to pollen. Twenty-five patients had a positive SPT to Sin a 1, and 19 to Sin a 2. Twenty-five of the 34 tested sera had positive IgE to Sin a 1, 16 to Sin a 2, 14 to rSin a 3 and eight to rSin a 4. A significant positive correlation was found between SPT and ELISA for Sin a 1 and Sin a 2, but not for rSin a 3 and rSin a 4.

Specific IgE against Sin a 1 was the most suitable diagnostic marker to determine genuine sensitisation to yellow mustard and specific IgE against Sin a 2 was an useful marker to predict the severity of symptoms, whereas specific IgE against Sin a 3 and Sin a 4 were associated with sensitisation to other plants of the *Rosaceae* family and to *Artemisia vulgaris* pollen (Vereda et al., 2011a).

Mustard also contains a number of irritating substances, such as isothiocyanates in *B. nigra*, sinalbin in *S. alba*, and capsaicin, which may trigger non-immune mediated reactions mimicking allergic reactions. These may lead to false positive SPT and difficult interpretation of labial provocation tests. For example, capsaicin induces release of substance P, which may trigger non-IgE-mediated mast cell degranulation (Rancé et al., 2000).

26.4. Cross-reactivities

Specific IgE for both Sin a 1 and the 2S fraction of *Brassica juncea* were detected in 10 sera from mustard sensitive individuals. Also six monoclonal antibodies and a rabbit polyclonal serum specific for Sin a 1 recognised the 2S fraction of *Brassica juncea*, suggesting that Bra j 1 and Sin a 1 may share a homologous epitope and that subjects allergic to one type of mustard may also react to other types (Gonzalez de la Peña et al., 1991; Monsalve et al., 1993; Palomares et al., 2007).

The *Brassicaceae* (*Cruciferae)* family includes a number of common vegetables, like cabbage, cauliflower, Chinese cabbage, Brussels sprouts, broccoli, turnip, rutabaga and radishes, and rape (Monreal et al., 1992). High *in vitro* cross-reactivity between Sin a 1 and the major allergen of rapeseed (*Brassica napus*) Bra n 1 has been reported (Bartolome et al., 1997; Asero et al., 2002). Bra n 1 is a close homologue of Sin a 1, with 94 % of sequence homology. The antigenic properties of Bra n 1 and Sin a 1 were studied using sera from mustard and rapeseed-sensitive patients. The recombinant rapeseed 2S pronapin precursor protein binded IgE in sera from mustard allergic patients. Also, a Sin a 1-specific polyclonal rabbit antiserum was able to bind IgE in serum from a rapeseed allergic patient (Palomares et al., 2002), which indicates serological cross-reactivity between mustard and rapeseed.

Sensitisation and allergy to turnip rape (*Brassica rapa* spp. *oleifera*), oilseed rape (*B. napus* spp *oleifera*) and mustard seeds (*S. alba*) was observed in Finnish and French children with atopic dermatitis (AD) (Poikonen et al., 2009). Turnip rape challenge was positive in 5 (36 %) French and all the 14 Finnish children, although the frequency of positive mustard challenge was the same (36 %). Specific IgE antibodies from the challenged children, measured by ImmunoCAP and ELISA, were

cross-reactive with the purified 2S albumin allergens present in the seeds of these plants (Bra r 1, Bra n 1 and Sin a 1, respectively), which are highly homologous.

Few reports of clinical cross-reactivity between mustard and foods other than *Brassicaceae* species are available (Asero et al., 2002; Caballero et al., 2002). A significant association between allergies to nuts and spices has been found (Castillo et al., 1996). At the molecular level, the 11S globulin Sin a 2, which is associated to severe adverse reactions in mustard allergic patients, shares IgG epitopes with 11S globulins of almond, walnut, pistachio and hazelnuts, but not from peanuts, and is involved in IgE cross-reactivity with tree nuts and peanuts (Sirvent et al., 2012).

Sin a 3 and Sin a 4 showed IgE cross-reactivity with fruits of the *Rosaceae* family, such as peach and melon (Sirvent et al., 2009). An association between specific IgE to rSin a 3 and allergy to *Rosaceae* fruits (mainly peach) or *Artemisia vulgaris* pollen was observed in patients with mustard allergy (Vereda et al., 2011a).

An association between mustard allergy and pollen allergy has been observed as part of the "celery-mugwort-birch-spice syndrome" (Bauer et al., 1996). Food homologues of the major mugwort allergen Art v 1 may be responsible. An analogous "mugwort-mustard allergy syndrome" has been proposed (Figueroa et al., 2005) owing to the high association found between sensitisation to *Artemisia vulgaris* pollen and mustard allergy (37 out of 38 patients). Partial cross-reactivity between mustard and mugwort pollen was confirmed by CAP-inhibition assays. The same patients (92.1 %) were sensitised to other pollens belonging to weeds (*Chenopodium* and *Chrysanthemum*), grasses (*Poa*, *Lolium* and *Anthoxanthum*) and trees (*Ulmus* and *Platanus*), although at lower rates.

26.5. Effects of food processing on allergenicity

No clinical studies addressing the allergenicity of mustard after food processing are available. However, the stability of mustard allergens to thermal treatments is well documented. Sin a 1 showed the characteristic resistance of the 2S albumin family to denaturation upon heat treatments, keeping the integrity of IgE and IgG epitopes because the global folding is maintained. Sin a 3, a nsLTP, despite its conformational change after strong heating (95 °C for 30 min), also maintained the IgE and IgG reactivity. Both Sin a 1 and Sin a 3 belong to the prolamin superfamily and share a stable structural folding, with four α-helices stabilised by disulphide bridges.

Sin a 1 extracted from yellow mustard seeds and recombinant Sin a 3 were resistant to gastric digestion and partially resistant to intestinal digestion in an *in vitro* model, retaining significant IgE-binding (Gonzalez De La Peña et al., 1996; Sirvent et al., 2012). The resistance of LTP proteins to *in vivo* proteolytic degradation within the gastrointestinal tract may explain the severe allergic reactions of LTP-sensitised patients (Fu et al., 2002). Sin a 1 and Sin a 3 could reach unaltered the gut immune system and trigger systemic reactions (Moreno, 2007). In contrast, the profilin Sin a 4 was completely digested by gastric enzymes and its secondary structure was irreversibly unfolded by heat treatment.

Edible oils may be produced from mustard seeds by different processes. Depending on the degree of refinement, oils may contain various amounts of proteins. In one study (Koppelman et al., 2007), no allergenic proteins were detected in a mustard seed oil using an ELISA method. However, the solvent used for the extraction of the proteins (aqueous buffer at pH 8) was not appropriate for the purpose.

26.6. Detection of allergens and allergenic ingredients in food

A number of methods of detection, based on either ELISA assays or PCR analysis, have been developed for mustard.

26.6.1. ELISA

Koppelman et al. (Koppelman et al., 2007) described an inhibition ELISA assay for detecting the presence of allergens from *B. juncea* in a mustard oil with a LOD of 1.5 mg/kg. Proteins were

extracted at pH 8 with a TRIS buffer. Weak cross-reactivity with soy (0.016 %) and milk (0.28 %) was reported.

Two quantitative sandwich ELISA assays have been developed for detecting the three varieties of mustard seeds with a LOQ of 1-3 µg/mL (Lee et al., 2008). Their performance was tested in retail foods (Lee et al., 2009). The detectability of mustard allergens was much lower in acidic salad dressings, probably owing to the decreased solubility of the proteins, highlighting the importance of evaluating the applicability of the ELISA assays to the different food matrices.

A less sensitive sandwich ELISA targeting the Sin a 1 allergen from *S. alba*, with a LOD of 0.3 µg/mL for the purified protein, has been described (Shim and Wanasundara, 2008). The Sin a 1 content of six mustard seed genetic lines was in the range of 0.82-2.94 mg/g when extracted with phosphate buffer saline (PBS) at pH 7.4. The sample extraction conditions for full recovery of Sin a 1 need to be considered when assessing its allergenicity.

Limitations of these ELISA methods are the partial recovery of the proteins and cross-reactivity (up to 50 %) with rapeseed (*Brassica napus*) (Monsalve et al., 1997; Lee et al., 2008).

ELISA kits for mustard detection are commercially available. One has been recently validated in an inter-laboratory study (Cuhra et al., 2011) with a LOQ of 1.8 mg/kg and a LOD of 0.5 mg/kg. The method did not show cross-reactions with other allergenic foods.

26.6.2. PCR

A real-time PCR method (Fuchs et al., 2010) specifically targeted the gene coding for white mustard (Sin a 1). The method is specific and does not show cross-reactivity with other biological species, including members of the *Brassicaceae* family. The LOD was 1 pg of white mustard DNA/µl, corresponding to 5 pg of white mustard DNA. In model sausages, the LOD was 10 mg/kg. The method was successfully applied to a series of commercial products. Another real-time PCR method targeted the simultaneous detection of black mustard (*B. nigra*) and brown mustard (*B. juncea*) in food (Palle-Reisch et al., 2013). The DNA of both mustard species could be detected down to 0.1 pg. The method applied to brewed sausages allowed the detection of 5mg/kg of black and brown mustard. No cross-reactivity was observed with other *Brassicaceae* species, with the exception of white mustard. A real-time PCR method (Mustorp et al., 2008), which targeted the mustard SinA gene showed some cross-reactivity with other *Brassica* species.

A quantitative multiplex ligation-dependent probe amplification (MLPA) method (Mustorp et al., 2011) for the simultaneous detection of eight allergenic ingredients including mustard also detected other members of the *Brassicaceae* family such as cabbage, radish and broccoli. The LOD was 5-400 gene copies.

Mustard DNA has also been detected by two hexaplex real-time PCR systems targeting twelve allergenic ingredients in foods (Köppel et al., 2012). The two tests exhibited a good specificity and a LOD of at least 0.1 % of total DNA for all analytes, but no quantitative results relative to the allergenic ingredient by weight could be given.

Optical thin-film biochips for multiplex visible detection of eight allergenic ingredients, including mustard, have been developed based on two tetraplex PCR systems (Wang et al., 2011b). The method is fast, high throughput, and the results are visible at the naked eye. The LOD for mustard was not reported.

26.7. Minimal (observed) eliciting doses

Two DBPCFC studies (Morisset et al., 2003b; Figueroa et al., 2005) and one SBPCFC (Rancé et al., 2002) documenting mustard allergy and anaphylactic reactions to mustard have been published.

A study was performed on 38 mustard hypersensitive patients (mean age 21.9 ± 8.6 years; age range 3-39 years old), 10.5 % of which had reported systemic anaphylaxis after mustard ingestion (Figueroa et al., 2005). Fourteen patients were not tested with DBPCFC because of severe symptoms or denial of consent. The remaining 24 patients underwent DBPCFCs with a commercial mustard sauce mixed in vanilla-lemon flavoured yoghurt to mask its strong taste. The mustard sauce was composed of water, *S. alba* seeds (14 % w/v), vinegar, salt, turmeric, paprika and cloves. Increasing doses of the yoghurt mixture (80, 240, 800, 2400 and 6480 mg) were administered at 15-min intervals until symptoms appeared or a cumulative dose of 10g of mustard sauce was reached. The test resulted positive in 14 cases (58 %) and the most frequent symptom observed was OAS (10 subjects; 71 %). The MOED was 156.8 mg of mustard sauce in most severe cases (one case of angioedema and bronchial asthma and one case of systemic anaphylaxis), while the MOED for milder symptoms (OAS) was 44.8 mg of mustard sauce. A significant relationship between the SPT and the DBPCFC results was reported.

A non randomised DBPCFC was conducted in mustard seasoning on 24 patients (age 3-20 years) recruited on the basis of being SPT positive to mustard, and not on clinical symptoms (Morisset et al., 2003b). Six additional patients were tested with a SBPCFC. Increasing doses of seasoning (10, 30, 100, 300 and 900 mg) were given every 20 minutes, to a total cumulative dose of 1340 mg. Seven patients tested positive, indicating that 23 % of the SPT positive patients had clinical allergy to mustard. SPTs were performed with four different mustard seasoning preparations, and specific serum IgE to mustard was determined (RAST). The MOED was 440 mg of mustard seasoning, while a dose of 40 mg of mustard seasoning triggered a reaction in a subject experiencing rhinitis and urticaria. The 40 mg dose corresponds to 13.5 mg of mustard seeds (*Brassica juncea*), which is roughly equivalent to 0.8 mg of mustard proteins (*B. juncea* is considered to contain an average of 6 % proteins).

In a SBPCFC with mustard seed powder (including *S. alba* and *B. juncea*), 36 skin prick test positive children (average age 5.5 years: range from 10 months to 15 years) were tested and compared with 22 control subjects with no history of food allergies (Rancé et al., 2000; Rancé et al., 2001). A mustard seed powder containing both *S. alba* and *B. juncea* was used for the SPT. Progressive doses of mustard (1, 5, 10, 20, 50, 100, 250, and 500 mg) were given. Of the 36 challenged subjects, 15 had positive reactions (42 %) and 21 were not allergic to mustard. The mean cumulative reactive dose was 153 mg of mustard powder. Eight of the subjects with a positive reaction (53 %) had exhibited symptoms of allergy to mustard under the age of 3 years.

26.8. Conclusion

Mustard is commonly used all over the world. Mustard allergy and anaphylactic reactions to mustard have been documented by DBPCFC studies, and the major allergens in mustard have been characterised. The prevalence of mustard allergy in the general unselected population is unknown because frequency estimates are mainly based on patient series. The major mustard allergens are heat-resistant and food processing is unlikely to alter their immunogenic properties. A number of methods of detection, based on either ELISA assays or PCR analysis, have been developed for mustard. Protein doses triggering allergic reactions in mustard allergic patients are around 1 mg.

27. Adverse reactions to sulphites

27.1. Background

Sulphites, or sulphiting agents, are defined as sulphur dioxide and several inorganic sulphite salts that may liberate SO_2 under appropriate conditions. These include sodium and potassium metabisulphites ($Na_2S_2O_5$, $K_2S_2O_5$), sodium and potassium bisulphites ($NaHSO_3$, $KHSO_3$) and sodium and potassium sulphites (Na_2SO_3, Na_2SO_3) (Simon, 1998).

Sulphites can occur naturally in foods as a consequence of fermentation (e.g. of wine) (Taylor et al., 1986), may be added to foods as preservatives or colours (Bush et al., 1986a), and may be found in medications, including those used for the treatment of allergic reactions (Nicklas, 1989). Sulphites have been used for centuries in the preservation of alcoholic drinks (e.g. cider, wine and beer), but

their use has expanded to several other products (Bush et al., 1986b). Sulphiting agents used as food additives are given in Table 30.

When added to foods, sulphites inhibit enzymatic browning (e.g. in fresh fruits and vegetables, shrimps and raw potatoes) as well as non-enzymatic browning (e.g. in dried foods and dehydrated vegetables) (Taylor et al., 1997; Simon, 1998). They also have antimicrobial activity (as in wine and beer), dough-conditioning properties (as in frozen pies and pizza crusts) and bleaching effects (as in maraschino cherries) and they are used as processing aids in beet sugar (Bush et al., 1986b; Simon, 1998).

The levels of sulphites contained in foods range from < 10 mg/kg (e.g. frozen dough, corn syrup, jellies) to 60 mg/kg (e.g. fresh shrimp, pickles, fresh mushrooms) and 100 mg/kg (e.g. dried potatoes, wine vinegar). The highest levels of sulphites (up to 1 000 mg/kg) can be found in dried fruit, wine, fruit juices (e.g. lemon, lime, grape) and certain freshly prepared sauces available from retailers (Simon, 1998).

Table 30: Sulphiting agents used as food additives

Type	E number	Sulphiting agent
Preservatives	E 220	sulphur dioxide
	E 221	sodium sulphite
	E 222	sodium hydrogen sulphite
	E 223	sodium metabisulphite
	E 224	potassium metabisulphite
	E 226	calcium sulphite
	E 227	calcium hydrogen sulphite
	E 228	potassium hydrogen sulphite
Colours	E150b	caustic sulphite caramel
	E150d	sulphite ammonia caramel

Directive 95/2/EC[13] on food additives other than colours and sweeteners states maximum levels of sulphites for several foods and beverages expressed as SO_2 equivalents in mg/kg or mg/L, which refer to the total quantity available from all sources. The capacity to release SO_2 varies between the salts. In Directive 95/2/EC, in case of "an SO_2 content of no more than 10 mg/kg or 10 mg/L, SO_2 is considered not to be present". Regulation (EC) No 606/2009 states maximum levels of SO_2 in wines[14]. Sulphur dioxide and sulphites in foods and beverages at concentrations of more than 10 mg/kg or 10 mg/L expressed as SO_2 equivalents are subject to mandatory labelling in Europe[15]. The basis of this threshold was the LOD of sulphites in foods and beverages with the methods of detection available at that time.

Indeed early assessments of consumer's exposure to sulphites in foods were difficult owing to shortcomings of the methods of measurement and to the fact that storage and preparation of food affects the final content of sulphites. Average daily intakes in the US were estimated to be 19 mg of sulphur dioxide equivalents (SDE; 297 μmol of sulphite), with the 99th percentile of the population consuming daily 163 mg of SDE (~ 2.5 mmol of sulphite) (FDA (Food and Drug Administration),

[13] European Parliament and Council Directive 95/2/EEC on food additives other than colours and sweeteners. OJ L 061, 18.03.1995, p. 1-40.

[14] Commission Regulation (EC) No 606/2009 of 10 July 2009 laying down certain detailed rules for implementing Council Regulation (EC) No 479/2008 as regards the categories of grapevine products, oenological practices and the applicable restrictions. OJ L 193, 24.07.2009, p. 1-59.

[15] Directive 2003/89/EC of the European Parliament and of the Council of 10 November 2003 amending Directive 2000/13/EC as regards indication of the ingredients present in foodstuffs. OJ L 308, 25.11.2003, p. 15-18.

1985). In France, average daily intakes were estimated as 20 mg SO_2, reaching 31.5 mg/day among consumers of cider, beer and wine (Mareschi et al., 1992), and as 23 mg SO_2 (0.78 mg/kg/day) in children and 50 mg/day (0.84 mg/kg/day) in adults in Italy, where dried fruits and wine (in adults) were the major contributors (Leclercq et al., 2000). Average intakes estimated in European countries using more sensitive methods for the detection and quantification of sulphites in foods and beverages are 0.16-0.17 mg/kg/day in adults (95th percentile 0.59-0.60 mg/kg/day) and 0.031-0.04 mg/kg/day in children (95th percentile 0.12-0.14 mg/kg/day) in France (Bemrah et al., 2012); 0.59-0.62 mg/kg/day in adults and 0.24 mg/kg/day in children in Austria (Mischek and Krapfenbauer-Cermak, 2012); and 0.34 mg/kg/day (97.5th percentile 1.1 mg/kg/day) in adults in Belgium (Vandevijvere et al., 2010).

Adverse reactions to ingested sulphites were first reported in 1976 (Prenner and Stevens, 1976). Data on adverse reactions to sulphites have accumulated in the 80's and 90s, but very few reports have become available since the year 2000, and particularly after their labelling became mandatory in the US and the EU.

27.2. Frequency

The prevalence of sensitivity to sulphiting agents in the general population is unknown (Bush et al., 1986a).

Prevalence estimates of sulphite sensitivity among asthmatics reported in the literature (1-4 % among all asthmatics; 5-10 % among steroid-dependent asthmatics) are generally based on series of patients referred to allergy clinics and may overestimate prevalence in the general population (SCF (Scientific Committee for Foods), 1994), as do estimates of the percentage of asthmatics sensitive to oral challenges with sulphites, which range from less than 4 % up to 66 % depending on the selection criteria and challenge protocol used (EFSA, 2004; Vally et al., 2009). The FDA estimates that 1 % people in the general population are sulphite sensitive, and that 5 % of those who have asthma are also at risk of suffering an adverse reaction to sulphites (FDA (Food and Drug Administration), 1996).

The average age individuals experiencing asthma after exposure to sulphites is 40 years, and women appear to be more sensitive (Gunnison and Jacobsen, 1987; Simon, 1989). Adverse reactions to sulphites are less commonly reported in pre-school children, possibly owing to their lower consumption of foods with high sulphite content, including alcoholic beverages (Lester, 1995).

27.3. Clinical features

27.3.1. Symptoms

Most reactions to sulphites are characterised by bronchospasm, occasionally severe, which can occur within minutes after ingestion of sulphite-containing foods. In restaurants, the sudden choking sensation may incorrectly be attributed to aspiration of food (Nicklas, 1989). Bradycardia, flushing and prominent gastrointestinal symptoms (Sheppard et al., 1980; Schwartz, 1983), 1983), as well as urticaria, angioedema, hypotension (Prenner and Stevens, 1976; Habenicht et al., 1983; Schwartz, 1983) and shock (Lester, 1995) have also been reported (Vally et al., 2009).

27.3.2. Diagnosis

A careful clinical history, though important in detecting sulphite sensitivity, is not sufficient for diagnosis, whereas skin testing (prick puncture or intradermal technique) allows identifying only a small fraction of patients. Challenge protocols for the diagnosis of sensitivity to ingested sulphites have been developed. The standard practice has been to use oral challenges with < 100 mg/mL of sulphites for asthmatics and a maximum dose of 200 mg for subjects with a history of sulphite-induced urticaria or anaphylaxis (Simon, 2003). Unlike non-asthmatic individuals, most subjects with asthma are sensitive to inhaled SO_2, so that oral challenges with acid solutions may induce false positive results in terms of oral sensitivity if the dosage is high (Simon, 1998). Substances used for the challenges are usually contained in opaque capsules, which are consumed orally, and thus negative results do not exclude sensitivity to inhaled sulphates.

27.4. Pathogenesis

The pathogenesis of adverse reactions to sulphites has not been clearly documented. Three possible mechanisms have been invoked: an IgE-mediated reaction, a sulphite-induced cholinergic response and low levels of the enzyme sulphite oxidase (Bush et al., 1986b; Nicklas, 1989; Lester, 1995).

Several studies have not been able to demonstrate an IgE-mediated mechanism (Gunnison and Jacobsen, 1987; Nicklas, 1989) or the presence of a specific antibody (Lester, 1995). In addition, an IgE-mediated reaction to sulphites is unlikely, given the nature of the molecule.

The bronchoconstrictive effect of inhaled SO_2, mediated by parasympathetic nerve endings in the bronchi, has been studied with respect to environmental pollutants. Whether gastroesophageal reflux of SO_2 causes bronchospasm in sulphite sensitive patients is not clear. It has been hypothesised that sulphites can induce a cholinergic response and stimulate release of gastrin and other active mediators in sulphite sensitive patients (Nicklas, 1989).

Low levels of the mitochondrial enzyme sulphite oxidase have been demonstrated in some sulphite sensitive patients (Stevenson and Simon, 1984). Absorbed sulphites are added to those produced endogenously and increase the demand placed on the enzyme sulphite oxidase. It is possible that when this demand is not met, sulphite sensitive patients exhibit symptoms. It has also been hypothesised that a number of food additives, including sulphites, induce intolerance because of their aspirin-like properties (Williams et al., 1989), and an association between respiratory reactions to aspirin and those to sulphites has been reported (Sabbah et al., 1987; Hassoun et al., 1994).

Two DBPCFCs performed to address the role of sulphites in wine-induced asthma suggest that the changes in bronchial hyperresponsiveness observed in some of the patients tested could not be attributed only to the presence of sulphites in wine (Vally et al., 1999; Vally et al., 2007).

27.5. Possible effects of food processing on adverse reactions to sulphites

The amounts of sulphites initially used to treat foods do not reflect residue levels after processing. Storage and preparation of food also affects the final amount of sulphites consumed. Mechanisms of loss include volatilisation to SO_2 in acidic conditions, leaching, auto-oxidation, as well as the irreversible reactions with food constituents (Gunnison and Jacobsen, 1987).

Sulphites can react with food constituents, including sugars, proteins and lipids, to form adducts or derivatives. Some of these reactions are reversible, while others are not. The former lead to compounds that may serve as reservoirs for free sulphite, while the latter remove sulphites permanently from the pool of available free SO_2. Since free SO_2 is the most likely cause of adverse reactions to sulphiting agents, these chemical reactions have significant implications regarding foods that may cause difficulty in sensitive patients (Bush et al., 1986b; Simon, 1998). The likelihood of a particular food provoking a reaction depends upon the ratio of free to bound sulphite. For example, lettuce has few components to which sulphites can react, therefore most of the sulphite in lettuce remains in the free inorganic state and this explains why lettuce (salad bars) seems to provoke sulphite sensitive reactions frequently (Martin et al., 1986; Simon, 1998). In contrast, sulphites added to shrimp and potatoes tend to be bound and are not as likely to produce reactions in sulphite sensitive subjects.

27.6. Methods of detection of sulphites in foods

Many methods are available for the determination of sulphites in foods and beverages, the most commonly used being titration, flow injection analysis (FIA) and spectrophotometry, but also CE, HPLC, ion-exclusion chromatography (IC), gas chromatography (GC), fluorometry, chemiluminescence, anodic stripping voltammetry, sensors and biosensors. The available methods for the detection of sulphites in foods have been extensively reviewed (Isaac et al., 2006; Ruiz-Capillas and Jiménez-Colmenero, 2009; Pundir and Rawal, 2013). There are several Official AOAC methods for the detection of sulphites in meats (qualitative), fruits and wines (http://www.eoma.aoac.org/).

Sulphites can be present in foods and beverages as free, reversely bound adducts or irreversibly bound compounds according to the matrix and processing conditions, since they can react with other food constituents (e.g. aldehydes, ketones, sugars). Thus, it is necessary to recover the sulphites either as free or total sulphites (i.e. free plus reversibly bound sulphites). Most methods require preliminary extraction of sulphites from the solid or liquid food through, e.g. distillation or acid or alkaline extractants, with the risk of substantial losses of SO_2. In few cases, liquid foods (e.g. water, wines, and fruit juice) can be analysed without preliminary treatments, although the risk of interfering agents must be considered.

27.6.1. Titration

The most commonly used techniques, mostly applied to the analysis of sulphites in wine, are based on titration according to the classical optimised Monier-Williams method (OMW) (AOAC, 1995), and to the Ripper procedure (Vahl and Converse, 1980). The OMW method requires distillation of SO_2, after acidification and oxidation to sulphuric acid with hydrogen peroxide. The sulphuric acid is then titrated with sodium hydroxide. The method is robust, with a LOD $\geq$ 10 mg/kg, but is time consuming and subject to SO_2 losses and/or co-distillation of other oxidisable volatile compounds present in food.

The Ripper procedure is based on iodometric titration. The bound sulphite is degraded by alkali, then the solution is acidified and the resulting total sulphurous acid is oxidised with iodine to sulphuric acid, while iodine is reduced to iodide. The remaining iodine is titrated with a solution of sodium thiosulphate in the presence of starch as an indicator. The LOD is 5 mg/kg. The method lacks accuracy and precision owing to the fact that iodine can react with other oxidisable compounds present in foods and cannot be used for coloured matrices.

27.6.2. Flow injection analysis

Flow injection procedures provide fast analytical responses in real time and are suitable for the routine analysis of a large number of samples (Ruiz-Capillas and Jiménez-Colmenero, 2009). To assess total sulphites, the sample undergoes an alkaline treatment to release most of the bound sulphite, which is then extracted by e.g. a tetracloromercurate solution to form a stable sulphite-mercury complex, with a good recovery. Stabilisers e.g. EDTA are added to the solution to avoid oxidation of sulphites by atmospheric oxygen. Once injected into a continuous flow of a strong acidic donor solution, the released SO_2 diffuses through a membrane, commonly via gas diffusion (GD), and dissolves into an acceptor solution, chosen according to the detector to be used, e.g. spectrophotometric, fluorometric, amperometric, potentiometric. For spectrophotometric detectors, which are robust and available in most control laboratories, reagents developing a colour or changing colour are used as acceptors of SO_2 and the difference in absorbance, measured at a defined wavelength, is taken as linearly proportional to the amount of sulphite. Malachite Green is the acceptor reagent most commonly used. A FIA-spectrophotometric method for the analysis of sulphites is accepted by the AOAC for the analysis of sulphites in food, with a LOD $\geq$ 5 mg/kg (AOAC, 2005).

27.6.3. Chromatographic methods

27.6.3.1. Ion chromatography

A method adopted by the AOAC (AOAC, 2000), which uses ion-exclusion chromatography with direct current amperometric detection, has an LOD $\geq$ 10 mg/kg and can be applied to liquid samples after filtration. However, fouling of the platinum electrode occurs rather quickly, leading to a significant decrease of the response.

A method using an anion-exchange column eluted with sodium carbonate and sodium hydroxide with conductivity detection, when applied to the determination of sulphites in fresh meats and shrimps, provided good results with respect to linearity, LOD (2.7 mg/kg) and LOQ (8.2 mg/kg), expressed as SO_2 (Iammarino et al., 2010). Higher sensitivity was achieved when release of SO_2 from bound sulphites by addition of sodium carbonate, acidification and distillation with vapour and CO_2 stream preceded IC (Zhong et al., 2012). The distilled SO_2 was captured in a sodium hydroxide solution and

measured as sulphite by IC, with a LOD of 0.013 mg/L. This method was also used to detect sulphites in preserved foods, dried vegetables and wines.

27.6.3.2. Gas chromatography

GC was applied to the separation of free and combined sulphites in foods. Tartaric acid allows the selective extraction of free sulphites, whereas an alkaline extractant containing potassium sodium tartrate allows detecting total sulphites. The LOD is 0.5 mg/kg (Pundir and Rawal, 2013).

27.6.3.3. High Performance Liquid Chromatography

Free and total sulphites can be separated by HPLC and quantified by a UV/vis detector with a LOD of 0.5 mg/L (McFeeters and Barish, 2003), and with a fluorometric detector (via derivatisation with *o*-phthaldialdehyde) with a LOD of 5 mg/kg (Chung et al., 2008a). Coupling HPLC with an immobilised enzyme reactor (HPLC–IMER), the method became more sensitive (LOD 0.01 mg/L SO_3^{2-}) and specific (Theisen et al., 2010).

27.6.4. Spectrophotometry

Spectrophotometric methods for the analysis of sulphites are simple, sensitive and convenient, although some require preliminary distillation and relatively large amount of samples (Hassan et al., 2006). They measure the absorbance of a coloured compound resulting from reaction of sulphites with a reagent such as *o*-phthaldialdehyde in the presence of ammonia (LOD 0.04 mg/L), *p*-rosaniline-formaldehyde (LOD 0.03 mg/L), or 5,5-dithiobis(2-nitrobenzoic acid) (LOD 0.10 mg/L).

The performance of batch and flow injection spectrophotometric modes for sulphite detection in beverages has been compared (Hassan et al., 2006). The method is based on the reaction of SO_2 with a diaquacobester reagent, resulting in a sulphite aquacobester (SO_3Cbs) complex. Changes of the absorbances at 313, 349, 425 and 525 nm are linearly related to sulphite concentrations, with an average LOD of 10 µg/L. The flow injection system allowed analysis of 50 samples per hour.

A method based on UV/vis fiber optic-linear array detection spectrophotometry was developed with a preliminary dispersive liquid–liquid microextraction (DLLME) in order to pre-concentrate sulphite ions from aqueous samples. The procedure is based on the colour reaction of sulphite with *o*-phthaldialdehyde (OPA) in the presence of ammonia to form isoindole, which is extracted by the DLLME technique. The LOD was 0.2 µg/L (Filik and Cetintas, 2012).

27.6.5. Sensors and Biosensors

The (bio)sensing methods have experienced a great development in the last few years, since they allow selective, rapid and highly sensitive detection and a wide working range.

Electrochemical sensors are based on non-enzymatic metal complexes, which catalyse production or consumption of ions or electrons, thus changing the electrical properties of the solution, which are used as measuring parameters.

Biosensors are based on immobilised enzymes, such as sulphite oxidase (SO) from chicken liver or plant leaves or bacterial sulphite dehydrogenase (SDH), which catalyse oxidation of sulphite to sulphates with high selectivity. The aerobic oxidation of sulphites by sulphite oxidase produces H_2O_2, which undergoes electrochemical breakdown under high voltage generating electrons, i.e. current, which is directly proportional to the sulphite concentration. Coating the electrode with a polymeric film, in which the enzyme is embedded, has been shown to retain selectivity, since the polymer acts as a selective barrier allowing only H_2O_2 to reach the electrode. Direct electrocatalytic voltammetry of SDH immobilised on a pyrolytic graphite electrode or mediated by cytochrome c as an electroactive relay between the enzyme and a gold electrode have been reported (Kalimuthu et al., 2010). (Bio)sensors may be classified into several “classes” according to the type of transducers used (e.g. dissolved oxygen meter, electrochemical, amperometric, conducting polymer, nanoparticle-based, fill

and flow channel, chemiluminescence, optical, screen printed electrode, sol-gel based, gas diffusion-sequential injection, FIA-based). The principles, characteristics, advantages and disadvantages of the different biosensors have been reviewed (Pundir and Rawal, 2013).

27.6.5.1. Chemiluminescence biosensors

Chemiluminescence biosensors combine the specificity of the biological reaction with the sensitivity of light emitting reactions. They are mostly based on sulphite oxidase immobilised on different supports, using chemiluminescent oxidation of luminol for detection. The LODs vary from 0.0003 µM (Sasaki et al., 1997) to 1 µM (Yaqoob et al., 2004) and 4.7 µM of sulphite (Navarro et al., 2010).

27.6.5.2. Electrochemical sensors

Sulphites have been oxidised at simple electrodes (platinum, gold, carbon and metal oxides), or at electrodes modified with enzymes (sulphite oxidase, sulphite dehydrogenase) or metal complexes (iron and copper-cobalt hexacyanoferrate, cobalt porphyrins, ferrocenedicarboxilic acid) in order to overcome the lack of selectivity at the bare electrode. The catalysts are immobilised on the electrode as mono/multilayer films or incorporated within the body of composite electrode materials, such as sol-gel. The LODs are in the range 0.3-1 µM. The relative methods have been reviewed (Isaac et al., 2006; Pundir and Rawal, 2013).

Ion-selective electrodes are not suitable for sulphite detection owing to the lack of sufficiently selective ionophores. Redox indicators have been used to avoid interference with other anions, but the selectivity depends also on the food matrix. The problem of non-specific oxidation of interfering species can be avoided by integrating highly specific oxidising enzymes into the transducing surface. A combination of sulphite dehydrogenase, horse heart cytochrome c (cyt c), and a self-assembled monolayer of 11-mercaptoundecanol cast on a gold electrode led to a LOD of 44 pM using an amperometric detector (Kalimuthu et al., 2010).

27.6.5.3. Screen-printed electrode-based biosensors

Screen printed carbon electrodes have been devised in order to construct portable or disposable electrodes. The active substrate (enzyme, metal complex) is deposited onto inert backing supports, such as PVC or ceramic materials. One of these, based on sulphite oxidase and an osmium redox polymer as mediator, is able to work at a desirable low potential, thus avoiding co-oxidation of interferents, with a LOD of 0.08 µM (Spricigo et al., 2010).

27.6.5.4. Biosensors based on conducting polymer matrices

Different types of conducting polymers have been used as support for construction of sulphite oxidase electrodes. Enzyme molecules can be entrapped during electropolymerisation, resulting in a uniformly coverage of the electrode working surface. These biosensors are sensitive, specific and rapid. A biosensor using sulphite oxidase entrapped in ultrathin polypyrrole film and amperometric detection showed a LOD of 0.9 µM (Ameer and Adeloju, 2008).

27.6.5.5. Nanoparticle-based biosensors

Nanoparticles increase the electroactive surface of electrodes, enhance the electron transport between the electrolyte medium and the electrode, and increase the loading capacity for the enzyme. Electrochemical biosensors modified with sulphite oxidase/magnetic nanoparticles (Fe_3O_4@GNPs)/Prussian blue nanoparticles on gold or/indium tin oxide electrodes, have been produced, with LODs of 0.15-0.1 µM (Rawal and Pundir, 2013).

27.6.6. Methods for the detection of sulphites in wine

Free and bound sulphites are present in wine. Free sulphites include SO_2, bisulphite (HSO_3^-) and sulphite (SO_3^{2-}) in a chemical equilibrium according to the pH. At the pH of wine (3.2-4.0) bisulphite

is the predominant species of free sulphite, which can bind reversibly to carbonyl compounds, such as aldehydes, and in particular acetaldehyde, ketones, ketoacids, and sugars.

Titration, spectrophotometry, FIA, sensors and biosensors can be used to measure sulphites in wine. The most commonly used is OMW (AOAC, 1995). The procedure is time consuming, cannot be used for high-throughput analysis, can overestimate sulphite levels due to the presence of volatile acidic compounds in wine, or may underestimate them due to loss of SO_2 during distillation. The Ripper procedure lacks accuracy and precision, particularly for coloured matrices such as red wine.

In order to overcome such limitations, two methods based on FIA with spectrophotometric detection have been adopted by the AOAC: the AOAC-990.29 method for total sulphites and the AOAC-990.30 method for free sulphites. The LOD is ≥ 5 mg/kg.

A GD multicommuted FIA for the determination of free and total sulphites in white and red wine has been reported (Oliveira et al., 2009). The methodology is based on two spectrophotometric reactions with malachite green (MG) and *para*-rosaniline (PRA), with no previous treatment of the sample. The procedure with MG is more sensitive but less accurate than with PRA, because of the negative interference with acetaldehyde. LODs of 0.3 and 0.6 mg/L and LOQs of 1.1 and 1.8 mg/L for free SO_2, LODs of 0.7 and 0.8 mg/L and a LOQ of 2.5 mg/L for total SO_2 were obtained with GM and PRA, respectively. These methods use low cost instrumentation, have high sample throughput and are easy to manipulate.

A sensitive sensor based on electrodes supported on ion-exchange membranes acting as a solid polymer electrolyte (SPE), which allows gaseous electroactive analytes to be detected, was used as an amperometric detector for a flow injection system (Toniolo et al., 2010). The LODs were 0.04 and 0.02 mg/L for free and total SO_2.

Another method based on head-space gas chromatography (HS-GC) with electron-capture detection (ECD) has been developed for the determination of free and total sulphites in wine (Aberl and Coelhan, 2013). Formation of gaseous SO_2 is achieved by acidification and heating in the presence of 2,4-dinitrophenylhydrazine. The LOD is 1 mg/L, the LOQ 5 mg/L. The method is quick, accurate, and requires minimal sample preparation.

27.7. Minimal doses eliciting adverse reactions

Toxicity studies in non-asthmatic individuals have been conducted primarily through oral challenges and inhalation studies (Bush et al., 1986b). Small numbers of individuals have ingested doses of up to 400 mg of SO_2 equivalents per day without adverse effects (Taylor et al., 1986). However, doses of 4 to 6 g per day predictably caused nausea, vomiting, gastric irritation and occasional gastrointestinal bleeding (Schwartz, 1984; Bush et al., 1986b). Sulphite sensitivity was confirmed in a patient after the ingestion of a total dose of 10 mg of $NaHSO_3$ solution (Prenner and Stevens, 1976). Case reports of positive oral challenges with encapsulated sulphites at doses of 10 mg (Schwartz, 1983) and 25 mg (Habenicht et al., 1983) are available. Challenge studies in larger numbers of non-asthmatic subjects suggest that few react to the ingestion of sulphites in foods or beverages (Meggs et al., 1985; Sonin and Patterson, 1985; Bush et al., 1986b).

Among asthmatics, the amount of sulphite required to produce a response also varies and quantities as low as 1 to 5 mg of ingested potassium metabisulphite (equivalent to 3.7 mg of free SO_2) have been reported to trigger a reaction in sulphite sensitive asthmatics (Stevenson and Simon, 1981). Ingestion of sulphited solutions is more likely to precipitate asthma than ingestion of encapsulated sulphites, perhaps owing to inhalation of volatilised SO_2 (Bush et al., 1986b).

Most sulphite sensitive individuals will react to ingested metabisulphite in quantities ranging from 20 to 50 mg (Simon, 1989; Lester, 1995). However, minimal eliciting doses have not been systematically assessed and the lowest concentration of sulphites able to trigger a reaction in a sensitive person is unknown.

The Panel notes that the studies available do not allow concluding on the lowest concentrations of sulphites that are able to trigger a reaction in a sensitive person.

27.8. Conclusion

The prevalence of sulphite sensitivity in the general population is unknown, but it appears to be rare among non-asthmatics. Most reactions to sulphites are characterised by severe bronchospasm, which can occur within minutes after ingestion of sulphite-containing foods. Average daily sulphite consumption in adults has been estimated to be approximately between 20 mg and 50 mg of sulphur dioxide equivalents, but interindividual variability is high. Most sulphite sensitive individuals will react to ingested quantities of metabisulphite within this range. Labelling of foods containing sulphiting agents in concentrations > 10 mg/kg or 10 mg/L is mandatory in the EU, which was based on the LOD of the detection method available at the time. Many very sensitive and reliable methods are now available for analysis of sulphites in foods, with LODs well below 10 mg/kg. However, MED have not been systematically assessed and the smallest concentration of sulphites able to trigger a reaction in a sensitive person is unknown.

REFERENCES

Aalberse RC, 1998. Clinical relevance of carbohydrate allergen epitopes. Allergy, 53, 54-57.

Aaronov D, Tasher D, Levine A, Somekh E, Serour F and Dalal I, 2008. Natural history of food allergy in infants and children in Israel. Ann Allergy Asthma Immunol, 101, 637-640.

Aas K and Jebsen JW, 1967. Studies of hypersensitivity to fish. Partial purification and crystallization of a major allergenic component of cod. Int Arch Allergy Appl Immunol, 32, 1-20.

Abdel Rahman AM, Lopata AL, Randell EW and Helleur RJ, 2010. Absolute quantification method and validation of airborne snow crab allergen tropomyosin using tandem mass spectrometry. Analytica Chimica Acta, 681, 49-55.

Abdel Rahman AM, Kamath SD, Lopata AL, Robinson JJ and Helleur RJ, 2011. Biomolecular characterization of allergenic proteins in snow crab (Chionoecetes opilio) and de novo sequencing of the second allergen arginine kinase using tandem mass spectrometry. J Proteomics, 74, 231-241.

Abdel Rahman AM, Kamath SD, Gagne S, Lopata AL and Helleur R, 2013. Comprehensive proteomics approach in characterizing and quantifying allergenic proteins from northern shrimp: toward better occupational asthma prevention. J Proteome Res, 12, 647-656.

Aberl A and Coelhan M, 2013. Determination of sulfur dioxide in wine using headspace gas chromatography and electron capture detection. Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 30, 226-233.

Abolhassani M and Roux KH, 2009. cDNA Cloning, expression and characterization of an allergenic 60s ribosomal protein of almond (prunus dulcis). Iran J Allergy Asthma Immunol, 8, 77-84.

Abramovitch JB, Kamath S, Varese N, Zubrinich C, Lopata AL, O'Hehir RE and Rolland JM, 2013. IgE Reactivity of Blue Swimmer Crab () Tropomyosin, Por p 1, and Other Allergens; Cross-Reactivity with Black Tiger Prawn and Effects of Heating. PLoS One, 8, e67487.

Achouri A, Nail V and Boye JI, 2012. Sesame protein isolate: Fractionation, secondary structure and functional properties. Food Research International, 46, 360-369.

Achouri A and Boye JI, 2013. Thermal processing, salt and high pressure treatment effects on molecular structure and antigenicity of sesame protein isolate. Food Research International, 53, 240-251.

Adachi A, Horikawa T, Shimizu H, Sarayama Y, Ogawa T, Sjolander S, Tanaka A and Moriyama T, 2009. Soybean beta-conglycinin as the main allergen in a patient with food-dependent exercise-induced anaphylaxis by tofu: food processing alters pepsin resistance. Clin Exp Allergy, 39, 167-173.

Agne PS, Bidat E, Agne PS, Rance F and Paty E, 2004. Sesame seed allergy in children. Eur Ann Allergy Clin Immunol, 36, 300-305.

Ahn K, 2007. Identification of Pistachio (Pistacia vera) Allergens of 11s Globulin and 2s Albumin Family. J Allergy Clin Immunol, 119, S121.

Ahn K, Bardina L, Grishina G, Beyer K and Sampson HA, 2009. Identification of two pistachio allergens, Pis v 1 and Pis v 2, belonging to the 2S albumin and 11S globulin family. Clinical & Experimental Allergy, 39, 926-934.

Aihara Y, Takahashi Y, Kotoyori T, Mitsuda T, Ito R, Aihara M, Ikezawa Z and Yokota S, 2001. Frequency of food-dependent, exercise-induced anaphylaxis in Japanese junior-high-school students. J Allergy Clin Immunol, 108, 1035-1039.

Akagawa M, Handoyo T, Ishii T, Kumazawa S, Morita N and Suyama K, 2007. Proteomic analysis of wheat flour allergens. J Agric Food Chem, 55, 6863-6870.

7803 Akkerdaas JH, Wensing M, Knulst AC, Stephan O, Hefle SL, Aalberse RC and van Ree R, 2004. A
7804 novel approach for the detection of potentially hazardous pepsin stable hazelnut proteins as
7805 contaminants in chocolate-based food. J Agric Food Chem, 52, 7726-7731.

7806 Akkerdaas JH, Schocker F, Vieths S, Versteeg S, Zuidmeer L, Hefle SL, Aalberse RC, Richter K,
7807 Ferreira F and van Ree R, 2006. Cloning of oleosin, a putative new hazelnut allergen, using a
7808 hazelnut cDNA library. Mol Nutr Food Res, 50, 18-23.

7809 Albillos SM, Al-Taher F and Maks N, 2011. Increasing extractability of protein for allergen detection
7810 after food processing. Food Chemistry, 127, 1831-1834.

7811 Alessandri S, Sancho A, Vieths S, Mills CEN, Wal J-M, Shewry PR, Rigby N and Hoffmann-
7812 Sommergruber K, 2012. High-Throughput NMR Assessment of the Tertiary Structure of Food
7813 Allergens. PLoS One, 7, e39785.

7814 Allen CW, Campbell DE and Kemp AS, 2007. Egg allergy: are all childhood food allergies the same?
7815 J Paediatr Child Health, 43, 214-218.

7816 Allen KJ, Remington BC, Baumert JL, Crevel RW, Houben GF, Brooke-Taylor S, Kruizinga AG and
7817 Taylor SL, 2013. Allergen reference doses for precautionary labeling (VITAL 2.0): Clinical
7818 implications. J Allergy Clin Immunol.

7819 Altschul SF, Gish W, Miller W, Myers EW and Lipman DJ, 1990. Basic local alignment search tool. J
7820 Mol Biol, 215, 403-410.

7821 Alvarez-Alvarez J, Guillamon E, Crespo JF, Cuadrado C, Burbano C, Rodriguez J, Fernandez C and
7822 Muzquiz M, 2005. Effects of extrusion, boiling, autoclaving, and microwave heating on lupine
7823 allergenicity. J Agric Food Chem, 53, 1294-1298.

7824 Ameer Q and Adeloju SB, 2008. Galvanostatic Entrapment of Sulfite Oxidase into Ultrathin
7825 Polypyrrole Films for Improved Amperometric Biosensing of Sulfite. Electroanalysis, 20, 2549-
7826 2556.

7827 Amlot PL, Kemeny DM, Zachary C, Parkes P and Lessof MH, 1987. Oral allergy syndrome (OAS):
7828 symptoms of IgE-mediated hypersensitivity to foods. Clin Allergy, 17, 33-42.

7829 Amo A, Rodriguez-Perez R, Blanco J, Villota J, Juste S, Moneo I and Caballero ML, 2010. Gal d 6 is
7830 the second allergen characterized from egg yolk. J Agric Food Chem, 58, 7453-7457.

7831 Anagnostou K, Islam S, King Y, Deighton J, Clark AT and Ewan PW, 2009. Induction of tolerance in
7832 severe peanut allergy. Clin. Exp. Allergy, 39, 1954.

7833 Anderson RP, Degano P, Godkin AJ, Jewell DP and Hill AV, 2000. In vivo antigen challenge in celiac
7834 disease identifies a single transglutaminase-modified peptide as the dominant A-gliadin T-cell
7835 epitope. Nat Med, 6, 337-342.

7836 Andersson K and Lidholm J, 2003. Characteristics and immunobiology of grass pollen allergens. Int
7837 Arch Allergy Immunol, 130, 87-107.

7838 Andre F, Andre C, Colin L, Cacaraci F and Cavagna S, 1994. Role of new allergens and of allergens
7839 consumption in the increased incidence of food sensitizations in France. Toxicology, 93, 77-83.

7840 Andre F, Cavagna S and Andre C, 2003. Gelatin prepared from tuna skin: a risk factor for fish allergy
7841 or sensitization? Int Arch Allergy Immunol, 130, 17-24.

7842 Anibarro B, Seoane FJ and Mugica MV, 2007. Involvement of hidden allergens in food allergic
7843 reactions. J Investig Allergol Clin Immunol, 17, 168-172.

7844 Añíbarro B, Seoane FJ, Vila C and Lombardero M, 2000. Allergy to eggs from duck and goose
7845 without sensitization to hen egg proteins. Journal of Allergy and Clinical Immunology, 105, 834-
7846 836.

7847 Anraku Y, Takahashi Y, Kitano H and Hakari M, 2007. Recognition of sugars on surface-bound cap-
7848 shaped gold particles modified with a polymer brush. Colloids and Surfaces B: Biointerfaces, 57,
7849 61-68.

7850 Ansari P, Stoppacher N, Rudolf J, Schuhmacher R and Baumgartner S, 2011. Selection of possible
7851 marker peptides for the detection of major ruminant milk proteins in food by liquid
7852 chromatography-tandem mass spectrometry. Anal Bioanal Chem, 399, 1105-1115.

7853 Ansari P, Stoppacher N and Baumgartner S, 2012. Marker peptide selection for the determination of
7854 hazelnut by LC–MS/MS and occurrence in other nuts. Anal Bioanal Chem, 402, 2607-2615.

7855 AOAC, 1995. Official methods of analysis. Sulphites in foods, Optimized Monier-Williams Method.
7856 No. 990.28, .

7857 AOAC, 2000. Official methods of analysis. Sulphites in foods and beverages, Ion exclusion
7858 chromatographic method. . No. 990.31.

7859 AOAC, 2005. Official methods of analysis. Total sulphites in wine. Flow injection analysis. No.
7860 990.29.

7861 Aranceta-Garza F, Perez-Enriquez R and Cruz P, 2011. PCR-SSCP method for genetic differentiation
7862 of canned abalone and commercial gastropods in the Mexican retail market. Food Control, 22,
7863 1015-1020.

7864 Arbes SJ, Jr., Gergen PJ, Elliott L and Zeldin DC, 2005. Prevalences of positive skin test responses to
7865 10 common allergens in the US population: results from the third National Health and Nutrition
7866 Examination Survey. J Allergy Clin Immunol, 116, 377-383.

7867 Arentz-Hansen H, McAdam SN, Molberg O, Fleckenstein B, Lundin KE, Jorgensen TJ, Jung G,
7868 Roepstorff P and Sollid LM, 2002. Celiac lesion T cells recognize epitopes that cluster in regions
7869 of gliadins rich in proline residues. Gastroenterology, 123, 803-809.

7870 Arif SH, 2009. A Ca(2+)-binding protein with numerous roles and uses: parvalbumin in molecular
7871 biology and physiology. Bioessays, 31, 410-421.

7872 Armentia A, Rodriguez R, Callejo A, Martin-Esteban M, Martin-Santos JM, Salcedo G, Pascual C,
7873 Sanchez-Monge R and Pardo M, 2002. Allergy after ingestion or inhalation of cereals involves
7874 similar allergens in different ages. Clin Exp Allergy, 32, 1216-1222.

7875 Arshad SH, Tariq SM, Matthews S and Hakim E, 2001. Sensitization to common allergens and its
7876 association with allergic disorders at age 4 years: a whole population birth cohort study. Pediatrics,
7877 108, E33.

7878 Artesani MC, Donnanno S, Cavagni G, Calzone L and D'Urbano L, 2008. Egg sensitization caused by
7879 immediate hypersensitivity reaction to drug-containing lysozyme. Ann Allergy Asthma Immunol,
7880 101, 105.

7881 Asero R, Mistrello G, Roncarolo D, Casarini M and Falagiani P, 1999. True monosensitivity to a
7882 tropical sole. Allergy, 54, 1228-1229.

7883 Asero R, Mistrello G, Roncarolo D, de Vries SC, Gautier MF, Ciurana CL, Verbeek E, Mohammadi
7884 T, Knul-Brettlova V, Akkerdaas JH, Bulder I, Aalberse RC and van Ree R, 2000. Lipid transfer
7885 protein: a pan-allergen in plant-derived foods that is highly resistant to pepsin digestion. Int Arch
7886 Allergy Immunol, 122, 20-32.

7887 Asero R, Mistrello G, Roncarolo D and Amato S, 2002. Allergenic similarities of 2S albumins.
7888 Allergy, 57, 62-63.

7889 Asero R, Amato S, Alfieri B, Folloni S and Mistrello G, 2007. Rice: another potential cause of food
7890 allergy in patients sensitized to lipid transfer protein. Int Arch Allergy Immunol, 143, 69-74.

7891 Asero R, 2011. Lipid transfer protein cross-reactivity assessed in vivo and in vitro in the office: pros
7892 and cons. J Investig Allergol Clin Immunol, 21, 129-136.

7893 Asturias JA, Arilla MC, Bartolomé B, Martínez J, Martínez A and Palacios R, 1997. Sequence
7894 polymorphism and structural analysis of timothy grass pollen profilin allergen (Phl p 11). Biochim
7895 Biophys Acta, 1352, 253-257.

7896 Asturias JA, Arilla MC, Gómez-Bayón N, Aguirre M, Martínez A, Palacios R and Martínez J, 1998.
7897 Cloning and immunological characterization of the allergen Hel a 2 (profilin) from sunflower
7898 pollen. Mol Immunol, 35, 469-478.

7899 Asturias JA, Eraso E, Moneo I and Martínez A, 2000. Is tropomyosin an allergen in Anisakis?
7900 Allergy, 55, 898-898.

7901 Asturias JA, Eraso E, Arilla MC, Gomez-Bayon N, Inacio F and Martinez A, 2002. Cloning, isolation,
7902 and IgE-binding properties of Helix aspersa (brown garden snail) tropomyosin. Int Arch Allergy
7903 Immunol, 128, 90-96.

7904 Astwood JD, Leach JN and Fuchs RL, 1996. Stability of food allergens to digestion in vitro. Nat
7905 Biotechnol, 14, 1269-1273.

7906 Atkins FM, Steinberg SS and Metcalfe DD, 1985. Evaluation of immediate adverse reactions to foods
7907 in adult patients. II. A detailed analysis of reaction patterns during oral food challenge. J Allergy
7908 Clin Immunol, 75, 356-363.

7909 Aukrust L, Apold J, Elsayed S and Aas K, 1978a. Crossed immunoelectrophoretic and crossed
7910 radioimmunoelectrophoretic studies employing a model allergen from codfish. Int Arch Allergy
7911 Appl Immunol, 57, 253-262.

7912 Aukrust L, Grimmer O and Aas K, 1978b. Demonstration of distinct allergens by means of
7913 immunological methods. Comparison of crossed radioimmunoelectrophoresis, radioallergosorbent
7914 test and in vivo passive transfer test. Int Arch Allergy Appl Immunol, 57, 183-192.

7915 Axelsson I, Jakobsson I, Lindberg T and Benediktsson B, 1986. Bovine beta-lactoglobulin in the
7916 human milk. A longitudinal study during the whole lactation period. Acta Paediatr Scand, 75, 702-
7917 707.

7918 Ayuso R, Reese G, Leong-Kee S, Plante M and Lehrer SB, 2002a. Molecular Basis of Arthropod
7919 Cross-Reactivity: IgE-Binding Cross-Reactive Epitopes of Shrimp, House Dust Mite and
7920 Cockroach Tropomyosins. Int Arch Allergy Immunol, 129, 38-48.

7921 Ayuso R, Lehrer SB and Reese G, 2002b. Identification of Continuous, Allergenic Regions of the
7922 Major Shrimp Allergen Pen a 1 (Tropomyosin). Int Arch Allergy Immunol, 127, 27-37.

7923 Ayuso R, Grishina G, Ahn K, Bardina L, Beyer K and Sampson H, 2007. Identification and cloning of
7924 MnSOD, a new major pistachio allergen. J Allergy Clin Immunol, 119, s115.

7925 Ayuso R, Grishina G, Bardina L, Carrillo T, Blanco C, Ibáñez MD, Sampson HA and Beyer K, 2008.
7926 Myosin light chain is a novel shrimp allergen, Lit v 3. Journal of Allergy and Clinical Immunology,
7927 122, 795-802.

7928 Ayuso R, Grishina G, Ibanez MD, Blanco C, Carrillo T, Bencharitiwong R, Sanchez S, Nowak-
7929 Wegrzyn A and Sampson HA, 2009. Sarcoplasmic calcium-binding protein is an EF-hand-type
7930 protein identified as a new shrimp allergen. J Allergy Clin Immunol, 124, 114-120.

7931 Ayuso R, Sánchez-Garcia S, Lin J, Fu Z, Ibáñez MD, Carrillo T, Blanco C, Goldis M, Bardina L,
7932 Sastre J and Sampson HA, 2010. Greater epitope recognition of shrimp allergens by children than
7933 by adults suggests that shrimp sensitization decreases with age. Journal of Allergy and Clinical
7934 Immunology, 125, 1286-1293.e1283.

7935 Azarnia S, Boye JI, Mongeon V and Sabik H, 2013. Detection of ovalbumin in egg white, whole egg
7936 and incurred pasta using LC–ESI-MS/MS and ELISA. Food Research International, 52, 526-534.

7937 Azofra J and Lombardero M, 2003. Limpet anaphylaxis: cross-reactivity between limpet and house-
7938 dust mite Dermatophagoides pteronyssinus. Allergy, 58, 146-149.

7939 Bachert C and van Cauwenberge P, 2003. The WHO ARIA (allergic rhinitis and its impact on asthma)
7940 initiative. Chem Immunol Allergy, 82, 119-126.

7941 Baderschneider B, Crevel RWR, Earl LK, Lalljie A, Sanders DJ and Sanders IJ, 2002. Sequence
7942 analysis and resistance to pepsin hydrolysis as part of an assessment of the potential allergenicity of
7943 ice structuring protein type III HPLC 12. Food and Chemical Toxicology, 40, 965-978.

7944 Baehler P, Chad Z, Gurbindo C, Bonin AP, Bouthillier L and Seidman EG, 1996. Distinct patterns of
7945 cow's milk allergy in infancy defined by prolonged, two-stage double-blind, placebo-controlled
7946 food challenges. Clinical & Experimental Allergy, 26, 254-261.

7947 Bahna SL, 2003. Diagnosis of food allergy. Ann Allergy Asthma Immunol, 90, 77-80.

7948 Bakos N, Scholl I, Szalai K, Kundi M, Untersmayr E and Jensen-Jarolim E, 2006. Risk assessment in
7949 elderly for sensitization to food and respiratory allergens. Immunol Lett, 107, 15-21.

7950 Balatsouras DG, Koukoutsis G, Ganelis P, Fassolis A, Korres GS and Kaberos A, 2011. Study of
7951 Allergic Rhinitis in Childhood. International Journal of Otolaryngology, 2011.

7952 Ball H, Luyt D, Bravin K and Kirk K, 2011. Single nut or total nut avoidance in nut allergic children:
7953 outcome of nut challenges to guide exclusion diets. Pediatric Allergy and Immunology, 22, 808-
7954 812.

7955 Ballabio C, Magni C, Restani P, Mottini M, Fiocchi A, Tedeschi G and Duranti M, 2010. IgE-
7956 mediated cross-reactivity among leguminous seed proteins in peanut allergic children. Plant Foods
7957 Hum Nutr, 65, 396-402.

7958 Ballabio C, Penas E, Uberti F, Fiocchi A, Duranti M, Magni C and Restani P, 2013. Characterization
7959 of the sensitization profile to lupin in peanut-allergic children and assessment of cross-reactivity
7960 risk. Pediatr Allergy Immunol, 24, 270-275.

7961 Ballmer-Weber BK, Vieths S, Luttkopf D, Heuschmann P and Wuthrich B, 2000. Celery allergy
7962 confirmed by double-blind, placebo-controlled food challenge: a clinical study in 32 subjects with a
7963 history of adverse reactions to celery root. J Allergy Clin Immunol, 106, 373-378.

7964 Ballmer-Weber BK, Wüthrich B, Wangorsch A, Fötisch K, Altmann F and Vieths S, 2001. Carrot
7965 allergy: Double-blinded, placebo-controlled food challenge and identification of allergens. Journal
7966 of Allergy and Clinical Immunology, 108, 301-307.

7967 Ballmer-Weber BK, Hoffmann A, Wüthrich B, Lüttkopf D, Pompei C, Wangorsch A, Kästner M and
7968 Vieths S, 2002. Influence of food processing on the allergenicity of celery: DBPCFC with celery
7969 spice and cooked celery in patients with celery allergy. Allergy, 57, 228-235.

7970 Ballmer-Weber BK, Holzhauser T, Scibilia J, Mittag D, Zisa G, Ortolani C, Oesterballe M, Poulsen
7971 LK, Vieths S and Bindslev-Jensen C, 2007. Clinical characteristics of soybean allergy in Europe: a
7972 double-blind, placebo-controlled food challenge study. J Allergy Clin Immunol, 119, 1489-1496.

7973 Ballmer-Weber BK and Vieths S, 2008. Soy allergy in perspective. Curr Opin Allergy Clin Immunol,
7974 8, 270-275.

7975 Barbi E, Gerarduzzi T, Longo G and Ventura A, 2004. Fatal allergy as a possible consequence of
7976 long-term elimination diet. Allergy, 59, 668-669.

7977 Barre A, Jacquet G, Sordet C, Culerrier R and Rougé P, 2007. Homology modelling and
7978 conformational analysis of IgE-binding epitopes of Ara h 3 and other legumin allergens with a
7979 cupin fold from tree nuts. Mol Immunol, 44, 3243-3255.

7980 Bartolome B, Mendez JD, Armentia A, Vallverdu A and Palacios R, 1997. Allergens from Brazil nut:
7981 immunochemical characterization. Allergol Immunopathol (Madr), 25, 135-144.

7982 Battais F, Pineau F, Popineau Y, Aparicio C, Kanny G, Guerin L, Moneret-Vautrin DA and Denery-
7983 Papini S, 2003. Food allergy to wheat: identification of immunogloglin E and immunoglobulin G-
7984 binding proteins with sequential extracts and purified proteins from wheat flour. Clin Exp Allergy,
7985 33, 962-970.

7986 Battais F, Mothes T, Moneret-Vautrin DA, Pineau F, Kanny G, Popineau Y, Bodinier M and Denery-
7987 Papini S, 2005. Identification of IgE-binding epitopes on gliadins for patients with food allergy to
7988 wheat. Allergy, 60, 815-821.

7989 Battais F, Richard C, Jacquenet S, Denery-Papini S and Moneret-Vautrin DA, 2008. Wheat grain
7990 allergies: an update on wheat allergens. Eur Ann Allergy Clin Immunol, 40, 67-76.

7991 Bauer L, Ebner C, Hirschwehr R, Wuthrich B, Pichler C, Fritsch R, Scheiner O and Kraft D, 1996. IgE
7992 cross-reactivity between birch pollen, mugwort pollen and celery is due to at least three distinct
7993 cross-reacting allergens: immunoblot investigation of the birch-mugwort-celery syndrome. Clin
7994 Exp Allergy, 26, 1161-1170.

7995 Bauermeister K, Wangorsch A, Garoffo LP, Reuter A, Conti A, Taylor SL, Lidholm J, DeWitt ÅM,
7996 Enrique E, Vieths S, Holzhauser T, Ballmer-Weber B and Reese G, 2011. Generation of a
7997 comprehensive panel of crustacean allergens from the North Sea Shrimp Crangon crangon. Mol
7998 Immunol, 48, 1983-1992.

7999 Baumgartner S, Steiner I, Kloiber S, Hirmann D, Krska R and Yeung J, 2002. Towards the
8000 development of a dipstick immunoassay for the detection of trace amounts of egg proteins in food.
8001 European Food Research and Technology, 214, 168-170.

8002 Baur X, Pau M, Czuppon A and Fruhmann G, 1996. Characterization of soybean allergens causing
8003 sensitization of occupationally exposed bakers. Allergy, 51, 326-330.

8004 Beardslee TA, Zeece MG, Sarath G and Markwell JP, 2000. Soybean glycinin G1 acidic chain shares
8005 IgE epitopes with peanut allergen Ara h 3. Int Arch Allergy Immunol, 123, 299-307.

8006 Beaudoin E, 2007. Buckwheat allergy: analysis of 22 cases recorded by the allergy vigilance network
8007 (2002-2006). Eur Ann Allergy Clin Immunol, 39(9):, 303-306.

8008 Becker WM, Kleber-Janke T and Lepp U, 2001. Four Novel Recombinant Peanut Allergens: More
8009 Information, More Problems. Int Arch Allergy Immunol, 124, 100-102.

8010 Bemrah N, Vin K, Sirot V, Aguilar F, Ladrat AC, Ducasse C, Gey JL, Retho C, Nougadere A and
8011 Leblanc JC, 2012. Assessment of dietary exposure to annatto (E160b), nitrites (E249-250),
8012 sulphites (E220-228) and tartaric acid (E334) in the French population: the second French total diet
8013 study. Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 29, 875-885.

8014 Ben-Shoshan M, Harrington DW, Soller L, Fragapane J, Joseph L, St Pierre Y, Godefroy SB, Elliott
8015 SJ and Clarke AE, 2010. A population-based study on peanut, tree nut, fish, shellfish, and sesame
8016 allergy prevalence in Canada. J Allergy Clin Immunol, 125, 1327-1335.

8017 Ben-Shoshan M, Turnbull E and Clarke A, 2012. Food allergy: temporal trends and determinants. Curr
8018 Allergy Asthma Rep, 12, 346-372.

8019 Ben Rejeb S, Abbott M, Davies D, Querry J, Cleroux C, Streng C, Delahaut P and Yeung JM, 2003.
8020 Immunochemical-based method for detection of hazelnut proteins in processed foods. J AOAC Int,
8021 86, 557-563.

8022 Ben Rejeb S, Abbott M, Davies D, Cleroux C and Delahaut P, 2005. Multi-allergen screening
8023 immunoassay for the detection of protein markers of peanut and four tree nuts in chocolate. Food
8024 Addit Contam, 22, 709-715.

8025 Benhamou AH, Zamora SA and Eigenmann PA, 2008. Correlation between specific immunoglobulin
8026 E levels and the severity of reactions in egg allergic patients. Pediatr Allergy Immunol, 19, 173-
8027 179.

8028 Berg JC, Visscher DW, Vierkant RA, Pankratz VS, Maloney SD, Lewis JT, Frost MH, Ghosh K,
8029 Degnim AC, Brandt KR, Vachon CM, Reynolds CA and Hartmann LC, 2008. Breast cancer risk in
8030 women with radial scars in benign breast biopsies. Breast Cancer Res Treat, 108, 167-174.

8031 Bergerová E, Brežná B and Kuchta T, 2011. A novel method with improved sensitivity for the
8032 detection of peanuts based upon single-tube nested real-time polymerase chain reaction. European
8033 Food Research and Technology, 232, 1087-1091.

8034 Bernard H, 1999. IgE Cross-reactivity with Caseins from Different Species in Humans Allergic to
8035 Cow's Milk. Food and Agricultural Immunology, 11, 101-111.

8036 Bernard H, Meisel H, Creminon C and Wal JM, 2000. Post-translational phosphorylation affects the
8037 IgE binding capacity of caseins. FEBS Lett, 467, 239-244.

8038 Bernard H, Paty E, Mondoulet L, Burks AW, Bannon GA, Wal JM and Scheinmann P, 2003.
8039 Serological characteristics of peanut allergy in children. Allergy, 58, 1285-1292.

8040 Bernhisel-Broadbent J, Taylor S and Sampson HA, 1989. Cross-allergenicity in the legume botanical
8041 family in children with food hypersensitivity. II. Laboratory correlates. J Allergy Clin Immunol,
8042 84, 701-709.

8043 Bernhisel-Broadbent J and Sampson HA, 1989. Cross-allergenicity in the legume botanical family in
8044 children with food hypersensitivity. J Allergy Clin Immunol, 83, 435-440.

8045 Bernhisel-Broadbent J, Strause D and Sampson HA, 1992. Fish hypersensitivity. II: Clinical relevance
8046 of altered fish allergenicity caused by various preparation methods. J Allergy Clin Immunol, 90,
8047 622-629.

8048 Bernhisel-Broadbent J, Dintzis HM, Dintzis RZ and Sampson HA, 1994. Allergenicity and
8049 antigenicity of chicken egg ovomucoid (Gal d III) compared with ovalbumin (Gal d I) in children
8050 with egg allergy and in mice. J Allergy Clin Immunol, 93, 1047-1059.

8051 Berni Canani R, Ruotolo S, Discepolo V and Troncone R, 2008. The diagnosis of food allergy in
8052 children. Curr Opin Pediatr, 20, 584-589.

8053 Berni Canani R, Nocerino R, Terrin G, Leone L and Troncone R, 2012. Hospital admissions for food-
8054 induced anaphylaxis in Italian children. Clinical & Experimental Allergy, 42, 1813-1814.

8055 Bernstein M, Day JH and Welsh A, 1982. Double-blind food challenge in the diagnosis of food
8056 sensitivity in the adult. J Allergy Clin Immunol, 70, 205-210.

8057 Berrens PDL, 1996. Neoallergens in heated pecan nut: products of Maillard-type degradation?
8058 Allergy, 51, 277-278.

8059 Bertrand-Harb C, Ivanova IV, Dalgalarrondo M and Haertllé T, 2003. Evolution of β-lactoglobulin
8060 and α-lactalbumin content during yoghurt fermentation. International Dairy Journal, 13, 39-45.

8061 Besler M, Steinhart H and Paschke A, 2001. Stability of food allergens and allergenicity of processed
8062 foods. Journal of Chromatography B: Biomedical Sciences and Applications, 756, 207-228.

8063 Besler M, Kasel U and Wichmann G, 2002. Determination of hidden allergens in foods by
8064 immunoassays. Internet Symposium on Food Allergens, 4, 1-18.

8065 Bessot JC, Metz-Favre C, Rame JM, De Blay F and Pauli G, 2010. Tropomyosin or not tropomyosin,
8066 what is the relevant allergen in house dust mite and snail cross allergies? Eur Ann Allergy Clin
8067 Immunol, 42, 3-10.

8068 Bettazzi F, Lucarelli F, Palchetti I, Berti F, Marrazza G and Mascini M, 2008. Disposable
8069 electrochemical DNA-array for PCR amplified detection of hazelnut allergens in foodstuffs.
8070 Analytica Chimica Acta, 614, 93-102.

8071 Beydon N, Davis SD, Lombardi E, Allen JL, Arets HG, Aurora P, Bisgaard H, Davis GM, Ducharme
8072 FM, Eigen H, Gappa M, Gaultier C, Gustafsson PM, Hall GL, Hantos Z, Healy MJ, Jones MH,
8073 Klug B, Lodrup Carlsen KC, McKenzie SA, Marchal F, Mayer OH, Merkus PJ, Morris MG,
8074 Oostveen E, Pillow JJ, Seddon PC, Silverman M, Sly PD, Stocks J, Tepper RS, Vilozni D, Wilson
8075 NM, American Thoracic Society/European Respiratory Society Working Group on I and Young
8076 Children Pulmonary Function T, 2007. An official American Thoracic Society/European

Respiratory Society statement: pulmonary function testing in preschool children. Am J Respir Crit Care Med, 175, 1304-1345.

Beyer K, Morrow E, Li XM, Bardina L, Bannon GA, Burks AW and Sampson HA, 2001. Effects of cooking methods on peanut allergenicity. J Allergy Clin Immunol, 107, 1077-1081.

Beyer K, Bardina L, Grishina G and Sampson HA, 2002a. Identification of sesame seed allergens by 2-dimensional proteomics and Edman sequencing: Seed storage proteins as common food allergens. Journal of Allergy and Clinical Immunology, 110, 154-159.

Beyer K, Grishina G, Bardina L, Grishin A and Sampson HA, 2002b. Identification of an 11S globulin as a major hazelnut food allergen in hazelnut-induced systemic reactions. J Allergy Clin Immunol, 110, 517-523.

Beyer K and Teuber SS, 2005. Food allergy diagnostics: scientific and unproven procedures. Curr Opin Allergy Clin Immunol, 5, 261-266.

Beyer K, Grishina G, Bardina L and Sampson HA, 2007. Identification of 2 new sesame seed allergens: Ses i 6 and Ses i 7. J Allergy Clin Immunol, 119, 1554-1556.

Biesiekierski JR, Newnham ED, Irving PM, Barrett JS, Haines M, Doecke JD, Shepherd SJ, Muir JG and Gibson PR, 2011. Gluten causes gastrointestinal symptoms in subjects without celiac disease: a double-blind randomized placebo-controlled trial. Am J Gastroenterol, 106, 508-514; quiz 515.

Bignardi C, Elviri L, Penna A, Careri M and Mangia A, 2010. Particle-packed column versus silica-based monolithic column for liquid chromatography–electrospray-linear ion trap-tandem mass spectrometry multiallergen trace analysis in foods. Journal of Chromatography A, 1217, 7579-7585.

Bignardi C, Mattarozzi M, Penna A, Sidoli S, Elviri L, Careri M and Mangia A, 2013. A Rapid Size-Exclusion Solid-Phase Extraction Step for Enhanced Sensitivity in Multi-Allergen Determination in Dark Chocolate and Biscuits by Liquid Chromatography–Tandem Mass Spectrometry. Food Analytical Methods, 6, 1144-1152.

Binder M, Mahler V, Hayek B, Sperr WR, Scholler M, Prozell S, Wiedermann G, Valent P, Valenta R and Duchene M, 2001. Molecular and immunological characterization of arginine kinase from the Indianmeal moth, Plodia interpunctella, a novel cross-reactive invertebrate pan-allergen. J Immunol, 167, 5470-5477.

Bindslev-Jensen C, Sten E, Earl LK, Crevel RW, Bindslev-Jensen U, Hansen TK, Stahl Skov P and Poulsen LK, 2003. Assessment of the potential allergenicity of ice structuring protein type III HPLC 12 using the FAO/WHO 2001 decision tree for novel foods. Food Chem Toxicol, 41, 81-87.

Bischoff SC, 2010. Food allergy and eosinophilic gastroenteritis and colitis. Curr Opin Allergy Clin Immunol, 10, 238-245.

Bjornsson E, Janson C, Plaschke P, Norrman E and Sjoberg O, 1996. Prevalence of sensitization to food allergens in adult Swedes. Ann Allergy Asthma Immunol, 77, 327-332.

Blais BW and Phillippe LM, 2000. A Cloth-based Enzyme Immunoassay for Detection of Peanut Proteins in Foods. Food and Agricultural Immunology, 12, 243-248.

Blais BW and Phillippe L, 2001. Detection of hazelnut proteins in foods by enzyme immunoassay using egg yolk antibodies. J Food Prot, 64, 895-898.

Blanc F, Vissers YM, Adel-Patient K, Rigby NM, Mackie AR, Gunning AP, Wellner NK, Skov PS, Przybylski-Nicaise L, Ballmer-Weber B, Zuidmeer-Jongejan L, Szepfalusi Z, Ruinemans-Koerts J, Jansen AP, Bernard H, Wal JM, Savelkoul HF, Wichers HJ and Mills EN, 2011. Boiling peanut Ara h 1 results in the formation of aggregates with reduced allergenicity. Mol Nutr Food Res, 55, 1887-1894.

8122 Blanco C, Diaz-Perales A, Collada C, Sanchez-Monge R, Aragoncillo C, Castillo R, Ortega N,
8123 Alvarez M, Carrillo T and Salcedo G, 1999. Class I chitinases as potential panallergens involved in
8124 the latex-fruit syndrome. J Allergy Clin Immunol, 103, 507-513.

8125 Blanco C, 2003. Latex-fruit syndrome. Curr Allergy Asthma Rep, 3, 47-53.

8126 Blanco C, Sánchez-Monge R, Recas M, López-Torrejón G, Cumplido J, Figueroa J, Carrillo T and
8127 Salcedo G, 2006. Cas S 8, the Lipid Transfer Protein from Chestnut Seeds, is a Major Allergen in
8128 Chestnut Allergic Patients without Associated Latex Allergy, but not in those with the Latex-Fruit
8129 Syndrome. J Allergy Clin Immunol, 117, S47.

8130 Blom WM, Vlieg-Boerstra BJ, Kruizinga AG, van der Heide S, Houben GF and Dubois AE, 2013.
8131 Threshold dose distributions for 5 major allergenic foods in children. J Allergy Clin Immunol, 131,
8132 172-179.

8133 Blumchen K, Ulbricht H, Staden U, Dobberstein K, Beschorner J, de Oliveira LCL, Shreffler WG,
8134 Sampson HA, Niggemann B, Wahn U and Beyer K, 2010. Oral peanut immunotherapy in children
8135 with peanut anaphylaxis. Journal of Allergy and Clinical Immunology, 126, 83-91.e81.

8136 Bock SA, 1982. The natural history of food sensitivity. J Allergy Clin Immunol, 69, 173-177.

8137 Bock SA, 1987. Prospective appraisal of complaints of adverse reactions to foods in children during
8138 the first 3 years of life. Pediatrics, 79, 683-688.

8139 Bock SA and Atkins FM, 1990. Patterns of food hypersensitivity during sixteen years of double-blind,
8140 placebo-controlled food challenges. J Pediatr, 117, 561-567.

8141 Bock SA, Munoz-Furlong A and Sampson HA, 2001. Fatalities due to anaphylactic reactions to foods.
8142 J Allergy Clin Immunol, 107, 191-193.

8143 Bock SA, Munoz-Furlong A and Sampson HA, 2007. Further fatalities caused by anaphylactic
8144 reactions to food, 2001-2006. J Allergy Clin Immunol, 119, 1016-1018.

8145 Bodd M, Kim CY, Lundin KE and Sollid LM, 2012. T-cell response to gluten in patients with HLA-
8146 DQ2.2 reveals requirement of peptide-MHC stability in celiac disease. Gastroenterology, 142, 552-
8147 561.

8148 Boehncke WH, Loeliger C, Kuehnl P, Kalbacher H, Bohm BO and Gall H, 1998. Identification of
8149 HLA-DR and -DQ alleles conferring susceptibility to pollen allergy and pollen associated food
8150 allergy. Clin Exp Allergy, 28, 434-441.

8151 Bohle B, Radakovics A, Jahn-Schmid B, Hoffmann-Sommergruber K, Fischer GF and Ebner C, 2003.
8152 Bet v 1, the major birch pollen allergen, initiates sensitization to Api g 1, the major allergen in
8153 celery: evidence at the T cell level. European Journal of Immunology, 33, 3303-3310.

8154 Boquete M, Iraola V, Morales M, Pinto H, Francisco C, Carballás C and Carnés J, 2011. Seafood
8155 hypersensitivity in mite sensitized individuals: is tropomyosin the only responsible allergen?
8156 Annals of Allergy, Asthma & Immunology, 106, 223-229.

8157 Bouchez-Mahiout I, Snegaroff J, Tylichova M, Pecquet C, Branlard G and Lauriere M, 2010. Low
8158 molecular weight glutenins in wheat-dependant, exercise-induced anaphylaxis: allergenicity and
8159 antigenic relationships with omega 5-gliadins. Int Arch Allergy Immunol, 153, 35-45.

8160 Boyano-Martinez T, Garcia-Ara C, Diaz-Pena JM and Martin-Esteban M, 2002. Prediction of
8161 tolerance on the basis of quantification of egg white-specific IgE antibodies in children with egg
8162 allergy. J Allergy Clin Immunol, 110, 304-309.

8163 Boyano Martinez T, Garcia-Ara C, Diaz-Pena JM, Munoz FM, Garcia Sanchez G and Esteban MM,
8164 2001. Validity of specific IgE antibodies in children with egg allergy. Clin Exp Allergy, 31, 1464-
8165 1469.

8166 Boyce JA, Assa'a A, Burks AW, Jones SM, Sampson HA, Wood RA, Plaut M, Cooper SF, Fenton MJ,
8167 Arshad SH, Bahna SL, Beck LA, Byrd-Bredbenner C, Camargo CA, Jr., Eichenfield L, Furuta GT,

8168 Hanifin JM, Jones C, Kraft M, Levy BD, Lieberman P, Luccioli S, McCall KM, Schneider LC,
8169 Simon RA, Simons FE, Teach SJ, Yawn BP, Schwaninger JM and Panel NI-sE, 2011. Guidelines
8170 for the diagnosis and management of food allergy in the United States: summary of the NIAID-
8171 Sponsored Expert Panel Report. Nutrition, 27, 253-267.

8172 Brambilla F, Resta D, Isak I, Zanotti M and Arnoldi A, 2009. A label-free internal standard method for
8173 the differential analysis of bioactive lupin proteins using nano HPLC-Chip coupled with Ion Trap
8174 mass spectrometry. Proteomics, 9, 272-286.

8175 Breiteneder H, Hoffmann-Sommergruber K, O'Riordain G, Susani M, Ahorn H, Ebner C, Kraft D and
8176 Scheiner O, 1995. Molecular characterization of Api g 1, the major allergen of celery (Apium
8177 graveolens), and its immunological and structural relationships to a group of 17-kDa tree pollen
8178 allergens. Eur J Biochem, 233, 484-489.

8179 Breiteneder H and Ebner C, 2000. Molecular and biochemical classification of plant-derived food
8180 allergens. Journal of Allergy and Clinical Immunology, 106, 27-36.

8181 Breiteneder H and Mills ENC, 2005. Molecular properties of food allergens. Journal of Allergy and
8182 Clinical Immunology, 115, 14-23.

8183 Bremer MG, Smits NG and Haasnoot W, 2009. Biosensor immunoassay for traces of hazelnut protein
8184 in olive oil. Anal Bioanal Chem, 395, 119-126.

8185 Brenna O, Pompei C, Ortolani C, Pravettoni V, Farioli L and Pastorello EA, 2000. Technological
8186 processes to decrease the allergenicity of peach juice and nectar. J Agric Food Chem, 48, 493-497.

8187 Brennecke S, Becker WM, Lepp U and Jappe U, 2007. Anaphylactic reaction to lupine flour. J Dtsch
8188 Dermatol Ges, 5, 774-776.

8189 Brett GM, Bull VJ and Morgan MRA, 1998. Identification of hidden allergens within foods. Allergy,
8190 53, 109-110.

8191 Brežná B, Hudecová L and Kuchta T, 2006. A novel real-time polymerase chain reaction (PCR)
8192 method for the detection of walnuts in food. European Food Research and Technology, 223, 373-
8193 377.

8194 Brežná B and Kuchta T, 2008. A novel real-time polymerase chain reaction method for the detection
8195 of pecan nuts in food. European Food Research and Technology, 226, 1113-1118.

8196 Brežná B, Dudášová H and Kuchta T, 2008. A novel real-time polymerase chain reaction method for
8197 the qualitative detection of pistachio in food. European Food Research and Technology, 228, 197-
8198 203.

8199 Brežná B, Piknova L and Kuchta T, 2009. A novel real-time polymerase chain reaction method for the
8200 detection of macadamia nuts in food. European Food Reasearch and Technology, 229, 397-401.

8201 Brežná B, Dudasova H and Kuchta T, 2010. A novel real-time polymerase chain reaction method for
8202 the detection of Brazil nuts in food. J AOAC Int, 93, 197-201.

8203 Brugman E, Meulmeester JF, Spee-van der Wekke A, Beuker RJ, Radder JJ and Verloove-Vanhorick
8204 SP, 1998. Prevalence of self-reported food hypersensitivity among school children in The
8205 Netherlands. Eur J Clin Nutr, 52, 577-581.

8206 Brusic V, Millot M, Petrovsky N, Gendel SM, Gigonzac O and Stelman SJ, 2003. Allergen databases.
8207 Allergy, 58, 1093-1100.

8208 Brzezinski JL, 2005. Detection of crustacean DNA and species identification using a PCR-restriction
8209 fragment length polymorphism method. J Food Prot, 68, 1866-1873.

8210 Brzezinski JL, 2007. Detection of sesame seed DNA in foods using real-time PCR. J Food Prot, 70,
8211 1033-1036.

8212 Bu G, Luo Y, Zheng Z and Zheng H, 2009. Effect of heat treatment on the antigenicity of bovine α-
8213 lactalbumin and β-lactoglobulin in whey protein isolate. Food and Agricultural Immunology, 20,
8214 195-206.

8215 Bu G, Luo Y, Zhang Y and Chen F, 2010. Effects of fermentation by lactic acid bacteria on the
8216 antigenicity of bovine whey proteins. J Sci Food Agric, 90, 2015-2020.

8217 Bublin M, Radauer C, Wilson IB, Kraft D, Scheiner O, Breiteneder H and Hoffmann-Sommergruber
8218 K, 2003. Cross-reactive N-glycans of Api g 5, a high molecular weight glycoprotein allergen from
8219 celery, are required for immunoglobulin E binding and activation of effector cells from allergic
8220 patients. FASEB J, 17, 1697-1699.

8221 Bugajska-Schretter A, Grote M, Vangelista L, Valent P, Sperr WR, Rumpold H, Pastore A, Reichelt
8222 R, Valenta R and Spitzauer S, 2000. Purification, biochemical, and immunological characterisation
8223 of a major food allergen: different immunoglobulin E recognition of the apo- and calcium-bound
8224 forms of carp parvalbumin. Gut, 46, 661-669.

8225 Burks AW, Williams LW, Helm RM, Thresher W, Brooks JR and Sampson HA, 1991a. Identification
8226 of soy protein allergens in patients with atopic dermatitis and positive soy challenges;
8227 determination of change in allergenicity after heating or enzyme digestion. Adv Exp Med Biol,
8228 289, 295-307.

8229 Burks AW, Williams LW, Helm RM, Connaughton C, Cockrell G and O'Brien T, 1991b.
8230 Identification of a major peanut allergen, Ara h I, in patients with atopic dermatitis and positive
8231 peanut challenges. J Allergy Clin Immunol, 88, 172-179.

8232 Burks AW, Williams LW, Thresher W, Connaughton C, Cockrell G and Helm RM, 1992a.
8233 Allergenicity of peanut and soybean extracts altered by chemical or thermal denaturation in
8234 patients with atopic dermatitis and positive food challenges. J Allergy Clin Immunol, 90, 889-897.

8235 Burks AW, Williams LW, Connaughton C, Cockrell G, O'Brien TJ and Helm RM, 1992b.
8236 Identification and characterization of a second major peanut allergen, Ara h II, with use of the sera
8237 of patients with atopic dermatitis and positive peanut challenge. J Allergy Clin Immunol, 90, 962-
8238 969.

8239 Burks AW, Casteel HB, Fiedorek SC, Williams LW and Pumphrey CL, 1994. Prospective oral food
8240 challenge study of two soybean protein isolates in patients with possible milk or soy protein
8241 enterocolitis. Pediatr Allergy Immunol, 5, 40-45.

8242 Burks AW, Jones SM, Boyce JA, Sicherer SH, Wood RA, Assa'ad A and Sampson HA, 2011. NIAID-
8243 sponsored 2010 guidelines for managing food allergy: applications in the pediatric population.
8244 Pediatrics, 128, 955-965.

8245 Burks AW, Jones SM, Wood RA, Fleischer DM, Sicherer SH, Lindblad RW, Stablein D, Henning
8246 AK, Vickery BP, Liu AH, Scurlock AM, Shreffler WG, Plaut M, Sampson HA and Consortium of
8247 Food Allergy R, 2012a. Oral immunotherapy for treatment of egg allergy in children. N Engl J
8248 Med, 367, 233-243.

8249 Burks AW, Tang M, Sicherer S, Muraro A, Eigenmann PA, Ebisawa M, Fiocchi A, Chiang W, Beyer
8250 K, Wood R, Hourihane J, Jones SM, Lack G and Sampson HA, 2012b. ICON: food allergy. J
8251 Allergy Clin Immunol, 129, 906-920.

8252 Burks W, Sampson HA and Bannon GA, 1998. Peanut allergens. Allergy, 53, 725-730.

8253 Burks W, 2003. Skin manifestations of food allergy. Pediatrics, 111, 1617-1624.

8254 Burney P, Summers C, Chinn S, Hooper R, van Ree R and Lidholm J, 2010. Prevalence and
8255 distribution of sensitization to foods in the European Community Respiratory Health Survey: a
8256 EuroPrevall analysis. Allergy, 65, 1182-1188.

8257 Burney PG, Potts J, Kummeling I, EN CM, Clausen M, Dubakiene R, Barreales L, Fernandez-Perez
8258 C, Fernandez-Rivas M, Le TM, Knulst AC, Kowalski ML, Lidholm J, Ballmer-Weber BK, Braun-
8259 Fahlander C, Mustakov T, Kralimarkova T, Popov T, Sakellariou A, Papadopoulos NG, Versteeg

SA, Zuidmeer L, Akkerdaas JH, Hoffmann-Sommergruber K and van Ree R, 2013. The prevalence and distribution of food sensitization in European adults. Allergy.

Bush RK, Taylor SL, Nordlee JA and Busse WW, 1985. Soybean oil is not allergenic to soybean-sensitive individuals. J Allergy Clin Immunol, 76, 242-245.

Bush RK, Taylor SL, Holden K, Nordlee JA and Busse WW, 1986a. Prevalence of sensitivity to sulfiting agents in asthmatic patients. Am J Med, 81, 816-820.

Bush RK, Taylor SL and Busse W, 1986b. A critical evaluation of clinical trials in reactions to sulfites. J Allergy Clin Immunol, 78, 191-202.

Busse PJ, Jarvinen KM, Vila L, Beyer K and Sampson HA, 2002. Identification of sequential IgE-binding epitopes on bovine alpha(s2)-casein in cow's milk allergic patients. Int Arch Allergy Immunol, 129, 93-96.

Caballero T, Pascual C, GarcÍA-Ara MC, Ojeda JA and MartÍN-Esteban M, 1997. IgE crossreactivity between mugwort pollen (Artemisia vulgaris) and hazelnut (Abellana nux) in sera from patients with sensitivity to both extracts. Clinical & Experimental Allergy, 27, 1203-1211.

Caballero T, San-Martin MS, Padial MA, Contreras J, Cabanas R, Barranco P and Lopez-Serrano MC, 2002. Clinical characteristics of patients with mustard hypersensitivity. Ann Allergy Asthma Immunol, 89, 166-171.

Cabanillas B, Pedrosa MM, Rodriguez J, Muzquiz M, Maleki SJ, Cuadrado C, Burbano C and Crespo JF, 2012. Influence of enzymatic hydrolysis on the allergenicity of roasted peanut protein extract. Int Arch Allergy Immunol, 157, 41-50.

Caffarelli C, Cavagni G, Giordano S, Stapane I and Rossi C, 1995. Relationship between oral challenges with previously uningested egg and egg-specific IgE antibodies and skin prick tests in infants with food allergy. J Allergy Clin Immunol, 95, 1215-1220.

Caffarelli C, Plebani A, Poiesi C, Petroccione T, Spattini A and Cavagni G, 2002. Determination of allergenicity to three cow's milk hydrolysates and an amino acid-derived formula in children with cow's milk allergy. Clin Exp Allergy, 32, 74-79.

Cahen YD, Fritsch R and Wuthrich B, 1998. Food allergy with monovalent sensitivity to poultry meat. Clin Exp Allergy, 28, 1026-1030.

Caiado J, Lundberg M, Pedro E, Pereira-Santos MC and Barbosa MP, 2009. Snail allergy without house dust mites sensitisation. Allergol Immunopathol (Madr), 37, 107-108.

Calabrese EJ and Baldwin LA, 1994. Improved method for selection of the NOAEL. Regul Toxicol Pharmacol, 19, 48-50.

Calvani M, Cardinale F, Martelli A, Muraro A, Pucci N, Savino F, Zappala D, Panetta V, Italian Society of Pediatric A and Immunology Anaphylaxis' Study G, 2011. Risk factors for severe pediatric food anaphylaxis in Italy. Pediatr Allergy Immunol, 22, 813-819.

Caminiti L, Passalacqua G, Barberi S, Vita D, Barberio G, De Luca R and Pajno GB, 2009. A new protocol for specific oral tolerance induction in children with IgE-mediated cow's milk allergy. Allergy Asthma Proc, 30, 443-448.

Campbell CP, Jackson AS, Johnson AR, Thomas PS and Yates DH, 2007. Occupational sensitization to lupin in the workplace: occupational asthma, rhinitis, and work-aggravated asthma. J Allergy Clin Immunol, 119, 1133-1139.

Campbell RL, Hagan JB, Manivannan V, Decker WW, Kanthala AR, Bellolio MF, Smith VD and Li JT, 2012. Evaluation of national institute of allergy and infectious diseases/food allergy and anaphylaxis network criteria for the diagnosis of anaphylaxis in emergency department patients. J Allergy Clin Immunol, 129, 748-752.

Capocchi A, Muccilli V, Cunsolo V, Saletti R, Foti S and Fontanini D, 2013. A heterotetrameric alpha-amylase inhibitor from emmer (Triticum dicoccon Schrank) seeds. Phytochemistry, 88, 6-14.

8307 Careri M, Costa A, Elviri L, Lagos JB, Mangia A, Terenghi M, Cereti A and Garoffo LP, 2007a. Use
8308 of specific peptide biomarkers for quantitative confirmation of hidden allergenic peanut proteins
8309 Ara h 2 and Ara h 3/4 for food control by liquid chromatography-tandem mass spectrometry. Anal
8310 Bioanal Chem, 389, 1901-1907.

8311 Careri M, Elviri L, Mangia A and Mucchino C, 2007b. ICP-MS as a novel detection system for
8312 quantitative element-tagged immunoassay of hidden peanut allergens in foods. Anal Bioanal Chem,
8313 387, 1851-1854.

8314 Careri M, Elviri L, Lagos J, Mangia A, Speroni F and Terenghi M, 2008. Selective and rapid
8315 immunomagnetic bead-based sample treatment for the liquid chromatography-electrospray ion-trap
8316 mass spectrometry detection of Ara h 3/4 peanut protein in foods. J Chromatogr A, 1206, 89-94.

8317 Carrera M, Canas B and Gallardo JM, 2012. Rapid direct detection of the major fish allergen,
8318 parvalbumin, by selected MS/MS ion monitoring mass spectrometry. J Proteomics, 75, 3211-3220.

8319 Carrillo T, Castillo R, Caminero J, Cuevas M, Rodriguez JC, Acosta O and Rodriguez de Castro F,
8320 1992. Squid hypersensitivity: a clinical and immunologic study. Ann Allergy, 68, 483-487.

8321 Carter CM, Urbanowicz M, Hemsley R, Mantilla L, Strobel S, Graham PJ and Taylor E, 1993. Effects
8322 of a few food diet in attention deficit disorder. Arch Dis Child, 69, 564-568.

8323 Castillo R, Delgado J, Quiralte J, Blanco C and Carrillo T, 1996. Food hypersensitivity among adult
8324 patients: epidemiological and clinical aspects. Allergol Immunopathol (Madr), 24, 93-97.

8325 Catassi C, Rossini M, Ratsch IM, Bearzi I, Santinelli A, Castagnani R, Pisani E, Coppa GV and Giorgi
8326 PL, 1993. Dose dependent effects of protracted ingestion of small amounts of gliadin in coeliac
8327 disease children: a clinical and jejunal morphometric study. Gut, 34, 1515-1519.

8328 Catassi C, Fabiani E, Iacono G, D'Agate C, Francavilla R, Biagi F, Volta U, Accomando S, Picarelli
8329 A, De Vitis I, Pianelli G, Gesuita R, Carle F, Mandolesi A, Bearzi I and Fasano A, 2007. A
8330 prospective, double-blind, placebo-controlled trial to establish a safe gluten threshold for patients
8331 with celiac disease. Am J Clin Nutr, 85, 160-166.

8332 Caubet JC, Kondo Y, Urisu A and Nowak-Wegrzyn A, 2011. Molecular diagnosis of egg allergy. Curr
8333 Opin Allergy Clin Immunol, 11, 210-215.

8334 Caubet JC and Sampson HA, 2012. Beyond skin testing: state of the art and new horizons in food
8335 allergy diagnostic testing. Immunol Allergy Clin North Am, 32, 97-109.

8336 Cawthorn D-M, Steinman HA and Witthuhn RC, 2011. Comparative study of different methods for
8337 the extraction of DNA from fish species commercially available in South Africa. Food Control, 22,
8338 231-244.

8339 CEN, 2009. EN 15633-1: 2009 - Foodstuffs - Detection of food allergens by immunological methods -
8340 Part 1: General considerations.

8341 CEN, 2010. EN 15842 :2010 Foodstuffs - Detection of food allergens. General considerations and
8342 validation of methods.

8343 Chan W-H, Ling K-H, Shaw P-C, Chiu S-W and Pui-Hay But P, 2012. Application of FINS and
8344 multiplex PCR for detecting genuine abalone products. Food Control, 23, 137-142.

8345 Chapela M, Sotelo C and Pérez-Martín R, 2003. Molecular identification of cephalopod species by
8346 FINS and PCR-RFLP of a cytochrome b gene fragment. European Food Research and Technology,
8347 217, 524-529.

8348 Chapman MD, Pomes A, Breiteneder H and Ferreira F, 2007. Nomenclature and structural biology of
8349 allergens. J Allergy Clin Immunol, 119, 414-420.

8350 Chassaigne H, Brohée M, Nørgaard JV and van Hengel AJ, 2007. Investigation on sequential
8351 extraction of peanut allergens for subsequent analysis by ELISA and 2D gel electrophoresis. Food
8352 Chemistry, 105, 1671-1681.

8353 Chassaigne H, Tregoat V, Norgaard JV, Maleki SJ and van Hengel AJ, 2009. Resolution and
8354 identification of major peanut allergens using a combination of fluorescence two-dimensional
8355 differential gel electrophoresis, Western blotting and Q-TOF mass spectrometry. J Proteomics, 72,
8356 511-526.

8357 Chatchatee P, Jarvinen KM, Bardina L, Vila L, Beyer K and Sampson HA, 2001. Identification of IgE
8358 and IgG binding epitopes on beta- and kappa-casein in cow's milk allergic patients. Clin Exp
8359 Allergy, 31, 1256-1262.

8360 Chen HL, Cao MJ, Cai QF, Su WJ, Mao HY and Liu GM, 2013. Purification and characterisation of
8361 sarcoplasmic calcium-binding protein, a novel allergen of red swamp crayfish (Procambarus
8362 clarkii). Food Chem, 139, 213-223.

8363 Chen J, Hu Y, Allen KJ, Ho MH and Li H, 2011. The prevalence of food allergy in infants in
8364 Chongqing, China. Pediatr Allergy Immunol, 22, 356-360.

8365 Chen L, Zhang S, Illa E, Song L, Wu S, Howad W, Arus P, Weg E, Chen K and Gao Z, 2008.
8366 Genomic characterization of putative allergen genes in peach/almond and their synteny with apple.
8367 BMC Genomics, 9, 543.

8368 Chen YH, Wu HJ, Tsai JJ and Lee MF, 2009. Anaphylactic shock caused by a 33-kDa alpha S1-
8369 casein-like allergen in kingfish caviar. J Investig Allergol Clin Immunol, 19, 245-246.

8370 Choi K and Hong K, 2007. Genomic DNA Sequence of mackerel parvalbumin and PCR test for rapid
8371 detection of allergenic mackerel ingredients in food. Food Sci Biotechnol, 16, 67-70.

8372 Chu KH, Wong SH and Leung PS, 2000. Tropomyosin Is the Major Mollusk Allergen: Reverse
8373 Transcriptase Polymerase Chain Reaction, Expression and IgE Reactivity. Mar Biotechnol (NY), 2,
8374 499-509.

8375 Chu PT, Lin CS, Chen WJ, Chen CF and Wen HW, 2012. Detection of gliadin in foods using a quartz
8376 crystal microbalance biosensor that incorporates gold nanoparticles. J Agric Food Chem, 60, 6483-
8377 6492.

8378 Chu PT and Wen HW, 2013. Sensitive detection and quantification of gliadin contamination in gluten-
8379 free food with immunomagnetic beads based liposomal fluorescence immunoassay. Anal Chim
8380 Acta, 787, 246-253.

8381 Chung SW, Chan BT and Chan AC, 2008a. Determination of free and reversibly-bound sulfite in
8382 selected foods by high-performance liquid chromatography with fluorometric detection. J AOAC
8383 Int, 91, 98-102.

8384 Chung SY, Yang W and Krishnamurthy K, 2008b. Effects of pulsed UV-light on peanut allergens in
8385 extracts and liquid peanut butter. J Food Sci, 73, C400-404.

8386 Cianferoni A and Muraro A, 2012. Food-induced anaphylaxis. Immunol Allergy Clin North Am, 32,
8387 165-195.

8388 Clark AT and Ewan PW, 2003. Interpretation of tests for nut allergy in one thousand patients, in
8389 relation to allergy or tolerance. Clinical & Experimental Allergy, 33, 1041-1045.

8390 Clark AT, King Y, Islam S, Anagnostou K, Deighton J and Ewan PW, 2008. The study of tolerance to
8391 oral peanut (STOP). Clin. Exp. Allergy, 38, 1995.

8392 Clark AT, Islam S, King Y, Deighton J, Anagnostou K and Ewan PW, 2009. Successful oral tolerance
8393 induction in severe peanut allergy. Allergy, 64, 1218-1220.

8394 Clarke MC, Kilburn SA, Hourihane JO, Dean KR, Warner JO and Dean TP, 1998. Serological
8395 characteristics of peanut allergy. Clin Exp Allergy, 28, 1251-1257.

8396 Clemente A, Chambers SJ, Lodi F, Nicoletti C and Brett GM, 2004. Use of the indirect competitive
8397 ELISA for the detection of Brazil nut in food products. Food Control, 15, 65-69.

8398 Codex Alimentarius Commission, 2003. Alinorm 03/34. Joint FAO/WHO Food Standard Programme,
8399 Twenty-fifth Session, Appendix IV, Annex on the assessment of possible allergenicity. Rome,
8400 Italy. 47-60.

8401 Codex Alimentarius Commission, 2006. Report of the twenty-seventh session of the Codex
8402 Committee on methods of analysis and sampling. ALINORM 06/29/23.

8403 Codex Alimentarius Commission, 2008. Draft revised codex standard for foods for special dietary use
8404 for persons intolerant to gluten. ALINORM 08/31/26, Appendix III, 50-51.

8405 Codina R, Oehling AG, Jr. and Lockey RF, 1998. Neoallergens in heated soybean hull. Int Arch
8406 Allergy Immunol, 117, 120-125.

8407 Codina R, Ardusso L, Lockey RF, Crisci C and Medina I, 2003. Allergenicity of varieties of soybean.
8408 Allergy, 58, 1293-1298.

8409 Cohen A, Goldberg M, Levy B, Leshno M and Katz Y, 2007. Sesame food allergy and sensitization in
8410 children: the natural history and long-term follow-up. Pediatr Allergy Immunol, 18, 217-223.

8411 Coïsson JD, Cereti E, Garino C, D'Andrea M, Recupero M, Restani P and Arlorio M, 2010. Microchip
8412 capillary electrophoresis (Lab-on-chip®) improves detection of celery (Apium graveolens L.) and
8413 sesame (Sesamum indicum L.) in foods. Food Research International, 43, 1237-1243.

8414 Colgrave ML, Goswami H, Howitt CA and Tanner GJ, 2012. What is in a beer? Proteomic
8415 characterization and relative quantification of hordein (gluten) in beer. J Proteome Res, 11, 386-
8416 396.

8417 Collin P, Reunala T, Pukkala E, Laippala P, Keyrilainen O and Pasternack A, 1994. Coeliac disease--
8418 associated disorders and survival. Gut, 35, 1215-1218.

8419 Collin P, Kaukinen K and Mäki M, 1999. Clinical Features of Celiac Disease Today. Digestive
8420 Diseases, 17, 100-106.

8421 Collin P, Thorell L, Kaukinen K and Maki M, 2004. The safe threshold for gluten contamination in
8422 gluten-free products. Can trace amounts be accepted in the treatment of coeliac disease? Aliment
8423 Pharmacol Ther, 19, 1277-1283.

8424 Comino I, Real A, de Lorenzo L, Cornell H, Lopez-Casado MA, Barro F, Lorite P, Torres MI, Cebolla
8425 A and Sousa C, 2011. Diversity in oat potential immunogenicity: basis for the selection of oat
8426 varieties with no toxicity in coeliac disease. Gut, 60, 915-922.

8427 Connett GJ, Gerez I, Cabrera-Morales EA, Yuenyongviwat A, Ngamphaiboon J, Chatchatee P,
8428 Sangsupawanich P, Soh SE, Yap GC, Shek LP and Lee BW, 2012. A population-based study of
8429 fish allergy in the Philippines, Singapore and Thailand. Int Arch Allergy Immunol, 159, 384-390.

8430 Cooke SK and Sampson HA, 1997. Allergenic properties of ovomucoid in man. J Immunol, 159,
8431 2026-2032.

8432 Cordewener JH, Luykx DM, Frankhuizen R, Bremer MG, Hooijerink H and America AH, 2009.
8433 Untargeted LC-Q-TOF mass spectrometry method for the detection of adulterations in skimmed-
8434 milk powder. J Sep Sci, 32, 1216-1223.

8435 Costa AJ, Sarinho ES, Motta ME, Gomes PN, de Oliveira de Melo SM and da Silva GA, 2011.
8436 Allergy to cow's milk proteins: what contribution does hypersensitivity in skin tests have to this
8437 diagnosis? Pediatr Allergy Immunol, 22, e133-138.

8438 Costa J, Mafra I, Kuchta T and Oliveira MB, 2012a. Single-tube nested real-time PCR as a new highly
8439 sensitive approach to trace hazelnut. J Agric Food Chem, 60, 8103-8110.

8440 Costa J, Mafra I, Carrapatoso I and Oliveira MB, 2012b. Almond allergens: molecular
8441 characterization, detection, and clinical relevance. J Agric Food Chem, 60, 1337-1349.

8442 Costa J, Oliveira MBPP and Mafra I, 2013. Novel approach based on single-tube nested real-time PCR
8443 to detect almond allergens in foods. Food Research International, 51, 228-235.

8444 Cox L, Williams B, Sicherer S, Oppenheimer J, Sher L, Hamilton R and Golden D, 2008. Pearls and
8445 pitfalls of allergy diagnostic testing: report from the American College of Allergy, Asthma and
8446 Immunology/American Academy of Allergy, Asthma and Immunology Specific IgE Test Task
8447 Force. Annals of Allergy, Asthma & Immunology, 101, 580-592.

8448 Crespo JF, Pascual C, Burks AW, Helm RM and Esteban MM, 1995a. Frequency of food allergy in a
8449 pediatric population from Spain. Pediatr Allergy Immunol, 6, 39-43.

8450 Crespo JF, Pascual C, Helm R, Sanchez-Pastor S, Ojeda I, Romualdo L, Martin-Esteban M and Ojeda
8451 JA, 1995b. Cross-reactivity of IgE-binding components between boiled Atlantic shrimp and
8452 German cockroach. Allergy, 50, 918-924.

8453 Crespo JF, Rodriguez J, Vives R, James JM, Reano M, Daroca P, Burbano C and Muzquiz M, 2001.
8454 Occupational IgE-mediated allergy after exposure to lupine seed flour. J Allergy Clin Immunol,
8455 108, 295-297.

8456 Crespo JF, Rodriguez J, James JM, Daroca P, Reano M and Vives R, 2002. Reactivity to potential
8457 cross-reactive foods in fruit-allergic patients: implications for prescribing food avoidance. Allergy,
8458 57, 946-949.

8459 Crespo JF and Rodriguez J, 2003. Food allergy in adulthood. Allergy, 58, 98-113.

8460 Crevel RW, Kerkhoff MA and Koning MM, 2000. Allergenicity of refined vegetable oils. Food Chem
8461 Toxicol, 38, 385-393.

8462 Crevel RW, Cooper KJ, Poulsen LK, Hummelshoj L, Bindslev-Jensen C, Burks AW and Sampson
8463 HA, 2007. Lack of immunogenicity of ice structuring protein type III HPLC12 preparation
8464 administered by the oral route to human volunteers. Food Chem Toxicol, 45, 79-87.

8465 Cuadrado C, Cabanillas B, Pedrosa MM, Muzquiz M, Haddad J, Allaf K, Rodriguez J, Crespo JF and
8466 Burbano C, 2011. Effect of instant controlled pressure drop on IgE antibody reactivity to peanut,
8467 lentil, chickpea and soybean proteins. Int Arch Allergy Immunol, 156, 397-404.

8468 Cucu T, Platteau C, Taverniers I, Devreese B, de Loose M and de Meulenaer B, 2011. ELISA
8469 detection of hazelnut proteins: effect of protein glycation in the presence or absence of wheat
8470 proteins. Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 28, 1-10.

8471 Cucu T, Devreese B, Kerkaert B, Rogge M, Vercruysse L and Meulenaer B, 2012a. ELISA-Based
8472 Detection of Soybean Proteins: A Comparative Study Using Antibodies Against Modified and
8473 Native Proteins. Food Analytical Methods, 5, 1121-1130.

8474 Cucu T, De Meulenaer B and Devreese B, 2012b. MALDI based identification of soybean protein
8475 markers--possible analytical targets for allergen detection in processed foods. Peptides, 33, 187-
8476 196.

8477 Cucu T, De Meulenaer B, Bridts C, Devreese B and Ebo D, 2012c. Impact of thermal processing and
8478 the Maillard reaction on the basophil activation of hazelnut allergic patients. Food and Chemical
8479 Toxicology, 50, 1722-1728.

8480 Cucu T, Devreese B, Trashin S, Kerkaert B, Rogge M and De Meulenaer B, 2012d. Detection of
8481 hazelnut in foods using ELISA: challenges related to the detectability in processed foodstuffs. J
8482 AOAC Int, 95, 149-156.

8483 Cuhra P, Gabrovska D, Rysova J, Hanak P and Stumr F, 2011. ELISA kit for mustard protein
8484 determination: interlaboratory study. J AOAC Int, 94, 605-610.

8485 Cunsolo V, Muccilli V, Saletti R and Foti S, 2012. Mass spectrometry in the proteome analysis of
8486 mature cereal kernels. Mass Spectrom Rev, 31, 448-465.

8487 Curciarello R, Smaldini PL, Candreva AM, González V, Parisi G, Cauerhff A, Barrios I, Blanch LB,
8488 Fossati CA, Petruccelli S and Docena GH, 2014. Targeting a Cross-Reactive Gly m 5 Soy Peptide
8489 as Responsible for Hypersensitivity Reactions in a Milk Allergy Mouse Model. PLoS One, 9,
8490 e82341.

8491 D'Andrea M, Coïsson JD, Travaglia F, Garino C and Arlorio M, 2009. Development and validation of
8492 a SYBR-Green I real-time PCR protocol to detect hazelnut (Corylus avellana L.) in foods through
8493 calibration via plasmid reference standard. J Agric Food Chem, 57, 11201-11208.

8494 D'Agata R, Corradini R, Ferretti C, Zanoli L, Gatti M, Marchelli R and Spoto G, 2010. Ultrasensitive
8495 detection of non-amplified genomic DNA by nanoparticle-enhanced surface plasmon resonance
8496 imaging. Biosensors and Bioelectronics, 25, 2095-2100.

8497 Dahinden I, von Büren M and Lüthy J, 2001. A quantitative competitive PCR system to detect
8498 contamination of wheat, barley or rye in gluten-free food for coeliac patients. European Food
8499 Research and Technology, 212, 228-233.

8500 Dalal I, Binson I, Reifen R, Amitai Z, Shohat T, Rahmani S, Levine A, Ballin A and Somekh E, 2002.
8501 Food allergy is a matter of geography after all: sesame as a major cause of severe IgE-mediated
8502 food allergic reactions among infants and young children in Israel. Allergy, 57, 362-365.

8503 Dalal I, Goldberg M and Katz Y, 2012. Sesame seed food allergy. Curr Allergy Asthma Rep, 12, 339-
8504 345.

8505 Dalby K, Nielsen RG, Kruse-Andersen S, Fenger C, Bindslev-Jensen C, Ljungberg S, Larsen K,
8506 Walsted AM and Husby S, 2010. Eosinophilic oesophagitis in infants and children in the region of
8507 southern Denmark: a prospective study of prevalence and clinical presentation. J Pediatr
8508 Gastroenterol Nutr, 51, 280-282.

8509 Dambacher WM, de Kort EH, Blom WM, Houben GF and de Vries E, 2013. Double-blind placebo-
8510 controlled food challenges in children with alleged cow's milk allergy: prevention of unnecessary
8511 elimination diets and determination of eliciting doses. Nutr J, 12, 22.

8512 Darewicz M, Dziuba B, Minkiewicz P and Dziuba J, 2011. The Preventive Potential of Milk and
8513 Colostrum Proteins and Protein Fragments. Food Reviews International, 27, 357-388.

8514 Daul CB, Morgan JE, Hughes J and Lehrer SB, 1988. Provocation-challenge studies in shrimp-
8515 sensitive individuals. J Allergy Clin Immunol, 81, 1180-1186.

8516 Davis PJ and Williams SC, 1998. Protein modification by thermal processing. Allergy, 53, 102-105.

8517 De Angelis M, Di Cagno R, Minervini F, Rizzello CG and Gobbetti M, 2010. Two-dimensional
8518 electrophoresis and IgE-mediated food allergy. ELECTROPHORESIS, 31, 2126-2136.

8519 de Boissieu D and Dupont C, 2006. Sublingual immunotherapy for cow's milk protein allergy: a
8520 preliminary report. Allergy, 61, 1238-1239.

8521 de Jong NW, van Maaren MS, Vlieg-Boersta BJ, Dubois AE, de Groot H and Gerth van Wijk R, 2010.
8522 Sensitization to lupine flour: is it clinically relevant? Clin Exp Allergy, 40, 1571-1577.

8523 de Jongh HH, Robles CL, Timmerman E, Nordlee JA, Lee PW, Baumert JL, Hamilton RG, Taylor SL
8524 and Koppelman SJ, 2013. Digestibility and IgE-binding of glycosylated codfish parvalbumin.
8525 Biomed Res Int, 2013, 756789.

8526 De Knop KJ, Verweij MM, Grimmelikhuijsen M, Philipse E, Hagendorens MM, Bridts CH, De Clerck
8527 LS, Stevens WJ and Ebo DG, 2011. Age-related sensitization profiles for hazelnut (Corylus
8528 avellana) in a birch-endemic region. Pediatr Allergy Immunol, 22, e139-149.

8529 de la Cruz S, Lopez-Calleja IM, Alcocer M, Gonzalez I, Martin R and Garcia T, 2013. Selection of
8530 recombinant antibodies by phage display technology and application for detection of allergenic
8531 Brazil nut (Bertholletia excelsa) in processed foods. J Agric Food Chem, 61, 10310-10319.

8532 de Leon MP, Glaspole IN, Drew AC, Rolland JM, O'Hehir RE and Suphioglu C, 2003. Immunological
8533 analysis of allergenic cross-reactivity between peanut and tree nuts. Clinical & Experimental
8534 Allergy, 33, 1273-1280.

8535 de Leon MP, Drew AC, Glaspole IN, Suphioglu C, Rolland JM and O'Hehir RE, 2005. Functional
8536 analysis of cross-reactive immunoglobulin E antibodies: peanut-specific immunoglobulin E
8537 sensitizes basophils to tree nut allergens. Clin Exp Allergy, 35, 1056-1064.

8538 de Leon MP, Drew AC, Glaspole IN, Suphioglu C, O'Hehir RE and Rolland JM, 2007. IgE cross-
8539 reactivity between the major peanut allergen Ara h 2 and tree nut allergens. Mol Immunol, 44, 463-
8540 471.

8541 de Luis R, Perez MD, Sanchez L, Lavilla M and Calvo M, 2007. Development of two immunoassay
8542 formats to detect beta-lactoglobulin: influence of heat treatment on beta-lactoglobulin
8543 immunoreactivity and assay applicability in processed food. J Food Prot, 70, 1691-1697.

8544 de Martino M, Novembre E, Galli L, de Marco A, Botarelli P, Marano E and Vierucci A, 1990.
8545 Allergy to different fish species in cod-allergic children: In vivo and in vitro studies. Journal of
8546 Allergy and Clinical Immunology, 86, 909-914.

8547 De Swert LF, Gadisseur R, Sjolander S, Raes M, Leus J and Van Hoeyveld E, 2012. Secondary soy
8548 allergy in children with birch pollen allergy may cause both chronic and acute symptoms. Pediatr
8549 Allergy Immunol, 23, 117-123.

8550 Dean TP, Adler BR, Ruge F and Warner JO, 1993. In vitro allergenicity of cows' milk substitutes. Clin
8551 Exp Allergy, 23, 205-210.

8552 Debnath J, Martin A and Gowda LR, 2009. A polymerase chain reaction directed to detect wheat
8553 glutenin: Implications for gluten-free labelling. Food Research International, 42, 782-787.

8554 Dechamp C, Michel J, Deviller P and Perrin LF, 1984. [Anaphylactic shock to celery and sensitization
8555 to ragweed and mugwort. Crossed or concomitant allergy?]. Presse Med, 13, 871-874.

8556 Declercq J-P, Tinant B, Parello J and Rambaud J, 1991. Ionic interactions with parvalbumins: Crystal
8557 structure determination of pike 4.10 parvalbumin in four different ionic environments. J Mol Biol,
8558 220, 1017-1039.

8559 Demmel A, Hupfer C, Ilg Hampe E, Busch U and Engel KH, 2008. Development of a real-time PCR
8560 for the detection of lupine DNA (lupinus species) in foods. J Agric Food Chem, 56, 4328-4332.

8561 Demmel A, Hupfer C, Busch U and Engel K-H, 2011. Detection of lupine (Lupinus spp.) DNA in
8562 processed foods using real-time PCR. Food Control, 22, 215-220.

8563 Demoncheaux JP, Michel R, Mazenot C, Duflos G, Iacini C, de Laval F, Saware EM and Renard JC,
8564 2012. A large outbreak of scombroid fish poisoning associated with eating yellowfin tuna
8565 (Thunnus albacares) at a military mass catering in Dakar, Senegal. Epidemiol Infect, 140, 1008-
8566 1012.

8567 Denery-Papini S, Bodinier M, Pineau F, Triballeau S, Tranquet O, Adel-Patient K, Moneret-Vautrin
8568 DA, Bakan B, Marion D, Mothes T, Mameri H and Kasarda D, 2011. Immunoglobulin-E-binding
8569 epitopes of wheat allergens in patients with food allergy to wheat and in mice experimentally
8570 sensitized to wheat proteins. Clin Exp Allergy, 41, 1478-1492.

8571 Derby CJ, Gowland MH and Hourihane JO, 2005. Sesame allergy in Britain: a questionnaire survey of
8572 members of the Anaphylaxis Campaign. Pediatr Allergy Immunol, 16, 171-175.

8573 Dermatitis ETFoA, 1993. Severity scoring of atopic dermatitis: the SCORAD index. Consensus
8574 Report of the European Task Force on Atopic Dermatitis. Dermatology, 186, 23-31.

8575 Devenney I, Norrman G, Oldaeus G, Strömberg L and Fälth-Magnusson K, 2006. A new model for
8576 low-dose food challenge in children with allergy to milk or egg. Acta Pædiatrica, 95, 1133-1139.

8577 Di Luccia A, Lamacchia C, Mamone G, Picariello G, Trani A, Masi P and Addeo F, 2009. Application
8578 of capillary electrophoresis to determine the technological properties of wheat flours by a glutenin
8579 index. J Food Sci, 74, C307-311.

8580 Diaz-Amigo C, 2010. Towards a Comprehensive Validation of ELISA Kits for Food Allergens: Case
8581 1—Egg. Food Analytical Methods, 3, 344-350.

8582 Diaz-Amigo C and Popping B, 2012. Gluten and gluten-free: issues and considerations of labeling
8583 regulations, detection methods, and assay validation. J AOAC Int, 95, 337-348.

8584 Diaz-Amigo C and Popping B, 2013. Accuracy of ELISA Detection Methods for Gluten and
8585 Reference Materials: A Realistic Assessment. J Agric Food Chem.

8586 Diaz-Perales A, Collada C, Blanco C, Sánchez-Monge R, Carrillo T, Aragoncillo C and Salcedo G,
8587 1998. Class I chitinases with hevein-like domain, but not class II enzymes, are relevant chestnut
8588 and avocado allergens. Journal of Allergy and Clinical Immunology, 102, 127-133.

8589 Diaz-Perales A, Collada C, Blanco C, Sanchez-Monge R, Carrillo T, Aragoncillo C and Salcedo G,
8590 1999. Cross-reactions in the latex-fruit syndrome: A relevant role of chitinases but not of complex
8591 asparagine-linked glycans. Journal of Allergy and Clinical Immunology, 104, 681-687.

8592 Djurtoft R, Pedersen HS, Aabin B and Barkholt V, 1991. Studies of food allergens: soybean and egg
8593 proteins. Adv Exp Med Biol, 289, 281-293.

8594 Docena GH, Fernandez R, Chirdo FG and Fossati CA, 1996. Identification of casein as the major
8595 allergenic and antigenic protein of cow's milk. Allergy, 51, 412-416.

8596 Dohi M, Suko M, Sugiyama H, Yamashita N, Tadokoro K, Juji F, Okudaira H, Sano Y, Ito K and
8597 Miyamoto T, 1991. Food-dependent, exercise-induced anaphylaxis: a study on 11 Japanese cases. J
8598 Allergy Clin Immunol, 87, 34-40.

8599 Doi H, Touhata Y, Shibata H, Sakai S, Urisu A, Akiyama H and Teshima R, 2008. Reliable enzyme-
8600 linked immunosorbent assay for the determination of walnut proteins in processed foods. J Agric
8601 Food Chem, 56, 7625-7630.

8602 Dong-Hwa S, Hyun-Jung K, Soo-Ho K and Bo-Yeon K, 2010. Enzyme-linked immunosorbent assay
8603 for the detection of hen's egg proteins in processed foods. Korean Food Sci Anim Resour, 30, 36-
8604 41.

8605 Donnelly SC, Ellis HJ and Ciclitira PJ, 2011. Pharmacotherapy and management strategies for coeliac
8606 disease. Expert Opin Pharmacother, 12, 1731-1744.

8607 Dooper MM, Holden L, Faeste CK, Thompson KM and Egaas E, 2007. Monoclonal antibodies against
8608 the candidate lupin allergens alpha-conglutin and beta-conglutin. Int Arch Allergy Immunol, 143,
8609 49-58.

8610 Dooper MM, Plassen C, Holden L, Lindvik H and Faeste CK, 2009. Immunoglobulin E cross-
8611 reactivity between lupine conglutins and peanut allergens in serum of lupine-allergic individuals. J
8612 Investig Allergol Clin Immunol, 19, 283-291.

8613 Dory D, Chopin C, Aimone-Gastin I, Gueant JL, Guerin L, Sainte-Laudy J, Moneret-Vautrin DA and
8614 Fleurence J, 1998. Recognition of an extensive range of IgE-reactive proteins in cod extract.
8615 Allergy, 53, 42-50.

8616 Douglas JD, McSharry C, Blaikie L, Morrow T, Miles S and Franklin D, 1995. Occupational asthma
8617 caused by automated salmon processing. Lancet, 346, 737-740.

8618 Dragoni I, Balzaretti C, Rossini S, Rossi L, Dell'Orto V and Baldi A, 2011. Detection of Hen
8619 Lysozyme on Proteic Profiles of Grana Padano Cheese through SELDI-TOF MS High-Throughput
8620 Technology during the Ripening Process. Food Analytical Methods, 4, 233-239.

8621 Drug and Therapeutics Bulletin, 2013. Management of infantile colic. BMJ, 347.

8622 Du Toit G, Katz Y, Sasieni P, Mesher D, Maleki SJ, Fisher HR, Fox AT, Turcanu V, Amir T, Zadik-
8623 Mnuhin G, Cohen A, Livne I and Lack G, 2008. Early consumption of peanuts in infancy is
8624 associated with a low prevalence of peanut allergy. J Allergy Clin Immunol, 122, 984-991.

8625 Dumont V, Kerbach S, Poms R, Johnson P, Mills C, Popping B, Tömösközi S and Delahaut P, 2010.
8626 Development of milk and egg incurred reference materials for the validation of food allergen
8627 detection methods. Quality Assurance and Safety of Crops & Foods, 2, 208-215.

8628 Dupont C, Kalach N, Soulaines P, Legoue-Morillon S, Piloquet H and Benhamou PH, 2010. Cow's
8629 milk epicutaneous immunotherapy in children: a pilot trial of safety, acceptability, and impact on
8630 allergic reactivity. J Allergy Clin Immunol, 125, 1165-1167.

8631 Dupont C, 2011. Food allergy: recent advances in pathophysiology and diagnosis. Ann Nutr Metab, 59
8632 Suppl 1, 8-18.

8633 Dupont D and Muller-Renaud S, 2006. Quantification of proteins in dairy products using an optical
8634 biosensor. J AOAC Int, 89, 843-848.

8635 Duranti M, Sironi E, Magni C, Sessa F and Scarafoni A, 2005. Biological activity, traceability and
8636 potential allergenicity of selected lupin proteins. Aracne publ, Rome, 121-129.

8637 Ebo DG, Ahrazem O, Lopez-Torrejon G, Bridts CH, Salcedo G and Stevens WJ, 2007. Anaphylaxis
8638 from mandarin (Citrus reticulata): identification of potential responsible allergens. Int Arch Allergy
8639 Immunol, 144, 39-43.

8640 Ebo DG, Kuehn A, Bridts CH, Hilger C, Hentges F and Stevens WJ, 2010a. Monosensitivity to
8641 pangasius and tilapia caused by allergens other than parvalbumin. J Investig Allergol Clin
8642 Immunol, 20, 84-88.

8643 Ebo DG, Bridts CH, Verweij MM, De Knop KJ, Hagendorens MM, De Clerck LS and Stevens WJ,
8644 2010b. Sensitization profiles in birch pollen-allergic patients with and without oral allergy
8645 syndrome to apple: lessons from multiplexed component-resolved allergy diagnosis. Clin Exp
8646 Allergy, 40, 339-347.

8647 Ecker C and Cichna-Markl M, 2012. Development and validation of a sandwich ELISA for the
8648 determination of potentially allergenic lupine in food. Food Chemistry, 130, 759-766.

8649 EFSA, 2004. Opinion of the Scientific Panel on Dietetic products, nutrition and allergies [NDA] on a
8650 request from the Commission relating to the evaluation of allergenic foods for labelling purposes.
8651 The EFSA Journal, 32, 1-197.

8652 EFSA, 2005a. Opinion of the Scientific Panel on Dietetic products, nutrition and allergies (NDA)
8653 related to the evaluation of molluscs for labelling purposes. The EFSA Journal, 302, 1-11.

8654 EFSA, 2005b. Opinion of the Scientific Panel on Dietetic products, nutrition and allergies [NDA]
8655 related to the evaluation of lupin for labelling purposes. The EFSA Journal, 302, 1-11.

8656 EFSA, 2010. Scientific Opinion on the assessment of allergenicity of GM plants and microorganisms
8657 and derived food and feed (Annex 3). EFSA Journal, 8:1700.

8658 EFSA Panel on Biological Hazards (BIOHAZ), 2010. Scientific Opinion on risk assessment of
8659 parasites in fishery products. EFSA Journal 2010; 8(4):1543, 91 pp.

8660 Egger M, Hauser M, Mari A, Ferreira F and Gadermaier G, 2010. The role of lipid transfer proteins in
8661 allergic diseases. Curr Allergy Asthma Rep, 10, 326-335.

8662 Egger M, Alessandri C, Wallner M, Briza P, Zennaro D, Mari A, Ferreira F and Gadermaier G, 2011.
8663 Is aboriginal food less allergenic? Comparing IgE-reactivity of eggs from modern and ancient
8664 chicken breeds in a cohort of allergic children. PLoS One, 6, e19062.

8665 Eggesbo M, Halvorsen R, Tambs K and Botten G, 1999. Prevalence of parentally perceived adverse
8666 reactions to food in young children. Pediatr Allergy Immunol, 10, 122-132.

8667 Eggesbo M, Botten G, Halvorsen R and Magnus P, 2001. The prevalence of allergy to egg: a
8668 population-based study in young children. Allergy, 56, 403-411.

8669 Ehlert A, Hypter C, Demmel A, Engel K and Busch U, 2008. Detection of cashew nut in foods by a
8670 specific real-time PCR method. Food Analytical Methods, 1, 136-143.

8671 Ehlert A, Demmel A, Hupfer C, Busch U and Engel KH, 2009. Simultaneous detection of DNA from
8672 10 food allergens by ligation-dependent probe amplification. Food Addit Contam Part A Chem
8673 Anal Control Expo Risk Assess, 26, 409-418.

8674 Ehn BM, Ekstrand B, Bengtsson U and Ahlstedt S, 2004. Modification of IgE binding during heat
8675 processing of the cow's milk allergen beta-lactoglobulin. J Agric Food Chem, 52, 1398-1403.

8676 Ehn BM, Allmere T, Telemo E, Bengtsson U and Ekstrand B, 2005. Modification of IgE binding to
8677 beta-lactoglobulin by fermentation and proteolysis of cow's milk. J Agric Food Chem, 53, 3743-
8678 3748.

8679 Eigenmann PA, Burks AW, Bannon GA and Sampson HA, 1996. Identification of unique peanut and
8680 soy allergens in sera adsorbed with cross-reacting antibodies. J Allergy Clin Immunol, 98, 969-978.

8681 Eigenmann PA and Sampson HA, 1998. Interpreting skin prick tests in the evaluation of food allergy
8682 in children. Pediatr Allergy Immunol, 9, 186-191.

8683 Eigenmann PA, Beyer K, Wesley Burks A, Lack G, Liacouras CA, Hourihane JO, Sampson HA and
8684 Sodergren E, 2008. New visions for food allergy: an iPAC summary and future trends. Pediatr
8685 Allergy Immunol, 19 Suppl 19, 26-39.

8686 Eischeid AC, Kim BH and Kasko SM, 2013. Two quantitative real-time PCR assays for the detection
8687 of penaeid shrimp and blue crab, crustacean shellfish allergens. J Agric Food Chem, 61, 5669-
8688 5674.

8689 Eissa S, L'Hocine L, Siaj M and Zourob M, 2013. A grapheme-based label-free voltammetric
8690 immunosensor for sensitive detection of the egg allergen ovalbumin. Analyst, 138, 4378-4384.

8691 El-Ghaish S, Rabesona H, Choiset Y, Sitohy M, Haertle T and Chobert JM, 2011a. Proteolysis by
8692 Lactobacillus fermentum IFO3956 isolated from Egyptian milk products decreases immuno-
8693 reactivity of alphaS1-casein. J Dairy Res, 1-8.

8694 El-Ghaish S, Ahmadova A, Hadji-Sfaxi I, El Mecherfi KE, Bazukyan I, Choiset Y, Rabesona H,
8695 Sitohy M, Popov YG, Kuliev AA, Mozzi F, Chobert J-M and Haertlé T, 2011b. Potential use of
8696 lactic acid bacteria for reduction of allergenicity and for longer conservation of fermented foods.
8697 Trends in Food Science & Technology, 22, 509-516.

8698 El-Hodhod MA, Younis NT, Zaitoun YA and Daoud SD, 2010. Cow's milk allergy related pediatric
8699 constipation: appropriate time of milk tolerance. Pediatr Allergy Immunol, 21, e407-412.

8700 Elizur A, Rajuan N, Goldberg MR, Leshno M, Cohen A and Katz Y, 2012. Natural course and risk
8701 factors for persistence of IgE-mediated cow's milk allergy. J Pediatr, 161, 482-487 e481.

8702 Eller E, Kjaer HF, Host A, Andersen KE and Bindslev-Jensen C, 2009. Food allergy and food
8703 sensitization in early childhood: results from the DARC cohort. Allergy, 64, 1023-1029.

8704 Eller E, Hansen TK and Bindslev-Jensen C, 2012. Clinical thresholds to egg, hazelnut, milk and
8705 peanut: results from a single-center study using standardized challenges. Ann Allergy Asthma
8706 Immunol, 108, 332-336.

8707 Elsayed S and Aas K, 1971. Characterization of a major allergen (cod). Observations on effect of
8708 denaturation on the allergenic activity. J Allergy, 47, 283-291.

8709 Elsayed S and Apold J, 1983. Immunochemical Analysis of Cod Fish Allergen M: Locations of the
8710 Immunoglobulin Binding Sites as Demonstrated by the Native and Synthetic Peptides. Allergy, 38,
8711 449-459.

8712 Emmett SE, Angus FJ, Fry JS and Lee PN, 1999. Perceived prevalence of peanut allergy in Great
8713 Britain and its association with other atopic conditions and with peanut allergy in other household
8714 members. Allergy, 54, 380-385.

8715 Emoto A, Ishizaki S and Shiomi K, 2009. Tropomyosins in gastropods and bivalves: Identification as
8716 major allergens and amino acid sequence features. Food Chemistry, 114, 634-641.

8717 Enrique E, Malek T, Pineda F, Palacios R, Bartra J, Tella R, Basagana M, Alonso R and Cistero-
8718 Bahima A, 2008. Sublingual immunotherapy for hazelnut food allergy: a follow-up study. Ann
8719 Allergy Asthma Immunol, 100, 283-284.

8720 Eriksson NE, Moller C, Werner S, Magnusson J, Bengtsson U and Zolubas M, 2004. Self-reported
8721 food hypersensitivity in Sweden, Denmark, Estonia, Lithuania, and Russia. J Investig Allergol Clin
8722 Immunol, 14, 70-79.

8723 Errahali Y, Morisset M, Moneret-Vautrin DA, Kanny G, Metche M, Nicolas JP and Fremont S, 2002.
8724 Allergen in soy oils. Allergy, 57, 648-649.

8725 Errahali Y, Kanny G, Morisset M, Cren-Olive C, Rolando C, Metche M, Moneret-Vautrin DA,
8726 Nicolas JP and Fremont S, 2004. Sequencing of soy oil and soy lecithin allergens. Journal of
8727 Allergy and Clinical Immunology, 113, S152.

8728 Escudero R, Gamboa PM, Anton J and Sanz ML, 2007. Food allergy due to trout roe. J Investig
8729 Allergol Clin Immunol, 17, 346-347.

8730 Espineira M, Herrero B, Vieites JM and Santaclara FJ, 2010. Validation of end-point and real-time
8731 PCR methods for the rapid detection of soy allergen in processed products. Food Addit Contam
8732 Part A Chem Anal Control Expo Risk Assess, 27, 426-432.

8733 Estrada-Girón Y, Swanson BG and Barbosa-Cánovas GV, 2005. Advances in the use of high
8734 hydrostatic pressure for processing cereal grains and legumes. Trends in Food Science &
8735 Technology, 16, 194-203.

8736 Ewan PW, 1996. Clinical study of peanut and nut allergy in 62 consecutive patients: new features and
8737 associations. BMJ, 312, 1074-1078.

8738 Faeste CK, Lovik M, Wiker HG and Egaas E, 2004. A case of peanut cross-allergy to lupine flour in a
8739 hot dog bread. Int Arch Allergy Immunol, 135, 36-39.

8740 Faeste CK, Holden L, Plassen C and Almli B, 2006. Sensitive time-resolved fluoroimmunoassay for
8741 the detection of hazelnut (Corylus avellana) protein traces in food matrices. J Immunol Methods,
8742 314, 114-122.

8743 Faeste CK and Plassen C, 2008. Quantitative sandwich ELISA for the determination of fish in foods. J
8744 Immunol Methods, 329, 45-55.

8745 Falcao H, Lunet N, Lopes C and Barros H, 2004. Food hypersensitivity in Portuguese adults. Eur J
8746 Clin Nutr, 58, 1621-1625.

8747 FAO/WHO, 2001. Evaluation of allergenicity of genetically modified food. Report of a joint
8748 FAO/WHO expert consultation on allergenicity of foods derived from biotechnology. Food and
8749 Agriculture Organization of the United Nations (FAO). Rome, Italy.

8750 Fasano A and Catassi C, 2001. Current approaches to diagnosis and treatment of celiac disease: an
8751 evolving spectrum. Gastroenterology, 120, 636-651.

8752 Fasoli E, Aldini G, Regazzoni L, Kravchuk AV, Citterio A and Righetti PG, 2010. Les Maitres de
8753 l'Orge: the proteome content of your beer mug. J Proteome Res, 9, 5262-5269.

8754 FDA (Food and Drug Administration), 1985. Ad Hoc Review Group. The re-examination of the
8755 GRAS status of sulphiting agents, prepared for the Center for Food Safety and Applied Nutrition,
8756 Food and Drug Administration, Washington D.C., Federation of American Societies for
8757 Experimental Biology, 96.

8758 FDA (Food and Drug Administration), 1996. Sulphites safe for most, dangerous for some. FDA
8759 Consumer, the magazine of the Food and Drug Administration Vol. 30, December 1996.

8760 FDA (Food and Drug Administration), 2006. Approaches to establish thresholds for major food
8761 allergens and for gluten in food. Threshold Report, 1-108.

8762 Fernandes J, Reshef A, Patton L, Ayuso R, Reese G and Lehrer SB, 2003. Immunoglobulin E antibody
8763 reactivity to the major shrimp allergen, tropomyosin, in unexposed Orthodox Jews. Clinical &
8764 Experimental Allergy, 33, 956-961.

8765 Fernandez-Rivas M, Benito C, Gonzalez-Mancebo E and de Durana DA, 2008. Allergies to fruits and
8766 vegetables. Pediatr Allergy Immunol, 19, 675-681.

8767 Ferreira F, Hawranek T, Gruber P, Wopfner N and Mari A, 2004. Allergic cross-reactivity: from gene
8768 to the clinic. Allergy, 59, 243-267.

8769 Fielder R, Higgs W and Barden K, 2010. Nut allergen detection. In: Molecular Biological and
8770 Immunological Techniques and Applications for Food Chemists. Eds Popping B, Diaz-Amigo C,
8771 Hoenicke K. J Wiley & Sons, Inc, 377-406.

8772 Figueroa J, Blanco C, Dumpierrez AG, Almeida L, Ortega N, Castillo R, Navarro L, Perez E, Gallego
8773 MD and Carrillo T, 2005. Mustard allergy confirmed by double-blind placebo-controlled food
8774 challenges: clinical features and cross-reactivity with mugwort pollen and plant-derived foods.
8775 Allergy, 60, 48-55.

8776 Filik H and Cetintas G, 2012. Determination of Sulfite in Water and Dried Fruit Samples by
8777 Dispersive Liquid-Liquid Microextraction Combined with UV-Vis Fiber Optic Linear Array
8778 Spectrophotometry. Food Analytical Methods, 5, 1362-1367.

8779 Fiocchi A, Restani P, Riva E, Qualizza R, Bruni P, Restelli AR and Galli CL, 1995. Meat allergy: I--
8780 Specific IgE to BSA and OSA in atopic, beef sensitive children. J Am Coll Nutr, 14, 239-244.

8781 Fiocchi A, Restani P, Leo G, Martelli A, Bouygue GR, Terracciano L, Ballabio C and Valsasina R,
8782 2003a. Clinical tolerance to lactose in children with cow's milk allergy. Pediatrics, 112, 359-362.

8783 Fiocchi A, Travaini M, D'Auria E, Banderali G, Bernardo L and Riva E, 2003b. Tolerance to a rice
8784 hydrolysate formula in children allergic to cow's milk and soy. Clin Exp Allergy, 33, 1576-1580.

8785 Fiocchi A, Terracciano L, Bouygue GR, Veglia F, Sarratud T, Martelli A and Restani P, 2008.
8786 Incremental prognostic factors associated with cow's milk allergy outcomes in infant and child
8787 referrals: the Milan Cow's Milk Allergy Cohort study. Ann Allergy Asthma Immunol, 101, 166-
8788 173.

8789 Fiocchi A, Sarratud P, Terracciano L, Vacca E, Bernardini R, Fuggetta D, Ballabio C, Duranti M,
8790 Magni C and Restani P, 2009. Assessment of the tolerance to lupine-enriched pasta in peanut-
8791 allergic children. Clin Exp Allergy, 39, 1045-1051.

8792 Fiocchi A, Brozek J, Schunemann H, Bahna SL, von Berg A, Beyer K, Bozzola M, Bradsher J,
8793 Compalati E, Ebisawa M, Guzman MA, Li H, Heine RG, Keith P, Lack G, Landi M, Martelli A,
8794 Rance F, Sampson H, Stein A, Terracciano L, Vieths S and World Allergy Organization Special
8795 Committee on Food A, 2010. World Allergy Organization (WAO) Diagnosis and Rationale for
8796 Action against Cow's Milk Allergy (DRACMA) Guidelines. Pediatr Allergy Immunol, 21 Suppl
8797 21, 1-125.

8798 Fisher HR, du Toit G and Lack G, 2011. Specific oral tolerance induction in food allergic children: is
8799 oral desensitisation more effective than allergen avoidance?: a meta-analysis of published RCTs.
8800 Arch Dis Child, 96, 259-264.

8801 Flais MJ, Kim SS, Harris KE and Greenberger PA, 2004. Salmon Caviar-Induced Anaphylactic
8802 Shock. Allergy and Asthma Proceedings, 25, 233-236.

8803 Fleischer AB, Jr., 2008. Diagnosis and management of common dermatoses in children: atopic,
8804 seborrheic, and contact dermatitis. Clin Pediatr (Phila), 47, 332-346.

8805 Fleischer DM, Conover-Walker MK, Christie L, Burks AW and Wood RA, 2003. The natural
8806 progression of peanut allergy: Resolution and the possibility of recurrence. J Allergy Clin
8807 Immunol, 112, 183-189.

8808 Fleischer DM, Conover-Walker MK, Christie L, Burks AW and Wood RA, 2004. Peanut allergy:
8809 recurrence and its management. J Allergy Clin Immunol, 114, 1195-1201.

8810 Fleischer DM, Conover-Walker MK, Matsui EC and Wood RA, 2005. The natural history of tree nut
8811 allergy. J Allergy Clin Immunol, 116, 1087-1093.

8812 Fleischer DM, 2007. The natural history of peanut and tree nut allergy. Curr Allergy Asthma Rep, 7,
8813 175-181.

8814 Fleischer DM, Spergel JM, Assa'ad AH and Pongracic JA, 2013. Primary Prevention of Allergic
8815 Disease Through Nutritional Interventions. The Journal of Allergy and Clinical Immunology: In
8816 Practice, 1, 29-36.

8817 Flinterman AE, Pasmans SG, Hoekstra MO, Meijer Y, van Hoffen E, Knol EF, Hefle SL, Bruijnzeel-
8818 Koomen CA and Knulst AC, 2006a. Determination of no-observed-adverse-effect levels and
8819 eliciting doses in a representative group of peanut-sensitized children. J Allergy Clin Immunol,
8820 117, 448-454.

8821 Flinterman AE, Knulst AC, Meijer Y, Bruijnzeel-Koomen CA and Pasmans SG, 2006b. Acute allergic
8822 reactions in children with AEDS after prolonged cow's milk elimination diets. Allergy, 61, 370-
8823 374.

8824 Flinterman AE, van Hoffen E, den Hartog Jager CF, Koppelman S, Pasmans SG, Hoekstra MO,
8825 Bruijnzeel-Koomen CA, Knulst AC and Knol EF, 2007. Children with peanut allergy recognize
8826 predominantly Ara h2 and Ara h6, which remains stable over time. Clin Exp Allergy, 37, 1221-
8827 1228.

8828 Foley RC, Gao LL, Spriggs A, Soo LY, Goggin DE, Smith PM, Atkins CA and Singh KB, 2011.
8829 Identification and characterisation of seed storage protein transcripts from Lupinus angustifolius.
8830 BMC Plant Biol, 11, 59.

8831 Foong R, Logan K, Fox A and du Toit G, 2013. Clinical characteristics of- and predictive diagnostic
8832 factors for- sesame seed allergy in food-allergic children. Current allergy and Clinical
8833 immunology, 26, 78-81.

8834 Foss N and Frökiær H, 2005. Lupin allergenicity explored in the cholera toxin model of food allergy.
8835 Aracne publ, Rome, 185-194.

8836 Fotisch K, Altmann F, Haustein D and Vieths S, 1999. Involvement of carbohydrate epitopes in the
8837 IgE response of celery-allergic patients. Int Arch Allergy Immunol, 120, 30-42.

8838 Foucard T and Malmheden Yman I, 1999. A study on severe food reactions in Sweden – is soy protein
8839 an underestimated cause of food anaphylaxis? Allergy, 54, 261-265.

8840 Fox AT, Sasieni P, du Toit G, Syed H and Lack G, 2009. Household peanut consumption as a risk
8841 factor for the development of peanut allergy. Journal of Allergy and Clinical Immunology, 123,
8842 417-423.

8843 France RM, Sellers DS and Grossman SH, 1997. Purification, characterization, and hydrodynamic
8844 properties of arginine kinase from gulf shrimp (Penaeus aztecus). Arch Biochem Biophys, 345, 73-
8845 78.

8846 Fremont S, Kanny G, Nicolas JP and Moneret-Vautrin DA, 1997. Prevalence of lysozyme
8847 sensitization in an egg-allergic population. Allergy, 52, 224-228.

8848 Fremont S, Zitouni N, Kanny G, Veneri V, Metche M, Moneret-Vautrin DA and Nicolas JP, 2002.
8849 Allergenicity of some isoforms of white sesame proteins. Clinical & Experimental Allergy, 32,
8850 1211-1215.

8851 Frias J, Song YS, Martinez-Villaluenga C, Gonzalez de Mejia E and Vidal-Valverde C, 2008.
8852 Immunoreactivity and amino acid content of fermented soybean products. J Agric Food Chem, 56,
8853 99-105.

8854 Fries JH, 1982. Peanuts: allergic and other untoward reactions. Ann Allergy, 48, 220-226.

8855 Frongia O and Bellamo AR, 2005. Food allergies and intolerance in infants and children. Medico
8856 Bambino, 24, 533-538.

8857 Fu TJ, Abbott UR and Hatzos C, 2002. Digestibility of food allergens and nonallergenic proteins in
8858 simulated gastric fluid and simulated intestinal fluid-a comparative study. J Agric Food Chem, 50,
8859 7154-7160.

8860 Fu TJ, Maks N and Banaszewski K, 2010. Effect of heat treatment on the quantitative detection of egg
8861 protein residues by commercial enzyme-linked immunosorbent assay test kits. J Agric Food Chem,
8862 58, 4831-4838.

8863 Fu TJ and Maks N, 2013. Impact of thermal processing on ELISA detection of peanut allergens. J
8864 Agric Food Chem, 61, 5649-5658.

8865 Fuchs M, Cichna-Markl M and Hochegger R, 2010. Development and Validation of a Real-Time PCR
8866 Method for the Detection of White Mustard (Sinapis alba) in Foods. J Agric Food Chem.

8867 Fuchs M, Cichna-Markl M and Hochegger R, 2013. Development and validation of a duplex real-time
8868 PCR method for the simultaneous detection of celery and white mustard in food. Food Chem, 141,
8869 229-235.

8870 Fukutomi Y, Sjolander S, Nakazawa T, Borres MP, Ishii T, Nakayama S, Tanaka A, Taniguchi M,
8871 Saito A, Yasueda H, Nakamura H and Akiyama K, 2012. Clinical relevance of IgE to recombinant
8872 Gly m 4 in the diagnosis of adult soybean allergy. J Allergy Clin Immunol, 129, 860-863 e863.

8873 Fuller HR, Goodwin PR and Morris GE, 2006. An enzyme-linked immunosorbent assay (ELISA) for
8874 the major crustacean allergen, tropomyosin, in food. Food and Agricultural Immunology, 17, 43-
8875 52.

8876 Furlong TJ, DeSimone J and Sicherer SH, 2001. Peanut and tree nut allergic reactions in restaurants
8877 and other food establishments. J Allergy Clin Immunol, 108, 867-870.

8878 Gadermaier G, Egger M, Girbl T, Erler A, Harrer A, Vejvar E, Liso M, Richter K, Zuidmeer L, Mari
8879 A and Ferreira F, 2011a. Molecular characterization of Api g 2, a novel allergenic member of the
8880 lipid-transfer protein 1 family from celery stalks. Mol Nutr Food Res, 55, 568-577.

8881 Gadermaier G, Hauser M, Egger M, Ferrara R, Briza P, Souza Santos K, Zennaro D, Girbl T,
8882 Zuidmeer-Jongejan L, Mari A and Ferreira F, 2011b. Sensitization Prevalence, Antibody Cross-
8883 Reactivity and Immunogenic Peptide Profile of Api g 2, the Non-Specific Lipid Transfer Protein 1
8884 of Celery. PLoS One, 6, e24150.

8885 Galland AV, Dory D, Pons L, Chopin C, Rabesona H, Guéant JL and Fleurence J, 1998. Purification
8886 of a 41 kDa cod-allergenic protein. Journal of Chromatography B: Biomedical Sciences and
8887 Applications, 706, 63-71.

8888 Ganglberger E, Radauer C, Grimm R, Hoffmann-Sommergruber K, Breiteneder H, Scheiner O and
8889 Jensen-Jarolim E, 2000. N-terminal sequences of high molecular weight allergens from celery
8890 tuber. Clin Exp Allergy, 30, 566-570.

8891 Garber EA and Perry J, 2010. Detection of hazelnuts and almonds using commercial ELISA test kits.
8892 Anal Bioanal Chem, 396, 1939-1945.

8893 García-Orozco KD, Aispuro-Hernandez E, Yepiz-Plascencia G, Calderon-de-la-Barca AM and Sotelo-
8894 Mundo RR, 2007. Molecular characterization of arginine kinase, an allergen from the shrimp
8895 Litopenaeus vannamei. Int Arch Allergy Immunol, 144, 23-28.

8896 García E, Llorente M, Hernando A, Kieffer R, Wieser H and Mendez E, 2005. Development of a
8897 general procedure for complete extraction of gliadins for heat processed and unheated foods. Eur J
8898 Gastroenterol Hepatol, 17, 529-539.

8899 Garino C, Zuidmeer L, Marsh J, Lovegrove A, Morati M, Versteeg S, Schilte P, Shewry P, Arlorio M
8900 and van Ree R, 2010. Isolation, cloning, and characterization of the 2S albumin: a new allergen
8901 from hazelnut. Mol Nutr Food Res, 54, 1257-1265.

8902 Gaskin FE and Taylor SL, 2011. Sandwich enzyme-linked immunosorbent assay (ELISA) for
8903 detection of cashew nut in foods. J Food Sci, 76, T218-226.

8904 Gatti M and Ferrett iC, 2010. Soy Allergen Detection, in Molecular Biological and Immunological
8905 Techniques and Applications for Food Chemists . John Wiley & Sons, Inc., Hoboken, NJ, USA.

8906 Gayraud J, Mairesse M, Fontaine JF, Thillay A, Leduc V, Rance F, Parisot L and Moneret-Vautrin
8907 DA, 2009. The prevalence of sensitization to lupin flour in France and Belgium: a prospective
8908 study in 5,366 patients, by the Allergy Vigilance Network. Eur Ann Allergy Clin Immunol, 41, 17-
8909 22.

8910 Gelincik A, Buyukozturk S, Gul H, Isik E, Issever H, Ozseker F, Colakoglu B, Dal M, Ayvaz O,
8911 Gungor G and Akkor A, 2008. Confirmed prevalence of food allergy and non-allergic food
8912 hypersensitivity in a Mediterranean population. Clin Exp Allergy, 38, 1333-1341.

8913 Gendel SM and Jenkins JA, 2006. Allergen sequence databases. Mol Nutr Food Res, 50, 633-637.

8914 Gendel SM, 2009. Allergen databases and allergen semantics. Regulatory Toxicology and
8915 Pharmacology, 54, S7-S10.

8916 Genuneit J, Cantelmo JL, Weinmayr G, Wong GW, Cooper PJ, Riikjarv MA, Gotua M, Kabesch M,
8917 von Mutius E, Forastiere F, Crane J, Nystad W, El-Sharif N, Batlles-Garrido J, Garcia-Marcos L,
8918 Garcia-Hernandez G, Morales-Suarez-Varela M, Nilsson L, Braback L, Saraclar Y, Weiland SK,
8919 Cookson WO, Strachan D, Moffatt MF and Group IPS, 2009. A multi-centre study of candidate
8920 genes for wheeze and allergy: the International Study of Asthma and Allergies in Childhood Phase
8921 2. Clin Exp Allergy, 39, 1875-1888.

8922 Germini A, Scaravelli E, Lesignoli F, Sforza S, Corradini R and Marchelli R, 2005. Polymerase chain
8923 reaction coupled with peptide nucleic acid high-performance liquid chromatography for the
8924 sensitive detection of traces of potentially allergenic hazelnut in foodstuffs. European Food
8925 Research and Technology, 220, 619-624.

8926 Giampietro PG, Ragno V, Daniele S, Cantani A, Ferrara M and Businco L, 1992. Soy hypersensitivity
8927 in children with food allergy. Ann Allergy, 69, 143-146.

8928 Giampietro PG, Kjellman NI, Oldaeus G, Wouters-Wesseling W and Businco L, 2001.
8929 Hypoallergenicity of an extensively hydrolyzed whey formula. Pediatr Allergy Immunol, 12, 83-
8930 86.

8931 Glaspole IN, de Leon MP, Prickett SR, O'Hehir RE and Rolland JM, 2011. Clinical allergy to hazelnut
8932 and peanut: identification of T cell cross-reactive allergens. Int Arch Allergy Immunol, 155, 345-
8933 354.

8934 Godoy-Navajas J, Aguilar Caballos MP and Gomez-Hens A, 2011. Heterogeneous immunoassay for
8935 soy protein determination using nile blue-doped silica nanoparticles as labels and front-surface
8936 long-wavelength fluorimetry. Anal Chim Acta, 701, 194-199.

8937 Goetz DW and Whisman BA, 2000. Occupational asthma in a seafood restaurant worker: cross-
8938 reactivity of shrimp and scallops. Annals of Allergy, Asthma & Immunology, 85, 461-466.

8939 Goetz DW, Whisman BA and Goetz AD, 2005. Cross-reactivity among edible nuts: double
8940 immunodiffusion, crossed immunoelectrophoresis, and human specific IgE serologic surveys.
8941 Annals of Allergy, Asthma & Immunology, 95, 45-52.

8942 Goggin DE, Mir G, Smith WB, Stuckey M and Smith PM, 2008. Proteomic analysis of lupin seed
8943 proteins to identify conglutin Beta as an allergen, Lup an 1. J Agric Food Chem, 56, 6370-6377.

8944 Goh DLM, Chew F-T, Chua K-Y, Chay O-M and Lee B-W, 2000. Edible “bird's nest”–induced
8945 anaphylaxis: An under-recognized entity? J Pediatr, 137, 277-279.

8946 Goh DLM, Chua KY, Chew FT, Liang RCMY, Seow TK, Ou KL, Yi FC and Lee BW, 2001.
8947 Immunochemical characterization of edible bird’s nest allergens. Journal of Allergy and Clinical
8948 Immunology, 107, 1082-1088.

8949 Goldman AS, Anderson DW, Jr., Sellers WA, Saperstein S, Kniker WT and Halpern SR, 1963a. Milk
8950 Allergy. I. Oral Challenge with Milk and Isolated Milk Proteins in Allergic Children. Pediatrics,
8951 32, 425-443.

8952 Goldman AS, Sellars WA, Halpern SR, Anderson DW, Jr., Furlow TE and Johnson CH, Jr., 1963b.
8953 Milk Allergy. Ii. Skin Testing of Allergic and Normal Children with Purified Milk Proteins.
8954 Pediatrics, 32, 572-579.

8955 Goliáš J, Humlová Z, Halada P, Hábová V, Janatková I and Tučková L, 2013. Identification of Rice
8956 Proteins Recognized by the IgE Antibodies of Patients with Food Allergies. J Agric Food Chem,
8957 61, 8851-8860.

8958 Gomaa A and Boye JI, 2013. Impact of thermal processing time and cookie size on the detection of
8959 casein, egg, gluten and soy allergens in food. Food Research International, 52, 483-489.

8960 Gomez Galan A, Brohée M, Scaravelli E, Hengel A and Chassaigne H, 2010. Development of real-
8961 time PCR assays for the detection of lupin residues in food products. European Food Research and
8962 Technology, 230, 597-608.

8963 Gomez Galan AM, Brohee M, de Andrade Silva E, van Hengel AJ and Chassaigne H, 2011.
8964 Development of a real-time PCR method for the simultaneous detection of soya and lupin
8965 mitochondrial DNA as markers for the presence of allergens in processed food. Food Chem, 127,
8966 834-841.

8967 Gonzalez-De-Olano D, Rodriguez-Marco A, Gonzalez-Mancebo E, Gandolfo-Cano M, Melendez-
8968 Baltanas A and Bartolome B, 2011. Allergy to red caviar. J Investig Allergol Clin Immunol, 21,
8969 493-494.

8970 Gonzalez-de-Olano D, Bartolome B, Maroto AS, Vivanco F and Pastor-Vargas C, 2012. Asthma after
8971 chicken consumption due to cross-reactivity between fish and chicken parvalbumin. J Investig
8972 Allergol Clin Immunol, 22, 227-228.

8973 Gonzalez-Perez A, Aponte Z, Vidaurre CF and Rodriguez LA, 2010. Anaphylaxis epidemiology in
8974 patients with and patients without asthma: a United Kingdom database review. J Allergy Clin
8975 Immunol, 125, 1098-1104 e1091.

8976 Gonzalez de la Peña MA, Menendez-Arias L, Monsalve RI and Rodriguez R, 1991. Isolation and
8977 characterization of a major allergen from oriental mustard seeds, BrajI. Int Arch Allergy Appl
8978 Immunol, 96, 263-270.

8979 Gonzalez de la Peña MA, Villalba M, Garcia-Lopez JL and Rodriguez R, 1993. Cloning and
8980 expression of the major allergen from yellow mustard seeds, Sin a I. Biochem Biophys Res
8981 Commun, 190, 648-653.

8982 Gonzalez De La Peña MA, Monsalve RI, Batanero E, Villalba M and Rodriguez R, 1996. Expression
8983 in Escherichia coli of Sin a 1, the major allergen from mustard. Eur J Biochem, 237, 827-832.

8984 Gonzalez Galan I, Garcia Menaya JM, Jimenez Ferrera G and Gonzalez Mateos G, 2002.
8985 Anaphylactic shock to oysters and white fish with generalized urticaria to prawns and white fish.
8986 Allergol Immunopathol (Madr), 30, 300-303.

8987 Gourbeyre P, Denery S and Bodinier M, 2011. Probiotics, prebiotics, and synbiotics: impact on the gut
8988 immune system and allergic reactions. J Leukoc Biol, 89, 685-695.

8989 Green TD, LaBelle VS, Steele PH, Kim EH, Lee LA, Mankad VS, Williams LW, Anstrom KJ and
8990 Burks AW, 2007. Clinical characteristics of peanut-allergic children: recent changes. Pediatrics,
8991 120, 1304-1310.

8992 Greenhawt M, 2010. The role of food allergy in atopic dermatitis. Allergy Asthma Proc, 31, 392-397.

8993 Greenhawt MJ, Singer AM and Baptist AP, 2009. Food allergy and food allergy attitudes among
8994 college students. J Allergy Clin Immunol, 124, 323-327.

8995 Greer FR, Sicherer SH, Burks AW, American Academy of Pediatrics Committee on N, American
8996 Academy of Pediatrics Section on A and Immunology, 2008. Effects of early nutritional
8997 interventions on the development of atopic disease in infants and children: the role of maternal

dietary restriction, breastfeeding, timing of introduction of complementary foods, and hydrolyzed formulas. Pediatrics, 121, 183-191.

Grimshaw KE, King RM, Nordlee JA, Hefle SL, Warner JO and Hourihane JO, 2003. Presentation of allergen in different food preparations affects the nature of the allergic reaction--a case series. Clin Exp Allergy, 33, 1581-1585.

Grundy J, Matthews S, Bateman B, Dean T and Arshad SH, 2002. Rising prevalence of allergy to peanut in children: Data from 2 sequential cohorts. J Allergy Clin Immunol, 110, 784-789.

Gryson N, Messens K and Dewettinck K, 2008. PCR detection of soy ingredients in bread. European Food Research and Technology, 227, 345-351.

Gu X, Beardslee T, Zeece M, Sarath G and Markwell J, 2001. Identification of IgE-binding proteins in soy lecithin. Int Arch Allergy Immunol, 126, 218-225.

Guandalini S and Newland C, 2011. Differentiating food allergies from food intolerances. Curr Gastroenterol Rep, 13, 426-434.

Guarneri F, Guarneri C and Benvenga S, 2005. Identification of potentially cross-reactive peanut-lupine proteins by computer-assisted search for amino acid sequence homology. Int Arch Allergy Immunol, 138, 273-277.

Guillamon E, Burbano C, Cuadrado C, Muzquiz M, Pedrosa MM, Sanchez M, Cabanillas B, Crespo JF, Rodriguez J, Haddad J and Allaf K, 2008. Effect of an instantaneous controlled pressure drop on in vitro allergenicity to lupins (Lupinus albus var Multolupa). Int Arch Allergy Immunol, 145, 9-14.

Guillamon E, Rodriguez J, Burbano C, Muzquiz M, Pedrosa MM, Cabanillas B, Crespo JF, Sancho AI, Mills EN and Cuadrado C, 2010. Characterization of lupin major allergens (Lupinus albus L.). Mol Nutr Food Res, 54, 1668-1676.

Guillet M-H and Guillet G, 2000. La prise en charge allergologique de l'atopique eczémateux: conclusions pratiques de l'exploration systématique de 500 enfants. Allerg Immunol (Paris), 32, 305-308.

Guilloux L, Vuitton D, Delbourg M, Lagier A, Adessi B, Marchand C and Ville G, 1998. Cross-reactivity between terrestrial snails (Helix species) and house-dust mite (Dermatophagoides pteronyssinus). II. In vitro study. . Allergy, 53, 151-158.

Gujral N, Suresh MR and Sunwoo HH, 2012. Quantitative double antibody sandwich ELISA for the determination of gliadin. J Immunoassay Immunochem, 33, 339-351.

Gultekin F and Doguc DK, 2013. Allergic and immunologic reactions to food additives. Clin Rev Allergy Immunol, 45, 6-29.

Gunnison AF and Jacobsen DW, 1987. Sulfite hypersensitivity. A critical review. CRC Crit Rev Toxicol, 17, 185-214.

Gupta R, Sheikh A, Strachan D and Anderson HR, 2003. Increasing hospital admissions for systemic allergic disorders in England: analysis of national admissions data. BMJ, 327, 1142-1143.

Gupta R, Sheikh A, Strachan DP and Anderson HR, 2007. Time trends in allergic disorders in the UK. Thorax, 62, 91-96.

Gupta RS, Springston EE, Warrier MR, Smith B, Kumar R, Pongracic J and Holl JL, 2011. The Prevalence, Severity, and Distribution of Childhood Food Allergy in the United States. Pediatrics.

Haas-Lauterbach S, Immer U, Richter M and Koehler P, 2012. Gluten fragment detection with a competitive ELISA. J AOAC Int, 95, 377-381.

Haasnoot W, Olieman K, Cazemier G and Verheijen R, 2001. Direct biosensor immunoassays for the detection of nonmilk proteins in milk powder. J Agric Food Chem, 49, 5201-5206.

9043 Haasnoot W and du Pre JG, 2007. Luminex-based triplex immunoassay for the simultaneous detection
9044 of soy, pea, and soluble wheat proteins in milk powder. J Agric Food Chem, 55, 3771-3777.

9045 Habenicht H, Preuss L and Lovell R, 1983. Sensitivity to ingested metabisulphites: cause of
9046 bronchiospasm and urticaria. Immunol Allergy Prac, 5.25.

9047 Hajeb P and Selamat J, 2012. A contemporary review of seafood allergy. Clin Rev Allergy Immunol,
9048 42, 365-385.

9049 Hamada Y, Nagashima Y and Shiomi K, 2001. Identification of collagen as a new fish allergen. Biosci
9050 Biotechnol Biochem, 65, 285-291.

9051 Hamada Y, Tanaka H, Ishizaki S, Ishida M, Nagashima Y and Shiomi K, 2003. Purification, reactivity
9052 with IgE and cDNA cloning of parvalbumin as the major allergen of mackerels. Food Chem
9053 Toxicol, 41, 1149-1156.

9054 Hamada Y, Nagashima Y and Shiomi K, 2004. Reactivity of serum immunoglobulin E to bullfrog
9055 Rana catesbeiana parvalbumins in fish-allergic patients. Fisheries Science, 70, 1137-1143.

9056 Hamilton RG, 2010. Clinical laboratory assessment of immediate-type hypersensitivity. J Allergy Clin
9057 Immunol, 125, S284-296.

9058 Hanifin J and Rajka G, 1980. Diagnostic features of atopic dermatitis. Acta Derm Venereol, Suppl. 92,
9059 44-47.

9060 Hansen KS, Ballmer-Weber BK, Lüttkopf D, Skov PS, Wüthrich B, Bindslev-Jensen C, Vieths S and
9061 Poulsen LK, 2003. Roasted hazelnuts – allergenic activity evaluated by double-blind, placebo-
9062 controlled food challenge. Allergy, 58, 132-138.

9063 Hansen KS, Ballmer-Weber BK, Sastre J, Lidholm J, Andersson K, Oberhofer H, Lluch-Bernal M,
9064 Ostling J, Mattsson L, Schocker F, Vieths S and Poulsen LK, 2009. Component-resolved in vitro
9065 diagnosis of hazelnut allergy in Europe. J Allergy Clin Immunol, 123, 1134-1141, 1141 e1131-
9066 1133.

9067 Hansen TK and Bindslev-Jensen C, 1992. Codfish allergy in adults. Identification and diagnosis.
9068 Allergy, 47, 610-617.

9069 Hansen TK, Bindslev-Jensen C, Skov PS and Poulsen LK, 1996. Codfish allergy in adults. Specific
9070 tests for IgE and histamine release vs double-blind, placebo-controlled challenges. Clin Exp
9071 Allergy, 26, 1276-1285.

9072 Hansen TK, Bindslev-Jensen C, Skov PS and Poulsen LK, 1997. Codfish allergy in adults: IgE cross-
9073 reactivity among fish species. Ann Allergy Asthma Immunol, 78, 187-194.

9074 Hansen TK, Poulsen LK, Stahl Skov P, Hefle SL, Hlywka JJ, Taylor SL, Bindslev-Jensen U and
9075 Bindslev-Jensen C, 2004. A randomized, double-blinded, placebo-controlled oral challenge study
9076 to evaluate the allergenicity of commercial, food-grade fish gelatin. Food and Chemical
9077 Toxicology, 42, 2037-2044.

9078 Haraszi R, Chassaigne H, Maquet A and Ulberth F, 2011. Analytical methods for detection of gluten
9079 in food--method developments in support of food labeling legislation. J AOAC Int, 94, 1006-1025.

9080 Harish Babu BN, Mahesh PA and Venkatesh YP, 2008. A cross-sectional study on the prevalence of
9081 food allergy to eggplant (Solanum melongena L.) reveals female predominance. Clin Exp Allergy,
9082 38, 1795-1802.

9083 Harrer A, Egger M, Gadermaier G, Erler A, Hauser M, Ferreira F and Himly M, 2010.
9084 Characterization of plant food allergens: an overview on physicochemical and immunological
9085 techniques. Mol Nutr Food Res, 54, 93-112.

9086 Hartz C, Lauer I, del Mar San Miguel Moncin M, Cistero-Bahima A, Foetisch K, Lidholm J, Vieths S
9087 and Scheurer S, 2010. Comparison of IgE-binding capacity, cross-reactivity and biological potency
9088 of allergenic non-specific lipid transfer proteins from peach, cherry and hazelnut. Int Arch Allergy
9089 Immunol, 153, 335-346.

9090 Hasegawa M, Inomata N, Yamazaki H, Morita A, Kirino M and Ikezawa Z, 2009. Clinical features of
9091 four cases with cashew nut allergy and cross-reactivity between cashew nut and pistachio. Allergol
9092 Int, 58, 209-215.

9093 Hassan SSM, Hamza MSA and Mohamed AHK, 2006. A novel spectrophotometric method for batch
9094 and flow injection determination of sulfite in beverages. Anal Chim Acta, 570, 232-239.

9095 Hassoun S, Bonneau J, Drouet M and Sabbah A, 1994. [Survey of pathologies caused by sulphites in
9096 allergology][in French]. Allerg Immunol (Paris), 26, 187-188.

9097 Hauser M, Roulias A, Ferreira F and Egger M, 2010. Panallergens and their impact on the allergic
9098 patient. Allergy, Asthma & Clinical Immunology, 6, 1.

9099 Hebling CM, Ross MM, Callahan JH and McFarland MA, 2012. Size-selective fractionation and
9100 visual mapping of allergen protein chemistry in Arachis hypogaea. J Proteome Res, 11, 5384-5395.

9101 Heffler E, Nebiolo F, Asero R, Guida G, Badiu I, Pizzimenti S, Marchese C, Amato S, Mistrello G,
9102 Canaletti F and Rolla G, 2011. Clinical manifestations, co-sensitizations, and immunoblotting
9103 profiles of buckwheat-allergic patients. Allergy, 66, 264-270.

9104 Hefle S, Christie L, Sicherer S, Althage K, Burks A, Sampson H, Mofidi S, Noone S, Michaelis L,
9105 Strobel S, Hourihane J, Nordlee J and Taylor S, 2003. Threshold dose for egg allergy determined
9106 by oral challenge. J Allergy Clin Immunol, 111, S351.

9107 Hefle SL, Lemanske RF, Jr. and Bush RK, 1994. Adverse reaction to lupine-fortified pasta. J Allergy
9108 Clin Immunol, 94, 167-172.

9109 Hefle SL, Jeanniton E and Taylor SL, 2001. Development of a sandwich enzyme-linked
9110 immunosorbent assay for the detection of egg residues in processed foodst. J Food Prot, 64, 1812-
9111 1816.

9112 Hefle SL, Lambrecht DM and Nordlee JA, 2005. Soy sauce retains allergenicity through the
9113 fermentation/production process. J Allergy Clin Immunol, 115, S32.

9114 Hei W, Li Z, Ma X and He P, 2012. Determination of beta-conglycinin in soybean and soybean
9115 products using a sandwich enzyme-linked immunosorbent assay. Anal Chim Acta, 734, 62-68.

9116 Heick J, Fischer M and Popping B, 2011a. First screening method for the simultaneous detection of
9117 seven allergens by liquid chromatography mass spectrometry. J Chromatogr A, 1218, 938-943.

9118 Heick J, Fischer M, Kerbach S, Tamm U and Popping B, 2011b. Application of a liquid
9119 chromatography tandem mass spectrometry method for the simultaneous detection of seven
9120 allergenic foods in flour and bread and comparison of the method with commercially available
9121 ELISA test kits. J AOAC Int, 94, 1060-1068.

9122 Heine RG, 2006. Gastroesophageal reflux disease, colic and constipation in infants with food allergy.
9123 Curr Opin Allergy Clin Immunol, 6, 220-225.

9124 Heine RG, 2008. Allergic gastrointestinal motility disorders in infancy and early childhood. Pediatr
9125 Allergy Immunol, 19, 383-391.

9126 Heiss S, Fischer S, Müller W, Weber B, Hirschwehr R, Spitzauer S, Kraft D and Valenta R, 1996.
9127 Identification of a 60 kDa cross-reactive allergen in pollen and plant derived food. J Allergy Clin
9128 Immunol, 98, 938-947.

9129 Helbling A, Lopez M and Lehrer SB, 1992. Fish Allergy: Is It a Real Problem with Surimi-Based
9130 Products? Int Arch Allergy Immunol, 99, 452-455.

9131 Helbling A, Haydel Jr R, McCants ML, Musmand JJ, El-Dahr J and Lehrer SB, 1999. Fish allergy: is
9132 cross-reactivity among fish species relevant? Double-blind placebo-controlled food challenge
9133 studies of fish allergic adults. Annals of Allergy, Asthma & Immunology, 83, 517-523.

9134 Helm R, Cockrell G, Herman E, Burks A, Sampson H and Bannon G, 1998. Cellular and molecular
9135 characterization of a major soybean allergen. Int Arch Allergy Immunol, 117, 29-37.

9136 Helm RM, Cockrell G, Connaughton C, West CM, Herman E, Sampson HA, Bannon GA and Burks
9137 AW, 2000. Mutational analysis of the IgE-binding epitopes of P34/Gly m Bd 30K. J Allergy Clin
9138 Immunol, 105, 378-384.

9139 Hernandez M, Esteve T and Pla M, 2005. Real-time polymerase chain reaction based assays for
9140 quantitative detection of barley, rice, sunflower, and wheat. J Agric Food Chem, 53, 7003-7009.

9141 Herrero B, Vieites JM and Espineira M, 2012. Fast real-time PCR for the detection of crustacean
9142 allergen in foods. J Agric Food Chem, 60, 1893-1897.

9143 Hickman C, Roberts L, Larson A, l'Anson H and Eisenhour D, 2004. Chapter 16 Molluscs – Phylum
9144 Mollusca. In: Integrated principles of zoology. McGrawHill Higher Education, Boston, 326-354.

9145 Hidalgo FJ and Zamora R, 2006. Peptides and proteins in edible oils: Stability, allergenicity, and new
9146 processing trends. Trends in Food Science & Technology, 17, 56-63.

9147 Hildebrandt S, Kratzin HD, Schaller R, Fritsche R, Steinhart H and Paschke A, 2008. In vitro
9148 determination of the allergenic potential of technologically altered hen's egg. J Agric Food Chem,
9149 56, 1727-1733.

9150 Hildebrandt S, 2010. Multiplexed identification of different fish species by detection of parvalbumin, a
9151 common fish allergen gene: a DNA application of multi-analyte profiling (xMAP) technology.
9152 Anal Bioanal Chem, 397, 1787-1796.

9153 Hilger C, Thill L, Grigioni F, Lehners C, Falagiani P, Ferrara A, Romano C, Stevens W and Hentges
9154 F, 2004. IgE antibodies of fish allergic patients cross-react with frog parvalbumin. Allergy, 59,
9155 653-660.

9156 Hill DJ, Ford RPK, Shelton MJ and Hosking CS, 1984. A study of 100 infants and young children
9157 with cow's milk allergy. Clinical Reviews in Allergy, 2, 125-142.

9158 Hird H, Lloyd J, Goodier R, Brown J and Reece P, 2003. Detection of peanut using real-time
9159 polymerase chain reaction. European Food Research and Technology, 217, 265-268.

9160 Hirschwehr R, Valenta R, Ebner C, Ferreira F, Sperr WR, Valent P, Rohac M, Rumpold H, Scheiner
9161 O and Kraft D, 1992. Identification of common allergenic structures in hazel pollen and hazelnuts:
9162 a possible explanation for sensitivity to hazelnuts in patients allergic to tree pollen. J Allergy Clin
9163 Immunol, 90, 927-936.

9164 Hischenhuber C, Crevel R, Jarry B, Maki M, Moneret-Vautrin DA, Romano A, Troncone R and Ward
9165 R, 2006. Review article: safe amounts of gluten for patients with wheat allergy or coeliac disease.
9166 Aliment Pharmacol Ther, 23, 559-575.

9167 Hoffman DR, Day ED, Jr. and Miller JS, 1981. The major heat stable allergen of shrimp. Ann Allergy,
9168 47, 17-22.

9169 Hoffmann-Sommergruber K, Demoly P, Crameri R, Breiteneder H, Ebner C, Laimer Da Camara
9170 Machado M, Blaser K, Ismail C, Scheiner O, Bousquet J and Menz G, 1999. IgE reactivity to Api g
9171 1, a major celery allergen, in a Central European population is based on primary sensitization by
9172 Bet v 1. J Allergy Clin Immunol, 104, 478-484.

9173 Hoffmann-Sommergruber K, Ferris R, Pec M, Radauer C, O'Riordain G, Laimer da Camara Machado
9174 M, Scheiner O and Breiteneder H, 2000. Characterization of Api g 1.0201, a New Member of the
9175 Api g 1 Family of Celery Allergens. Int Arch Allergy Immunol, 122, 115-123.

9176 Hoffmann-Sommergruber K and Mills ENC, 2009. Food allergen protein families and their structural
9177 characteristics and application in component-resolved diagnosis: new data from the EuroPrevall
9178 project. Anal Bioanal Chem, 395, 25-35.

9179 Hohensinner V, Maier I and Pittner F, 2007. A 'gold cluster-linked immunosorbent assay': Optical
9180 near-field biosensor chip for the detection of allergenic β-lactoglobulin in processed milk matrices.
9181 Journal of Biotechnology, 130, 385-388.

9182 Holden L and Egaas E, 2005. Quantitative Sandwich ELISA for the Determination of Lupine (Lupinus
9183 spp.) in Foods. J Agric Food Chem, 53, 5866-5871.

9184 Holden L, Moen LH, Sletten GB and Dooper MM, 2007. Novel polyclonal-monoclonal-based ELISA
9185 utilized to examine lupine (Lupinus species) content in food products. J Agric Food Chem, 55,
9186 2536-2542.

9187 Holden L, Sletten GB, Lindvik H, Faeste CK and Dooper MM, 2008. Characterization of IgE binding
9188 to lupin, peanut and almond with sera from lupin-allergic patients. Int Arch Allergy Immunol, 146,
9189 267-276.

9190 Holm K, Maki M, Vuolteenaho N, Mustalahti K, Ashorn M, Ruuska T and Kaukinen K, 2006. Oats in
9191 the treatment of childhood coeliac disease: a 2-year controlled trial and a long-term clinical follow-
9192 up study. Aliment Pharmacol Ther, 23, 1463-1472.

9193 Holzhauser T and Vieths S, 1999. Indirect competitive ELISA for determination of traces of peanut
9194 (Arachis hypogaea L.) protein in complex food matrices. J Agric Food Chem, 47, 603-611.

9195 Holzhauser T, Stephan O and Vieths S, 2002. Detection of potentially allergenic hazelnut (Corylus
9196 avellana) residues in food: a comparative study with DNA PCR-ELISA and protein sandwich-
9197 ELISA. J Agric Food Chem, 50, 5808-5815.

9198 Holzhauser T, Wackermann O, Ballmer-Weber BK, Bindslev-Jensen C, Scibilia J, Perono-Garoffo L,
9199 Utsumi S, Poulsen LK and Vieths S, 2009. Soybean (Glycine max) allergy in Europe: Gly m 5
9200 (beta-conglycinin) and Gly m 6 (glycinin) are potential diagnostic markers for severe allergic
9201 reactions to soy. J Allergy Clin Immunol, 123, 452-458.

9202 Hong X, Tsai HJ and Wang X, 2009. Genetics of food allergy. Curr Opin Pediatr, 21, 770-776.

9203 Hong X, Caruso D, Kumar R, Liu R, Liu X, Wang G, Pongracic JA and Wang X, 2012. IgE, but not
9204 IgG4, antibodies to Ara h 2 distinguish peanut allergy from asymptomatic peanut sensitization.
9205 Allergy, 67, 1538-1546.

9206 Host A and Samuelsson EG, 1988. Allergic reactions to raw, pasteurized, and
9207 homogenized/pasteurized cow milk: a comparison. A double-blind placebo-controlled study in
9208 milk allergic children. Allergy, 43, 113-118.

9209 Host A and Halken S, 1990. A prospective study of cow milk allergy in Danish infants during the first
9210 3 years of life. Clinical course in relation to clinical and immunological type of hypersensitivity
9211 reaction. Allergy, 45, 587-596.

9212 Host A, Halken S, Jacobsen HP, Christensen AE, Herskind AM and Plesner K, 2002. Clinical course
9213 of cow's milk protein allergy/intolerance and atopic diseases in childhood. Pediatr Allergy
9214 Immunol, 13 Suppl 15, 23-28.

9215 Hourihane JB, Kilburn SA, Nordlee JA, Hefle SL, Taylor SL and Warner JO, 1997. An evaluation of
9216 the sensitivity of subjects with peanut allergy to very low doses of peanut protein: a randomized,
9217 double-blind, placebo-controlled food challenge study. J Allergy Clin Immunol, 100, 596-600.

9218 Hourihane JO, Dean TP and Warner JO, 1996. Peanut allergy in relation to heredity, maternal diet,
9219 and other atopic diseases: results of a questionnaire survey, skin prick testing, and food challenges.
9220 BMJ, 313, 518-521.

9221 Hourihane JO, Roberts SA and Warner JO, 1998. Resolution of peanut allergy: case-control study.
9222 BMJ, 316, 1271-1275.

9223 Hourihane JO, Aiken R, Briggs R, Gudgeon LA, Grimshaw KE, DunnGalvin A and Roberts SR, 2007.
9224 The impact of government advice to pregnant mothers regarding peanut avoidance on the
9225 prevalence of peanut allergy in United Kingdom children at school entry. J Allergy Clin Immunol,
9226 119, 1197-1202.

9227 Houston NL, Lee DG, Stevenson SE, Ladics GS, Bannon GA, McClain S, Privalle L, Stagg N,
9228 Herouet-Guicheney C, MacIntosh SC and Thelen JJ, 2011. Quantitation of soybean allergens using
9229 tandem mass spectrometry. J Proteome Res, 10, 763-773.

9230 Howell WM, Turner SJ, Hourihane JO, Dean TP and Warner JO, 1998. HLA class II DRB1, DQB1
9231 and DPB1 genotypic associations with peanut allergy: evidence from a family-based and case-
9232 control study. Clin Exp Allergy, 28, 156-162.

9233 Hu CQ, Chen HB, Gao JY, Luo CP, Ma XJ and Tong P, 2011. High-pressure microfluidisation-
9234 induced changes in the antigenicity and conformation of allergen Ara h 2 purified from Chinese
9235 peanut. J Sci Food Agric, 91, 1304-1309.

9236 Hu Y, Chen J and Li H, 2010. Comparison of food allergy prevalence among Chinese infants in
9237 Chongqing, 2009 versus 1999. Pediatr Int, 52, 820-824.

9238 Huang F, Chawla K, Jarvinen KM and Nowak-Wegrzyn A, 2012. Anaphylaxis in a New York City
9239 pediatric emergency department: triggers, treatments, and outcomes. J Allergy Clin Immunol, 129,
9240 162-168 e161-163.

9241 Huang Y, Bell MC and Suni, II, 2008. Impedance biosensor for peanut protein Ara h 1. Anal Chem,
9242 80, 9157-9161.

9243 Hungerford JM, 2005. Committee on Natural Toxins and Food Allergens. Marine and freshwater
9244 toxins. J AOAC Int, 88, 299-313.

9245 Hupfer C, Waiblinger H and U B, 2007. Development and validation of a real-time PCR detection
9246 method for celery in food. European Food Research and Technology, 225, 329-335.

9247 Huriaux F, Vandewalle P and Focant B, 2002. Immunological study of muscle parvalbumin isotypes
9248 in three African catfish during development. Comp Biochem Physiol B Biochem Mol Biol, 132,
9249 579-584.

9250 Hurst WJ, Krout ER and Burks WR, 2002. A comparison of commercially available peanut ELISA
9251 test kits on the analysis of samples of dark and milk chocolate. J Immunoassay Immunochem, 23,
9252 451-459.

9253 Husain FT, Bretbacher IE, Nemes A and Cichna-Markl M, 2010. Development and validation of an
9254 indirect competitive enzyme linked-immunosorbent assay for the determination of potentially
9255 allergenic sesame (Sesamum indicum) in food. J Agric Food Chem, 58, 1434-1441.

9256 Husby S, Koletzko S, Korponay-Szabo IR, Mearin ML, Phillips A, Shamir R, Troncone R, Giersiepen
9257 K, Branski D, Catassi C, Lelgeman M, Maki M, Ribes-Koninckx C, Ventura A, Zimmer KP,
9258 Diagnosis EWGoCD, Committee EG, European Society for Pediatric Gastroenterology H and
9259 Nutrition, 2012. European Society for Pediatric Gastroenterology, Hepatology, and Nutrition
9260 guidelines for the diagnosis of coeliac disease. J Pediatr Gastroenterol Nutr, 54, 136-160.

9261 Hwang JB, Sohn SM and Kim AS, 2009. Prospective follow-up oral food challenge in food protein-
9262 induced enterocolitis syndrome. Arch Dis Child, 94, 425-428.

9263 Iacono G, Cavataio F, Montalto G, Florena A, Tumminello M, Soresi M, Notarbartolo A and
9264 Carroccio A, 1998. Intolerance of cow's milk and chronic constipation in children. N Engl J Med,
9265 339, 1100-1104.

9266 Iammarino M, Di Taranto A, Muscarella M, Nardiello D, Palermo C and Centonze D, 2010.
9267 Development of a new analytical method for the determination of sulfites in fresh meats and
9268 shrimps by ion-exchange chromatography with conductivity detection. Anal Chim Acta, 672, 61-
9269 65.

9270 Imamura T, Kanagawa Y and Ebisawa M, 2008. A survey of patients with self-reported severe food
9271 allergies in Japan. Pediatr Allergy Immunol, 19, 270-274.

9272 Immer U, Reck B, Lindeke S and Koppelman S, 2004. RIDASCREEN® FAST PEANUT, a rapid and
9273 safe tool to determine peanut contamination in food. International Journal of Food Science &
9274 Technology, 39, 869-871.

9275 Immer U and Haas Lauterbach S, 2010. Gluten detection in molecular biological and immunological
9276 techniques and applications for food chemists. In: Eds Popping B, Diaz-Amigo C, Hoenicke K.
9277 John Wiley & Sons, Inc, 359-375.

9278 Iparraguirre A, Rodriguez-Perez R, Juste S, Ledesma A, Moneo I and Caballero ML, 2009. Selective
9279 allergy to lobster in a case of primary sensitization to house dust mites. J Investig Allergol Clin
9280 Immunol, 19, 409-413.

9281 Ireland-Jenkin K, Wu X, Heine RG, Cameron DJ, Catto-Smith AG and Chow CW, 2008. Oesophagitis
9282 in children: reflux or allergy? Pathology, 40, 188-195.

9283 Isaac A, Livingstone C, Wain AJ, Compton RG and Davis J, 2006. Electroanalytical methods for the
9284 determination of sulfite in food and beverages. Trac-Trends in Analytical Chemistry, 25, 589-598.

9285 Ishizaki S, Sakai Y, Yano T, Nakano S, Yamada T, Nagashima Y, Shiomi K, Nakao Y and Akiyama
9286 H, 2012. Specific detection by the polymerase chain reaction of potentially allergenic salmonid fish
9287 residues in processed foods. Biosci Biotechnol Biochem, 76, 980-985.

9288 Isolauri E, Huurre A, Salminen S and Impivaara O, 2004. The allergy epidemic extends beyond the
9289 past few decades. Clin Exp Allergy, 34, 1007-1010.

9290 Ito K, Futamura M, Borres MP, Takaoka Y, Dahlstrom J, Sakamoto T, Tanaka A, Kohno K, Matsuo H
9291 and Morita E, 2008. IgE antibodies to omega-5 gliadin associate with immediate symptoms on oral
9292 wheat challenge in Japanese children. Allergy, 63, 1536-1542.

9293 Ito K, Sjölander S, Sato S, Movérare R, Tanaka A, Söderström L, Borres M, Poorafshar M and
9294 Ebisawa M, 2011. IgE to Gly m 5 and Gly m 6 is associated with severe allergic reactions to
9295 soybean in Japanese children. J Allergy Clin Immunol, 128, 673-675.

9296 Itoh N, Itagaki Y and Kurihara K, 2010. Rush specific oral tolerance induction in school-age children
9297 with severe egg allergy: one year follow up. Allergol Int, 59, 43-51.

9298 Ivanciuc O, Schein CH and Braun W, 2002. Data mining of sequences and 3D structures of allergenic
9299 proteins. Bioinformatics, 18, 1358-1364.

9300 Iwan M, Vissers YM, Fiedorowicz E, Kostyra H, Kostyra E, Savelkoul HF and Wichers HJ, 2011.
9301 Impact of Maillard reaction on immunoreactivity and allergenicity of the hazelnut allergen Cor a
9302 11. J Agric Food Chem, 59, 7163-7171.

9303 Jacobsen B, Hoffmann-Sommergruber K, Have TT, Foss N, Briza P, Oberhuber C, Radauer C,
9304 Alessandri S, Knulst AC, Fernandez-Rivas M and Barkholt V, 2008. The panel of egg allergens,
9305 Gal d 1-Gal d 5: Their improved purification and characterization. Mol Nutr Food Res, 52 Suppl 2,
9306 S176-185.

9307 James JM, Sixbey JP, Helm RM, Bannon GA and Burks AW, 1997. Wheat alpha-amylase inhibitor: a
9308 second route of allergic sensitization. J Allergy Clin Immunol, 99, 239-244.

9309 Janatuinen EK, Kemppainen TA, Julkunen RJ, Kosma VM, Maki M, Heikkinen M and Uusitupa MI,
9310 2002. No harm from five year ingestion of oats in coeliac disease. Gut, 50, 332-335.

9311 Jankiewicz A, Aulepp H, Baltes W, Bogl KW, Dehne LI, Zuberbier T and Vieths S, 1996. Allergic
9312 sensitization to native and heated celery root in pollen-sensitive patients investigated by skin test
9313 and IgE binding. Int Arch Allergy Immunol, 111, 268-278.

9314 Jankiewicz A, Baltes W, Bögl K, Dehne L, Jamin A, Hoffmann A, Haustein D and Vieths S, 1997.
9315 Influence of food processing on the immunochemical stability of celery allergens. J Sci Food
9316 Agric, 75, 359-370.

9317 Jappe U and Vieths S, 2010. Lupine, a source of new as well as hidden food allergens. Mol Nutr Food
9318 Res, 54, 113-126.

9319 Jarvinen KM, Beyer K, Vila L, Chatchatee P, Busse PJ and Sampson HA, 2002. B-cell epitopes as a
9320 screening instrument for persistent cow's milk allergy. J Allergy Clin Immunol, 110, 293-297.

9321 Jarvinen KM, Beyer K, Vila L, Bardina L, Mishoe M and Sampson HA, 2007. Specificity of IgE
9322 antibodies to sequential epitopes of hen's egg ovomucoid as a marker for persistence of egg allergy.
9323 Allergy, 62, 758-765.

9324 Jarvinen KM and Chatchatee P, 2009. Mammalian milk allergy: clinical suspicion, cross-reactivities
9325 and diagnosis. Curr Opin Allergy Clin Immunol, 9, 251-258.

9326 Jarvinen KM, 2011. Food-induced anaphylaxis. Curr Opin Allergy Clin Immunol, 11, 255-261.

9327 Jedrychowski L, 1999. Reduction of the Antigenicity of Whey Proteins by Lactic Acid Fermentation.
9328 Food and Agricultural Immunology, 11, 91-99.

9329 Jeebhay MF, Lopata AL and Robins TG, 2000. Seafood processing in South Africa: a study of
9330 working practices, occupational health services and allergic health problems in the industry. Occup
9331 Med (Lond), 50, 406-413.

9332 Jenab M, Ferrari P, Mazuir M, Tjonneland A, Clavel-Chapelon F, Linseisen J, Trichopoulou A,
9333 Tumino R, Bueno-de-Mesquita HB, Lund E, Gonzalez CA, Johansson G, Key TJ, Riboli E,
9334 European Prospective Investigation into C and Nutrition s, 2005. Variations in lycopene blood
9335 levels and tomato consumption across European countries based on the European Prospective
9336 Investigation into Cancer and Nutrition (EPIC) study. J Nutr, 135, 2032S-2036S.

9337 Jenab M, Sabate J, Slimani N, Ferrari P, Mazuir M, Casagrande C, Deharveng G, Tjonneland A, Olsen
9338 A, Overvad K, Boutron-Ruault MC, Clavel-Chapelon F, Boeing H, Weikert C, Linseisen J,
9339 Rohrmann S, Trichopoulou A, Naska A, Palli D, Sacerdote C, Tumino R, Mattiello A, Pala V,
9340 Bueno-de-Mesquita HB, Ocke MC, Peeters PH, Engeset D, Skeie G, Jakszyn P, Ardanaz E, Quiros
9341 JR, Chirlaque MD, Martinez C, Amiano P, Berglund G, Palmqvist R, van Guelpen B, Bingham S,
9342 Key T and Riboli E, 2006. Consumption and portion sizes of tree nuts, peanuts and seeds in the
9343 European Prospective Investigation into Cancer and Nutrition (EPIC) cohorts from 10 European
9344 countries. Br J Nutr, 96 Suppl 2, S12-23.

9345 Jenkins JA, Griffiths-Jones S, Shewry PR, Breiteneder H and Mills ENC, 2005. Structural relatedness
9346 of plant food allergens with specific reference to cross-reactive allergens: An in silico analysis.
9347 Journal of Allergy and Clinical Immunology, 115, 163-170.

9348 Jensen LB, Pedersen MH, Skov PS, Poulsen LK, Bindslev-Jensen C, Andersen SB and Torp AM,
9349 2008. Peanut cross-reacting allergens in seeds and sprouts of a range of legumes. Clin Exp Allergy,
9350 38, 1969-1977.

9351 Jeoung BJ, Reese G, Hauck P, Oliver JB, Daul CB and Lehrer SB, 1997. Quantification of the major
9352 brown shrimp allergen Pen a 1 (tropomyosin) by a monoclonal antibody-based sandwich ELISA. J
9353 Allergy Clin Immunol, 100, 229-234.

9354 Jiang D, Ji J, an L, Sun X, Zhang Y, Zhang G and Tang L, 2013. Mast cell-based electrochemical
9355 biosensor for quantification of the major shrimp allergen Pen a 1 (tropomyosin). Biosens
9356 Bioelectron, 50, 150-156.

9357 Jin C, Hantusch B, Hemmer W, Stadlmann J and Altmann F, 2008. Affinity of IgE and IgG against
9358 cross-reactive carbohydrate determinants on plant and insect glycoproteins. J Allergy Clin
9359 Immunol, 121, 185-190 e182.

9360 Johansson SG, Hourihane JO, Bousquet J, Bruijnzeel-Koomen C, Dreborg S, Haahtela T, Kowalski
9361 ML, Mygind N, Ring J, van Cauwenberge P, van Hage-Hamsten M, Wuthrich B and force Ent,
9362 2001. A revised nomenclature for allergy. An EAACI position statement from the EAACI
9363 nomenclature task force. Allergy, 56, 813-824.

9364 Johnson PE, Van der Plancken I, Balasa A, Husband FA, Grauwet T, Hendrickx M, Knorr D, Mills
9365 EN and Mackie AR, 2010. High pressure, thermal and pulsed electric-field-induced structural
9366 changes in selected food allergens. Mol Nutr Food Res, 54, 1701-1710.

9367 Jones SM, Magnolfi CF, Cooke SK and Sampson HA, 1995. Immunologic cross-reactivity among
9368 cereal grains and grasses in children with food hypersensitivity. Journal of Allergy and Clinical
9369 Immunology, 96, 341-351.

9370 Jones SM, Pons L, Roberts JL, Scurlock AM, Perry TT, Kulis M, Shreffler WG, Steele P, Henry KA,
9371 Adair M, Francis JM, Durham S, Vickery BP, Zhong X and Burks AW, 2009. Clinical efficacy and
9372 immune regulation with peanut oral immunotherapy. J Allergy Clin Immunol, 124, 292-300, 300
9373 e291-297.

9374 Joseph CL, Ownby DR, Havstad SL, Woodcroft KJ, Wegienka G, MacKechnie H, Zoratti E, Peterson
9375 EL and Johnson CC, 2011. Early complementary feeding and risk of food sensitization in a birth
9376 cohort. J Allergy Clin Immunol, 127, 1203-1210 e1205.

9377 Julge K, Vasar M and Bjorksten B, 2001. Development of allergy and IgE antibodies during the first
9378 five years of life in Estonian children. Clin Exp Allergy, 31, 1854-1861.

9379 Kagan RS, Joseph L, Dufresne C, Gray-Donald K, Turnbull E, Pierre YS and Clarke AE, 2003.
9380 Prevalence of peanut allergy in primary-school children in Montreal, Canada. J Allergy Clin
9381 Immunol, 112, 1223-1228.

9382 Kajosaari M, 1982. Food allergy in Finnish children aged 1 to 6 years. Acta Paediatr Scand, 71, 815-
9383 819.

9384 Kalimuthu P, Tkac J, Kappler U, Davis JJ and Bernhardt PV, 2010. Highly sensitive and stable
9385 electrochemical sulfite biosensor incorporating a bacterial sulfite dehydrogenase. Anal Chem, 82,
9386 7374-7379.

9387 Kalyoncu AF and Stalenheim G, 1992. Serum IgE levels and allergic spectra in immigrants to
9388 Sweden. Allergy, 47, 277-280.

9389 Kamath SD, Abdel Rahman AM, Komoda T and Lopata AL, 2013. Impact of heat processing on the
9390 detection of the major shellfish allergen tropomyosin in crustaceans and molluscs using specific
9391 monoclonal antibodies. Food Chem, 141, 4031-4039.

9392 Kanerva P, Brinck O, Sontag-Strohm T, Salovaara H and Loponen J, 2011. Deamidation of gluten
9393 proteins and peptides decreases the antibody affinity in gluten analysis assays. Journal of Cereal
9394 Science, 53, 335-339.

9395 Kanerva PM, Sontag-Strohm TS, Ryöppy PH, Alho-Lehto P and Salovaara HO, 2006. Analysis of
9396 barley contamination in oats using R5 and ω-gliadin antibodies. Journal of Cereal Science, 44, 347-
9397 352.

9398 Kanny G, Guerin L and Moneret-Vautrin DA, 2000. [Risk of serious acute asthma due to lupine flour
9399 associated with peanut allergy]. Rev Med Interne, 21, 191-194.

9400 Kanny G, Moneret-Vautrin DA, Flabbee J, Beaudouin E, Morisset M and Thevenin F, 2001.
9401 Population study of food allergy in France. J Allergy Clin Immunol, 108, 133-140.

9402 Kasera R, Singh AB, Kumar R, Lavasa S, Prasad KN and Arora N, 2012. Effect of thermal processing
9403 and gamma-irradiation on allergenicity of legume proteins. Food Chem Toxicol, 50, 3456-3461.

9404 Kato I, Schrode J, Kohr WJ and Laskowski M, Jr., 1987. Chicken ovomucoid: determination of its
9405 amino acid sequence, determination of the trypsin reactive site, and preparation of all three of its
9406 domains. Biochemistry, 26, 193-201.

9407 Kattan JD, Cocco RR and Jarvinen KM, 2011. Milk and soy allergy. Pediatr Clin North Am, 58, 407-
9408 426, x.

9409 Katz Y, Gutierrez-Castrellon P, González M, Rivas R, Lee B and Alarcon P, 2014. A Comprehensive
9410 Review of Sensitization and Allergy to Soy-Based Products. Clin Rev Allergy Immunol, 1-10.

9411 Kaw CH, Hefle SL and Taylor SL, 2008. Sandwich Enzyme-Linked Immunosorbent Assay (ELISA)
9412 for the Detection of Lupine Residues in Foods. J Food Sci, 73, T135-T140.

9413 Keet CA, Matsui EC, Dhillon G, Lenehan P, Paterakis M and Wood RA, 2009. The natural history of
9414 wheat allergy. Ann Allergy Asthma Immunol, 102, 410-415.

9415 Keet CA, Frischmeyer-Guerrerio PA, Thyagarajan A, Schroeder JT, Hamilton RG, Boden S, Steele P,
9416 Driggers S, Burks AW and Wood RA, 2012. The safety and efficacy of sublingual and oral
9417 immunotherapy for milk allergy. J Allergy Clin Immunol, 129, 448-455, 455 e441-445.

9418 Kelly KJ, 2000. Eosinophilic gastroenteritis. J Pediatr Gastroenterol Nutr, 30 Suppl, S28-35.

9419 Kelso JM, Jones RT and Yunginger JW, 1996. Monospecific allergy to swordfish. Ann Allergy
9420 Asthma Immunol, 77, 227-228.

9421 Kelso JM, Cockrell GE, Helm RM and Burks AW, 1999. Common allergens in avian meats. J Allergy
9422 Clin Immunol, 104, 202-204.

9423 Kemp AS, 2007. Egg allergy. Pediatr Allergy Immunol, 18, 696-702.

9424 Kemppainen T, Janatuinen E, Holm K, Kosma VM, Heikkinen M, Maki M, Laurila K, Uusitupa M
9425 and Julkunen R, 2007. No observed local immunological response at cell level after five years of
9426 oats in adult coeliac disease. Scand J Gastroenterol, 42, 54-59.

9427 Kerkaert B, Mestdagh F and De Meulenaer B, 2010. Detection of hen's egg white lysozyme in food:
9428 Comparison between a sensitive HPLC and a commercial ELISA method. Food Chemistry, 120,
9429 580-584.

9430 Khuda S, Slate A, Pereira M, Al-Taher F, Jackson L, Diaz-Amigo C, Bigley EC, 3rd, Whitaker T and
9431 Williams K, 2012a. Effect of processing on recovery and variability associated with
9432 immunochemical analytical methods for multiple allergens in a single matrix: dark chocolate. J
9433 Agric Food Chem, 60, 4204-4211.

9434 Khuda S, Slate A, Pereira M, Al-Taher F, Jackson L, Diaz-Amigo C, Bigley EC, 3rd, Whitaker T and
9435 Williams KM, 2012b. Effect of processing on recovery and variability associated with
9436 immunochemical analytical methods for multiple allergens in a single matrix: sugar cookies. J
9437 Agric Food Chem, 60, 4195-4203.

9438 Kiefte-de Jong JC, Escher JC, Arends LR, Jaddoe VW, Hofman A, Raat H and Moll HA, 2010. Infant
9439 nutritional factors and functional constipation in childhood: the Generation R study. Am J
9440 Gastroenterol, 105, 940-945.

9441 Kilgallen I and Gibney MJ, 1996. Parental perception of food allergy or intolerance in children under
9442 4 years of age. Journal of Human Nutrition and Dietetics, 9, 473-478.

9443 Kim J, Lee J, Seo WH, Han Y, Ahn K and Lee SI, 2012. Changes in Major Peanut Allergens Under
9444 Different pH Conditions. Allergy Asthma Immunol Res, 4, 157-160.

9445 Kim MJ, Lee JW, Yook HS, Lee SY, Kim MC and Byun MW, 2002. Changes in the antigenic and
9446 immunoglobulin E-binding properties of hen's egg albumin with the combination of heat and
9447 gamma irradiation treatment. J Food Prot, 65, 1192-1195.

9448 King TP, Hoffman D, Lowenstein H, Marsh DG, Platts-Mills TA and Thomas W, 1994. Allergen
9449 nomenclature. WHO/IUIS Allergen Nomenclature Subcommittee. Int Arch Allergy Immunol, 105,
9450 224-233.

9451 Kirsch S, Fourdrilis S, Dobson R, Scippo ML, Maghuin-Rogister G and De Pauw E, 2009.
9452 Quantitative methods for food allergens: a review. Anal Bioanal Chem, 395, 57-67.

9453 Kjelkevik R, Edberg U and Malmheden Yman I, 1997. Labelling of potential allergens in food.
9454 Environ Toxicol Pharmacol, 4, 157-162.

9455 Kleber N, Weyrich U and Hinrichs J, 2006. Screening for lactic acid bacteria with potential to reduce
9456 antigenic response of β-lactoglobulin in bovine skim milk and sweet whey. Innovative Food
9457 Science & Emerging Technologies, 7, 233-238.

9458 Kleine-Tebbe J, Vogel L, Crowell DN, Haustein UF and Vieths S, 2002. Severe oral allergy syndrome
9459 and anaphylactic reactions caused by a Bet v 1- related PR-10 protein in soybean, SAM22. J
9460 Allergy Clin Immunol, 110, 797-804.

9461 Klemans RJ, Knol EF, Michelsen-Huisman A, Pasmans SG, de Kruijf-Broekman W, Bruijnzeel-
9462 Koomen CA, van Hoffen E and Knulst AC, 2013. Components in soy allergy diagnostics: Gly m
9463 2S albumin has the best diagnostic value in adults. Allergy, 68, 1396-1402.

9464 Klos P, Poreba E, Springer E, Lampart-Szczapa E and Gozdzicka Jozefiak A, 2010. Identification of a
9465 specific IgE-binding protein from narrow-leafed lupin (L. Angustifolius) seeds. J Food Sci, 75,
9466 H39-43.

9467 Knight AK, Shreffler WG, Sampson HA, Sicherer SH, Noone S, Mofidi S and Nowak-Wegrzyn A,
9468 2006. Skin prick test to egg white provides additional diagnostic utility to serum egg white-specific
9469 IgE antibody concentration in children. J Allergy Clin Immunol, 117, 842-847.

9470 Kobayashi A, Tanaka H, Hamada Y, Ishizaki S, Nagashima Y and Shiomi K, 2006. Comparison of
9471 allergenicity and allergens between fish white and dark muscles. Allergy, 61, 357-363.

9472 Koch P, Schappi GF, Poms RE, Wuthrich B, Anklam E and Battaglia R, 2003. Comparison of
9473 commercially available ELISA kits with human sera-based detection methods for peanut allergens
9474 in foods. Food Addit Contam, 20, 797-803.

9475 Kondo Y, Kakami M, Koyama H, Yasuda T, Nakajima Y, Kawamura M, Tokuda R, Tsuge I and
9476 Urisu A, 2005. IgE cross-reactivity between fish roe (salmon, herring and pollock) and chicken egg
9477 in patients anaphylactic to salmon roe. Allergology International, 54, 317-323.

9478 Kondo Y, Komatsubara R, Nakajima Y, Yasuda T, Kakami M, Tsuge I and Urisu A, 2006.
9479 Parvalbumin is not responsible for cross-reactivity between tuna and marlin: A case report. J
9480 Allergy Clin Immunol, 118, 1382-1383.

9481 Kondo Y, Tanaka K, Inuo C, Tsuge I and Urisu A, 2011. A patient with salmon roe allergy showing
9482 taxonomy-unrelated cross-reactivity with sea urchin roe. Ann Allergy Asthma Immunol, 107, 283-
9483 284.

9484 Konecna H, Muller L, Dosoudilova H, Potesil D, Bursikova J, Sedo O, Marova I and Zdrahal Z, 2012.
9485 Exploration of beer proteome using OFFGEL prefractionation in combination with two-
9486 dimensional gel electrophoresis with narrow pH range gradients. J Agric Food Chem, 60, 2418-
9487 2426.

9488 Koning F, Gilissen L and Wijmenga C, 2005. Gluten: a two-edged sword. Immunopathogenesis of
9489 celiac disease. Springer Semin Immunopathol, 27, 217-232.

9490 Koplin J, Dharmage SC, Gurrin L, Osborne N, Tang ML, Lowe AJ, Hosking C, Hill D and Allen KJ,
9491 2008. Soy consumption is not a risk factor for peanut sensitization. J Allergy Clin Immunol, 121,
9492 1455-1459.

9493 Koplin JJ, Osborne NJ, Wake M, Martin PE, Gurrin LC, Robinson MN, Tey D, Slaa M, Thiele L,
9494 Miles L, Anderson D, Tan T, Dang TD, Hill DJ, Lowe AJ, Matheson MC, Ponsonby A-L, Tang
9495 MLK, Dharmage SC and Allen KJ, 2010. Can early introduction of egg prevent egg allergy in
9496 infants? A population-based study. Journal of Allergy and Clinical Immunology, 126, 807-813.

9497 Köppel R, Dvorak V, Zimmerli F, Breitenmoser A, Eugster A and Waiblinger H-U, 2010. Two
9498 tetraplex real-time PCR for the detection and quantification of DNA from eight allergens in food.
9499 European Food Research and Technology, 230, 367-374.

9500 Köppel R, Velsen-Zimmerli F and Bucher T, 2012. Two quantitative hexaplex real-time PCR systems
9501 for the detection and quantification of DNA from twelve allergens in food. European Food
9502 Research and Technology, 235, 843-852.

9503 Koppelman SJ, Knulst AC, Koers WJ, Penninks AH, Peppelman H, Vlooswijk R, Pigmans I, van
9504 Duijn G and Hessing M, 1999. Comparison of different immunochemical methods for the detection
9505 and quantification of hazelnut proteins in food products. J Immunol Methods, 229, 107-120.

9506 Koppelman SJ, Lakemond CM, Vlooswijk R and Hefle SL, 2004. Detection of soy proteins in
9507 processed foods: literature overview and new experimental work. J AOAC Int, 87, 1398-1407.

9508 Koppelman SJ, Vlooswijk R, Bottger G, Van Duijn G, Van der Schaft P, Dekker J and Van Bergen H,
9509 2007. Development of an enzyme-linked immunosorbent assay method to detect mustard protein in
9510 mustard seed oil. J Food Prot, 70, 179-183.

9511 Koppelman SJ, Nordlee JA, Lee PW, Happe RP, Hessing M, Norland R, Manning T, Deschene R, De
9512 Jong GA and Taylor SL, 2012. Parvalbumin in fish skin-derived gelatin: is there a risk for fish
9513 allergic consumers? Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 29, 1347-
9514 1355.

9515 Kos T, Hoffmann-Sommergruber K, Ferreira F, Hirschwehr R, Ahorn H, Horak F, Jager S, Sperr W,
9516 Kraft D and Scheiner O, 1993. Purification, characterization and N-terminal amino acid sequence
9517 of a new major allergen from European chestnut pollen--Cas s 1. Biochem Biophys Res Commun,
9518 196, 1086-1092.

9519 Koshte VL, Kagen SL and Aalberse RC, 1989. Cross-reactivity of IgE antibodies to caddis fly with
9520 arthropoda and mollusca. J Allergy Clin Immunol, 84, 174-183.

9521 Kosma P, Sjolander S, Landgren E, Borres MP and Hedlin G, 2011. Severe reactions after the intake
9522 of soy drink in birch pollen-allergic children sensitized to Gly m 4. Acta Paediatr, 100, 305-306.

9523 Kosunen TU, Hook-Nikanne J, Salomaa A, Sarna S, Aromaa A and Haahtela T, 2002. Increase of
9524 allergen-specific immunoglobulin E antibodies from 1973 to 1994 in a Finnish population and a
9525 possible relationship to Helicobacter pylori infections. Clin Exp Allergy, 32, 373-378.

9526 Kotaniemi-Syrjanen A, Palosuo K, Jartti T, Kuitunen M, Pelkonen AS and Makela MJ, 2010. The
9527 prognosis of wheat hypersensitivity in children. Pediatr Allergy Immunol, 21, e421-428.

9528 Koyama H, Kakami M, Kawamura M, Tokuda R, Kondo Y, Tsuge I, Yamada K, Yasuda T and Urisu
9529 A, 2006. Grades of 43 fish species in Japan based on IgE-binding activity. Allergol Int, 55, 311-
9530 316.

9531 Kramer MS and Kakuma R, 2012. Maternal dietary antigen avoidance during pregnancy or lactation,
9532 or both, for preventing or treating atopic disease in the child. Cochrane Database Syst Rev, 9,
9533 CD000133.

9534 Krane Kvenshagen B, Jacobsen M and Halvorsen R, 2010. Can conjunctival provocation test facilitate
9535 the diagnosis of food allergy in children? Allergol Immunopathol (Madr), 38, 321-326.

9536 Krause TG, Koch A, Poulsen LK, Kristensen B, Olsen OR and Melbye M, 2002. Atopic sensitization
9537 among children in an Arctic environment. Clinical & Experimental Allergy, 32, 367-372.

9538 Kristjansson I, Ardal B, Jonsson JS, Sigurdsson JA, Foldevi M and Bjorksten B, 1999. Adverse
9539 reactions to food and food allergy in young children in Iceland and Sweden. Scand J Prim Health
9540 Care, 17, 30-34.

9541 Kucukosmanoglu E, Yazi D, Yesil O, Akkoc T, Gezer M, Ozdemir C, Bakirci N, Bahceciler NN and
9542 Barlan IB, 2008. Prevalence of immediate hypersensitivity reactions to cow's milk in infants based
9543 on skin prick test and questionnaire. Allergol Immunopathol (Madr), 36, 254-258.

9544 Kuehn A, Hilger C and Hentges F, 2009. Anaphylaxis provoked by ingestion of marshmallows
9545 containing fish gelatin. J Allergy Clin Immunol, 123, 708-709.

9546 Kuehn A, Hutt-Kempf E, Hilger C and Hentges F, 2011. Clinical monosensitivity to salmonid fish
9547 linked to specific IgE-epitopes on salmon and trout beta-parvalbumins. Allergy, 66, 299-301.

9548 Kuehn A, Hilger C, Lehners-Weber C, Codreanu-Morel F, Morisset M, Metz-Favre C, Pauli G, de
9549 Blay F, Revets D, Muller CP, Vogel L, Vieths S and Hentges F, 2013. Identification of enolases
9550 and aldolases as important fish allergens in cod, salmon and tuna: component resolved diagnosis
9551 using parvalbumin and the new allergens. Clin Exp Allergy, 43, 811-822.

9552 Kuitunen P, Visakorpi JK, Savilahti E and Pelkonen P, 1975. Malabsorption syndrome with cow's
9553 milk intolerance. Clinical findings and course in 54 cases. Arch Dis Child, 50, 351-356.

9554 Kulig M, Bergmann R, Niggemann B, Burow G and Wahn U, 1998. Prediction of sensitization to
9555 inhalant allergens in childhood: evaluating family history, atopic dermatitis and sensitization to
9556 food allergens. The MAS Study Group. Multicentre Allergy Study. Clin Exp Allergy, 28, 1397-
9557 1403.

9558 Kulis M, Macqueen I, Li Y, Guo R, Zhong XP and Burks AW, 2012. Pepsinized cashew proteins are
9559 hypoallergenic and immunogenic and provide effective immunotherapy in mice with cashew
9560 allergy. J Allergy Clin Immunol, 130, 716-723.

9561 Kumagai H, Suda A, Sakurai H, Kumagai H, Arai S, Inomata N and Ikezawa Z, 2007. Improvement of
9562 digestibility, reduction in allergenicity, and induction of oral tolerance of wheat gliadin by
9563 deamidation. Biosci Biotechnol Biochem, 71, 977-985.

9564 Kumar R, Caruso DM, Arguelles L, Kim JS, Schroeder A, Rowland B, Meyer KE, Schwarz KE, Birne
9565 JS, Ouyang F, Pongracic JA and Wang X, 2010. Early Life Eczema, Food Introduction, and Risk
9566 of Food Allergy in Children. Pediatr Allergy Immunol Pulmonol, 23, 175-182.

9567 Kumar R, Tsai HJ, Hong X, Liu X, Wang G, Pearson C, Ortiz K, Fu M, Pongracic JA, Bauchner H
9568 and Wang X, 2011. Race, ancestry, and development of food-allergen sensitization in early
9569 childhood. Pediatrics, 128, e821-829.

9570 Kurosaka F, Terada T, Tanaka A, Nakatani Y, Yamada K, Nishikawa J, Oka K, Takahashi H, Mogami
9571 A, Yamada T, Nakano T, Shima M and Nishio H, 2011. Risk factors for wheezing, eczema and
9572 rhinoconjunctivitis in the previous 12 months among six-year-old children in Himeji City, Japan:
9573 food allergy, older siblings, day-care attendance and parental allergy history. Allergol Int, 60, 317-
9574 330.

9575 Kütting B and Brehler R, 2001. Das Milben-Krustazeen-Mollusken-Syndrom Eine seltenere Variante
9576 einer Nahrungsmittelallergie bei primärer Sensibilisierung auf ein Aeroallergen. Der Hautarzt, 52,
9577 708-711.

9578 Kvasnička F, 2003. Determination of egg white lysozyme by on-line coupled capillary
9579 isotachophoresis with capillary zone electrophoresis. ELECTROPHORESIS, 24, 860-864.

9580 L'Hocine L and Boye JI, 2007. Allergenicity of soybean: new developments in identification of
9581 allergenic proteins, cross-reactivities and hypoallergenization technologies. Crit Rev Food Sci
9582 Nutr, 47, 127-143.

9583 L'Hocine L, Boye JI and Munyana C, 2007. Detection and quantification of soy allergens in food:
9584 study of two commercial enzyme-linked immunosorbent assays. J Food Sci, 72, C145-153.

9585 Lack G, Fox D, Northstone K, Golding J, Avon Longitudinal Study of P and Children Study T, 2003.
9586 Factors associated with the development of peanut allergy in childhood. N Engl J Med, 348, 977-
9587 985.

9588 Lack G, 2008. Clinical practice. Food allergy. N Engl J Med, 359, 1252-1260.

9589 Lack G, 2012. Update on risk factors for food allergy. J Allergy Clin Immunol, 129, 1187-1197.

9590 Laffond Yges E, 1996. Allergic reaction to molluscs and crustaceans. Allergol Immunopathol (Madr),
9591 24 Suppl 1, 36-44.

9592 Lagrain B, Brunnbauer M, Rombouts I and Koehler P, 2013. Identification of intact high molecular
9593 weight glutenin subunits from the wheat proteome using combined liquid chromatography-
9594 electrospray ionization mass spectrometry. PLoS One, 8, e58682.

9595 Lalles JP and Peltre G, 1996. Biochemical features of grain legume allergens in humans and animals.
9596 Nutr Rev, 54, 101-107.

9597 Lam HY, van Hoffen E, Michelsen A, Guikers K, van der Tas CH, Bruijnzeel-Koomen CA and Knulst
9598 AC, 2008. Cow's milk allergy in adults is rare but severe: both casein and whey proteins are
9599 involved. Clin Exp Allergy, 38, 995-1002.

9600 Langeland T, 1982a. A clinical and immunological study of allergy to hen's egg white. III. Allergens
9601 in hen's egg white studied by crossed radio-immunoelectrophoresis (CRIE). Allergy, 37, 521-530.

9602 Langeland T, 1982b. A clinical and immunological study of allergy to hen's egg white. II. Antigens in
9603 hen's egg white studied by crossed immunoelectrophoresis (CIE). Allergy, 37, 323-333.

9604 Langeland T, 1983. A clinical and immunological study of allergy to hen's egg white. VI. Occurrence
9605 of proteins cross-reacting with allergens in hen's egg white as studied in egg white from turkey,
9606 duck, goose, seagull, and in hen egg yolk, and hen and chicken sera and flesh. Allergy, 38, 399-
9607 412.

9608 Lao-araya M and Trakultivakorn M, 2011. Prevalence of Food Allergy Among Preschool Children in
9609 Northern Thailand. J Allergy Clin Immunol, 127, AB186.

9610 Laoprasert N, Wallen ND, Jones RT, Hefle SL, Taylor SL and Yunginger JW, 1998. Anaphylaxis in a
9611 milk-allergic child following ingestion of lemon sorbet containing trace quantities of milk. J Food
9612 Prot, 61, 1522-1524.

9613 Lapteva YS, Uversky VN and Permyakov SE, 2013. Sequence microheterogeneity of parvalbumin, the
9614 major fish allergen. Biochim Biophys Acta, 1834, 1607-1614.

9615 Larenas-Linnemann D, 2009. Sublingual immunotherapy in children: complete and updated review
9616 supporting evidence of effect. Curr Opin Allergy Clin Immunol, 9, 168-176.

9617 Lauer I, Foetisch K, Kolarich D, Ballmer-Weber BK, Conti A, Altmann F, Vieths S and Scheurer S,
9618 2004. Hazelnut (Corylus avellana) vicilin Cor a 11: molecular characterization of a glycoprotein
9619 and its allergenic activity. Biochem J, 383, 327-334.

9620 Leanizbarrutia I, Muñoz D, Bernaola G, Fernández E, Audicana M and Fernández de Corres L, 1988.
9621 Sensibilizaciones cutáneas a mostaza. Frecuencia e implicación clínica. Rev Esp Alergol Immunol
9622 Clin, 3, 113-119.

9623 Leclercq C, Molinaro MG, Piccinelli R, Baldini M, Arcella D and Stacchini P, 2000. Dietary intake
9624 exposure to sulphites in Italy--analytical determination of sulphite-containing foods and their
9625 combination into standard meals for adults and children. Food Addit Contam, 17, 979-989.

9626 Ledesma Benitez I, Regueras Santos L and Lapena Lopez de Armentia S, 2007. [Adverse drug
9627 reaction as the form of onset of egg sensitization]. An Pediatr (Barc), 66, 424-425.

9628 Leduc V, Moneret-Vautrin DA and Guerin L, 2002. [Allergenicity of lupin flour]. Allerg Immunol
9629 (Paris), 34, 213-217.

9630 Leduc V, Moneret-Vautrin DA, Guerin L, Morisset M and Kanny G, 2003. Anaphylaxis to wheat
9631 isolates: immunochemical study of a case proved by means of double-blind, placebo-controlled
9632 food challenge. J Allergy Clin Immunol, 111, 897-899.

9633 Leduc V, Moneret-Vautrin DA, Tzen JT, Morisset M, Guerin L and Kanny G, 2006. Identification of
9634 oleosins as major allergens in sesame seed allergic patients. Allergy, 61, 349-356.

9635 Lee PW, Hefle SL and Taylor SL, 2008. Sandwich enzyme-linked immunosorbent assay (ELISA) for
9636 detection of mustard in foods. J Food Sci, 73, T62-68.

9637 Lee PW, Niemann LM, Lambrecht DM, Nordlee JA and Taylor SL, 2009. Detection of mustard, egg,
9638 milk, and gluten in salad dressing using enzyme-linked immunosorbent assays (ELISAs). J Food
9639 Sci, 74, T46-50.

9640 Lee PW, Nordlee JA, Koppelman SJ, Baumert JL and Taylor SL, 2011. Evaluation and comparison of
9641 the species-specificity of 3 antiparvalbumin IgG antibodies. J Agric Food Chem, 59, 12309-12316.

9642 Lee PW, Nordlee JA, Koppelman SJ, Baumert JL and Taylor SL, 2012. Measuring parvalbumin levels
9643 in fish muscle tissue: relevance of muscle locations and storage conditions. Food Chem, 135, 502-
9644 507.

9645 Lee SK, Yoon SH, Kim SH, Choi JH and Park HS, 2005. Chestnut as a food allergen: identification of
9646 major allergens. J Korean Med Sci, 20, 573-578.

9647 Lehrer SB and McCants ML, 1987. Reactivity of IgE antibodies with crustacea and oyster allergens:
9648 evidence for common antigenic structures. J Allergy Clin Immunol, 80, 133-139.

9649 Lemon-Mule H, Sampson HA, Sicherer SH, Shreffler WG, Noone S and Nowak-Wegrzyn A, 2008.
9650 Immunologic changes in children with egg allergy ingesting extensively heated egg. J Allergy Clin
9651 Immunol, 122, 977-983 e971.

9652 Leonard SA, Martos G, Wang W, Nowak-Wegrzyn A and Berin MC, 2012. Oral immunotherapy
9653 induces local protective mechanisms in the gastrointestinal mucosa. J Allergy Clin Immunol, 129,
9654 1579-1587 e1571.

9655 Lester M, 1995. Sulphite sensitivity: significance in human health. J Am Coll Nutr, 14, 229-232.

9656 Leszczyńska J, Diowksz A, Łącka A, Wolska K and A B, 2012. Evaluation of immunoreactivity of
9657 wheat bread made from fermented wheat flour. Czech Journal of Food Sciences, 30, 336-342.

9658 Leung DYM, Sampson HA, Yunginger JW, Burks AW, Schneider LC, Wortel CH, Davis FM, Hyun
9659 JD and Shanahan WR, 2003. Effect of Anti-IgE Therapy in Patients with Peanut Allergy. New
9660 England Journal of Medicine, 348, 986-993.

9661 Leung PC and Chu K-H, 1998. Molecular and Immunological Characterization of Shellfish Allergens.
9662 In: New Developments in Marine Biotechnology. Eds Gal YL, Halvorson HO. Springer US, 155-
9663 164.

9664 Leung PSC, Chu KH, Chow WK, Ansari A, Bandea CI, Kwan HS, Nagy SM and Gershwin ME,
9665 1994. Cloning, expression, and primary structure of Metapenaeus ensis tropomyosin, the major
9666 heat-stable shrimp allergen. Journal of Allergy and Clinical Immunology, 94, 882-890.

9667 Leung PSC, Chow WK, Duffey S, Kwan HS, Gershwin ME and Chu KH, 1996. IgE reactivity against
9668 a cross-reactive allergen in crustacea and mollusca: Evidence for tropomyosin as the common
9669 allergen. Journal of Allergy and Clinical Immunology, 98, 954-961.

9670 Levinton J, 2001. Marine biology. Function, biodiversity, ecology. Oxford University Press NY. 249-
9671 251.

9672 Lewis SA, Grimshaw KEC, Warner JO and Hourihane JOB, 2005. The promiscuity of
9673 immunoglobulin E binding to peanut allergens, as determined by Western blotting, correlates with
9674 the severity of clinical symptoms. Clinical & Experimental Allergy, 35, 767-773.

9675 Lewit-Bentley A and Rety S, 2000. EF-hand calcium-binding proteins. Curr Opin Struct Biol, 10, 637-
9676 643.

9677 Li-Chan E and Nakai S, 1989. Biochemical basis for the properties of egg white. Critical Review of
9678 Poultry Biology, 2, 21-58.

9679 Li H, Zhu K, Zhou H and Peng W, 2012. Effects of high hydrostatic pressure treatment on
9680 allergenicity and structural properties of soybean protein isolate for infant formula. Food
9681 Chemistry, 132, 808-814.

9682 Li H, Yu J, Ahmedna M and Goktepe I, 2013. Reduction of major peanut allergens Ara h 1 and Ara h
9683 2, in roasted peanuts by ultrasound assisted enzymatic treatment. Food Chem, 141, 762-768.

9684 Li Y, Song C, Zhang K, Wang M, Yang K, Yang A and Jin B, 2008. Establishment of a highly
9685 sensitive sandwich enzyme-linked immunosorbent assay specific for ovomucoid from hen's egg
9686 white. J Agric Food Chem, 56, 337-342.

9687 Li ZX, Lin H, Cao LM and Jameel K, 2006. Effect of high intensity ultrasound on the allergenicity of
9688 shrimp. J Zhejiang Univ Sci B, 7, 251-256.

9689 Liacouras CA, Furuta GT, Hirano I, Atkins D, Attwood SE, Bonis PA, Burks AW, Chehade M,
9690 Collins MH, Dellon ES, Dohil R, Falk GW, Gonsalves N, Gupta SK, Katzka DA, Lucendo AJ,
9691 Markowitz JE, Noel RJ, Odze RD, Putnam PE, Richter JE, Romero Y, Ruchelli E, Sampson HA,
9692 Schoepfer A, Shaheen NJ, Sicherer SH, Spechler S, Spergel JM, Straumann A, Wershil BK,
9693 Rothenberg ME and Aceves SS, 2011. Eosinophilic esophagitis: updated consensus
9694 recommendations for children and adults. J Allergy Clin Immunol, 128, 3-20 e26; quiz 21-22.

9695 Lieberman JA and Sicherer SH, 2010. The diagnosis of food allergy. Am J Rhinol Allergy, 24, 439-
9696 443.

9697 Lieberman JA and Chehade M, 2012. Eosinophilic esophagitis: diagnosis and management. Immunol
9698 Allergy Clin North Am, 32, 67-81.

9699 Liew WK, Williamson E and Tang ML, 2009. Anaphylaxis fatalities and admissions in Australia. J
9700 Allergy Clin Immunol, 123, 434-442.

9701 Lifrani A, Dos Santos J, Dubarry M, Rautureau M, Blachier F and Tome D, 2009. Development of
9702 animal models and sandwich-ELISA tests to detect the allergenicity and antigenicity of fining
9703 agent residues in wines. J Agric Food Chem, 57, 525-534.

9704 Lim DL, Neo KH, Goh DL, Shek LP and Lee BW, 2005. Missing parvalbumin: implications in
9705 diagnostic testing for tuna allergy. J Allergy Clin Immunol, 115, 874-875.

9706 Lindvik H, Holden L, Lovik M, Cvancarova M and Halvorsen R, 2008. Lupin sensitization and
9707 clinical allergy in food allergic children in Norway. Acta Paediatr, 97, 91-95.

9708 Linneberg A, Nielsen NH, Madsen F, Frolund L, Dirksen A and Jorgensen T, 2000. Increasing
9709 prevalence of specific IgE to aeroallergens in an adult population: two cross-sectional surveys 8
9710 years apart: the Copenhagen Allergy Study. J Allergy Clin Immunol, 106, 247-252.

9711 Liu AH, Jaramillo R, Sicherer SH, Wood RA, Bock SA, Burks AW, Massing M, Cohn RD and Zeldin
9712 DC, 2010a. National prevalence and risk factors for food allergy and relationship to asthma:
9713 Results from the National Health and Nutrition Examination Survey 2005-2006. J Allergy Clin
9714 Immunol, 126, 798-806.e714.

9715 Liu B, Teng D, Wang X, Yang Y and Wang J, 2012a. Expression of the soybean allergenic protein
9716 P34 in Escherichia coli and its indirect ELISA detection method. Appl Microbiol Biotechnol, 94,
9717 1337-1345.

9718 Liu GM, Cheng H, Nesbit JB, Su WJ, Cao MJ and Maleki SJ, 2010b. Effects of boiling on the IgE-
9719 binding properties of tropomyosin of shrimp (Litopenaeus vannamei). J Food Sci, 75, T1-5.

9720 Liu GM, Cao MJ, Huang YY, Cai QF, Weng WY and Su WJ, 2010c. Comparative study of in vitro
9721 digestibility of major allergen tropomyosin and other food proteins of Chinese mitten crab
9722 (Eriocheir sinensis). J Sci Food Agric, 90, 1614-1620.

9723 Liu R, Yang E, Liu C and Xue W, 2012b. Tilapia (Oreochromis mossambicus) allergens characterized
9724 by ELISA, SDS-PAGE, 2D gels, Western blotting and MALDI-TOF mass spectrometry. Int J Food
9725 Sci Nutr, 63, 259-266.

9726 Liu R, Holck AL, Yang E, Liu C and Xue W, 2013. Tropomyosin from tilapia (Oreochromis
9727 mossambicus) as an allergen. Clin Exp Allergy, 43, 365-377.

9728 Locati D, Morandi S, Zanotti M and Arnoldi A, 2006. Preliminary approaches for the development of
9729 a high-performance liquid chromatography/electrospray ionization tandem mass spectrometry
9730 method for the detection and label-free semi-quantitation of the main storage proteins of Lupinus
9731 albus in foods. Rapid Commun Mass Spectrom, 20, 1305-1316.

9732 Lock RJ and Unsworth DJ, 2011. Food allergy: which tests are worth doing and which are not? Ann
9733 Clin Biochem, 48, 300-309.

9734 Longo G, Barbi E, Berti I, Meneghetti R, Pittalis A, Ronfani L and Ventura A, 2008. Specific oral
9735 tolerance induction in children with very severe cow's milk–induced reactions. Journal of Allergy
9736 and Clinical Immunology, 121, 343-347.

9737 Lopata A and Jeebhay M, 2013. Airborne Seafood Allergens as a Cause of Occupational Allergy and
9738 Asthma. Curr Allergy Asthma Rep, 13, 288-297.

9739 Lopata AL, Luijx T, Fenemore B, Sweijd NA and Cook PA, 2002. Development of a monoclonal
9740 antibody detection assay for species-specific identification of abalone. Mar Biotechnol (NY), 4,
9741 454-462.

9742 Lopata AL and Lehrer SB, 2009. New insights into seafood allergy. Curr Opin Allergy Clin Immunol,
9743 9, 270-277.

9744 López-Calleja IM, de la Cruz S, Pegels N, González I, García T and Martín R, 2013. High resolution
9745 TaqMan real-time PCR approach to detect hazelnut DNA encoding for ITS rDNA in foods. Food
9746 Chemistry, 141, 1872-1880.

9747 López-Exposito I, Chicon R, Belloque J, Recio I, Alonso E and Lopez-Fandino R, 2008. Changes in
9748 the ovalbumin proteolysis profile by high pressure and its effect on IgG and IgE binding. J Agric
9749 Food Chem, 56, 11809-11816.

9750 López-Matas MA, Ferrer A, Larramendi CH, Huertas AJ, Pagan JA, Garcia-Abujeta JL, Bartra J,
9751 Andreu C, Lavin JR and Carnes J, 2011. Acidic ribosomal protein 60S: A new tomato allergen.
9752 Food Chem, 127, 638-640.

9753 Løvik M and Namork N, 2004. The Norwegian reporting system and register of severe allergic
9754 reactions to food - results after three years. Allergi i praksis (in press).

9755 Loza C and Brostoff J, 1995. Peanut allergy. Clin Exp Allergy, 25, 493-502.

9756 Lu Y, Ohshima T, Ushio H, Hamada Y and Shiomi K, 2007. Immunological characteristics of
9757 monoclonal antibodies against shellfish major allergen tropomyosin. Food Chemistry, 100, 1093-
9758 1099.

9759 Lucassen PL, Assendelft WJ, van Eijk JT, Gubbels JW, Douwes AC and van Geldrop WJ, 2001.
9760 Systematic review of the occurrence of infantile colic in the community. Arch Dis Child, 84, 398-
9761 403.

9762 Ludvigsson JF, Leffler DA, Bai JC, Biagi F, Fasano A, Green PH, Hadjivassiliou M, Kaukinen K,
9763 Kelly CP, Leonard JN, Lundin KE, Murray JA, Sanders DS, Walker MM, Zingone F and Ciacci C,
9764 2013. The Oslo definitions for coeliac disease and related terms. Gut, 62, 43-52.

9765 Lundin KE, Nilsen EM, Scott HG, Loberg EM, Gjoen A, Bratlie J, Skar V, Mendez E, Lovik A and
9766 Kett K, 2003. Oats induced villous atrophy in coeliac disease. Gut, 52, 1649-1652.

9767 Luo C, Hu C, Gao J, Li X, Wu Z, Yang A and Chen H, 2013. A potential practical approach to reduce
9768 Ara h 6 allergenicity by gamma irradiation. Food Chem, 136, 1141-1147.

9769 Lutter P, Parisod V and Weymuth H, 2011. Development and validation of a method for the
9770 quantification of milk proteins in food products based on liquid chromatography with mass
9771 spectrometric detection. J AOAC Int, 94, 1043-1059.

9772 Lüttkopf D, Ballmer-Weber BK, Wuthrich B and Vieths S, 2000. Celery allergens in patients with
9773 positive double-blind placebo-controlled food challenge. J Allergy Clin Immunol, 106, 390-399.

9774 Lüttkopf D, Schocker F, Scheurer S and Ballmer-Weber B, 2002a. Cloning, expression and
9775 characterisation of profiling as a minor allergen in hazelnut. Allergy, 57, 87 (abstract).

9776 Lüttkopf D, Muller U, Skov PS, Ballmer-Weber BK, Wuthrich B, Skamstrup Hansen K, Poulsen LK,
9777 Kastner M, Haustein D and Vieths S, 2002b. Comparison of four variants of a major allergen in
9778 hazelnut (Corylus avellana) Cor a 1.04 with the major hazel pollen allergen Cor a 1.01. Mol
9779 Immunol, 38, 515-525.

9780 Luykx DM, Cordewener JH, Ferranti P, Frankhuizen R, Bremer MG, Hooijerink H and America AH,
9781 2007. Identification of plant proteins in adulterated skimmed milk powder by high-performance
9782 liquid chromatography -- mass spectrometry. J Chromatogr A, 1164, 189-197.

9783 Ma X, Sun P, He P, Han P, Wang J, Qiao S and Li D, 2010. Development of monoclonal antibodies
9784 and a competitive ELISA detection method for glycinin, an allergen in soybean. Food Chemistry,
9785 121, 546-551.

9786 Macdougall CF, Cant AJ and Colver AF, 2002. How dangerous is food allergy in childhood? The
9787 incidence of severe and fatal allergic reactions across the UK and Ireland. Arch Dis Child, 86, 236-
9788 239.

9789 Machtinger S and Moss R, 1986. Cow's milk allergy in breast-fed infants: the role of allergen and
9790 maternal secretory IgA antibody. J Allergy Clin Immunol, 77, 341-347.

9791 Madsen CB, Hattersley S, Buck J, Gendel SM, Houben GF, Hourihane JO, Mackie A, Mills EN,
9792 Norhede P, Taylor SL and Crevel RW, 2009. Approaches to risk assessment in food allergy: report
9793 from a workshop "developing a framework for assessing the risk from allergenic foods". Food
9794 Chem Toxicol, 47, 480-489.

9795 Magni C, Herndl A, Sironi E, Scarafoni A, Ballabio C, Restani P, Bernardini R, Novembre E, Vierucci
9796 A and Duranti M, 2005. One- and two-dimensional electrophoretic identification of IgE-binding
9797 polypeptides of Lupinus albus and other legume seeds. J Agric Food Chem, 53, 4567-4571.

9798 Magnolfi CF, Zani G, Lacava L, Patria MF and Bardare M, 1996. Soy allergy in atopic children. Ann
9799 Allergy Asthma Immunol, 77, 197-201.

9800 Maier I, Morgan MR, Lindner W and Pittner F, 2008. Optical resonance-enhanced absorption-based
9801 near-field immunochip biosensor for allergen detection. Anal Chem, 80, 2694-2703.

9802 Makinen-Kiljunen S, Kiistala R and Varjonen E, 2003. Severe reactions from roe without concomitant
9803 fish allergy. Ann Allergy Asthma Immunol, 91, 413-416.

9804 Malanin K, Lundberg M and Johansson SG, 1995. Anaphylactic reaction caused by neoallergens in
9805 heated pecan nut. Allergy, 50, 988-991.

9806 Maleki SJ, Chung SY, Champagne ET and Raufman JP, 2000. The effects of roasting on the allergenic
9807 properties of peanut proteins. J Allergy Clin Immunol, 106, 763-768.

9808 Maleki SJ, Viquez O, Jacks T, Dodo H, Champagne ET, Chung S-Y and Landry SJ, 2003. The major
9809 peanut allergen, Ara h 2, functions as a trypsin inhibitor, and roasting enhances this function.
9810 Journal of Allergy and Clinical Immunology, 112, 190-195.

9811 Maleki SJ and Hurlburt BK, 2004. Structural and functional alterations in major peanut allergens
9812 caused by thermal processing. J AOAC Int, 87, 1475-1479.

9813 Maleki SJ, Teuber SS, Cheng H, Chen D, Comstock SS, Ruan S and Schein CH, 2011.
9814 Computationally predicted IgE epitopes of walnut allergens contribute to cross-reactivity with
9815 peanuts. Allergy, 66, 1522-1529.

9816 Malik Z, Bottomley R and Austen B, 1988. Allergenic properties of the genetic variants A and B of
9817 bovine beta-lactoglobulin. Int Arch Allergy Appl Immunol, 86, 245-248.

9818 Maloney J and Nowak-Wegrzyn A, 2007. Educational clinical case series for pediatric allergy and
9819 immunology: allergic proctocolitis, food protein-induced enterocolitis syndrome and allergic
9820 eosinophilic gastroenteritis with protein-losing gastroenteropathy as manifestations of non-IgE-
9821 mediated cow's milk allergy. Pediatr Allergy Immunol, 18, 360-367.

9822 Mamone G, Addeo F, Chianese L, Di Luccia A, De Martino A, Nappo A, Formisano A, De Vivo P
9823 and Ferranti P, 2005. Characterization of wheat gliadin proteins by combined two-dimensional gel
9824 electrophoresis and tandem mass spectrometry. Proteomics, 5, 2859-2865.

9825 Mamone G, De Caro S, Di Luccia A, Addeo F and Ferranti P, 2009. Proteomic-based analytical
9826 approach for the characterization of glutenin subunits in durum wheat. J Mass Spectrom, 44, 1709-
9827 1723.

9828 Mandalari G, Adel-Patient K, Barkholt V, Baro C, Bennett L, Bublin M, Gaier S, Graser G, Ladics
9829 GS, Mierzejewska D, Vassilopoulou E, Vissers YM, Zuidmeer L, Rigby NM, Salt LJ, Defernez M,
9830 Mulholland F, Mackie AR, Wickham MSJ and Mills ENC, 2009. In vitro digestibility of β-casein
9831 and β-lactoglobulin under simulated human gastric and duodenal conditions: A multi-laboratory
9832 evaluation. Regulatory Toxicology and Pharmacology, 55, 372-381.

9833 Mann K and Mann M, 2008. The chicken egg yolk plasma and granule proteomes. Proteomics, 8, 178-
9834 191.

9835 Manzocco L and Nicoli MC, 2012. Macromolecular crowding affects protein photosensitivity: The
9836 case of egg white immunoreactivity. Food Chemistry, 132, 982-988.

9837 Marenholz I, Nickel R, Ruschendorf F, Schulz F, Esparza-Gordillo J, Kerscher T, Gruber C, Lau S,
9838 Worm M, Keil T, Kurek M, Zaluga E, Wahn U and Lee YA, 2006. Filaggrin loss-of-function
9839 mutations predispose to phenotypes involved in the atopic march. J Allergy Clin Immunol, 118,
9840 866-871.

9841 Mareschi JP, Francois-Collange M and Suschetet M, 1992. Estimation of sulphite in food in France.
9842 Food Addit Contam, 9, 541-549.

9843 Mari A, Scala E, Palazzo P, Ridolfi S, Zennaro D and Carabella G, 2006. Bioinformatics applied to
9844 allergy: Allergen databases, from collecting sequence information to data integration. The
9845 Allergome platform as a model. Cell Immunol, 244, 97-100.

9846 Mark BJ, Beaty AD and Slavin RG, 2008. Are fish oil supplements safe in finned fish-allergic
9847 patients? Allergy Asthma Proc, 29, 528-529.

9848 Marklund B, Ahlstedt S and Nordström G, 2004. Health-related quality of life among adolescents with
9849 allergy-like conditions - with emphasis on food hypersensitivity. Health and Quality of Life
9850 Outcomes, 2, 1-12.

9851 Marsh MN, 1992. Gluten, major histocompatibility complex, and the small intestine. A molecular and
9852 immunobiologic approach to the spectrum of gluten sensitivity ('celiac sprue'). Gastroenterology,
9853 102, 330-354.

9854 Marss T, 1996. Lupin based food. Health Bull, 64, 366-367.

9855 Martelli A, De Chiara A, Corvo M, Restani P and Fiocchi A, 2002. Beef allergy in children with cow's
9856 milk allergy; cow's milk allergy in children with beef allergy. Ann Allergy Asthma Immunol, 89,
9857 38-43.

9858 Martín-García C, Carnes J, Blanco R, Martinez-Alonso JC, Callejo-Melgosa A, Frades A and Colino
9859 T, 2007. Selective hypersensitivity to boiled razor shell. J Investig Allergol Clin Immunol, 17, 271-
9860 273.

9861 Martin-Hernandez C, Benet S and Marvin-Guy LF, 2005. Characterization and quantification of
9862 proteins in lecithins. J Agric Food Chem, 53, 8607-8613.

9863 Martin-Hernandez C, Benet S and Obert L, 2008. Determination of proteins in refined and nonrefined
9864 oils. J Agric Food Chem, 56, 4348-4351.

9865 Martin L, Nordlee J and Taylor S, 1986. Sulphite residues in restaurant salads. J Food Protection, 49,
9866 126-129.

9867 Martínez-Gimeno A, Del C, Garcia-Hernandez G, Luna-Paredes C and Garcia-Sanchez J, 2000.
9868 Prevalence of food allergy/intolerance in children: Results from a population based survey. Journal
9869 of Allergy and Clinical Immunology, 105, S130-S130.

9870 Martínez-Villaluenga C, Sironi E, Vidal-Valverde C and Duranti M, 2006. Effects of oligosaccharide
9871 removing procedure on the protein profiles of lupin seeds. European Food Research and
9872 Technology, 223, 691-696.

9873 Martínez A, Martinez J, Palacios R and Panzani R, 1997. Importance of tropomyosin in the allergy to
9874 household arthropods. Cross-reactivity with other invertebrate extracts. Allergol Immunopathol
9875 (Madr), 25, 118-126.

9876 Martins LM, Peltre G, da Costa Faro CJ, Pires EM and da Cruz Inacio FF, 2005. The Helix aspersa
9877 (brown garden snail) allergen repertoire. Int Arch Allergy Immunol, 136, 7-15.

9878 Maruyama N, Prak K, Motoyama S, Choi SK, Yagasaki K, Ishimoto M and Utsumi S, 2004.
9879 Structure-physicochemical function relationships of soybean glycinin at subunit levels assessed by
9880 using mutant lines. J Agric Food Chem, 52, 8197-8201.

9881 Masthoff LJ, Hoff R, Verhoeckx KC, van Os-Medendorp H, Michelsen-Huisman A, Baumert JL,
9882 Pasmans SG, Meijer Y and Knulst AC, 2013. A systematic review of the effect of thermal
9883 processing on the allergenicity of tree nuts. Allergy, 68, 983-993.

9884 Mata E, Favier C, Moneret-Vautrin DA, Nicolas JP, Han Ching L and Gueant JL, 1994. Surimi and
9885 native codfish contain a common allergen identified as a 63-kDa protein. Allergy, 49, 442-447.

9886 Matheu V, de Barrio M, Sierra Z, Gracia-Bara MT, Tornero P and Baeza ML, 1999. Lupine-induced
9887 anaphylaxis. Ann Allergy Asthma Immunol, 83, 406-408.

9888 Matricardi PM, Bockelbrink A, Beyer K, Keil T, Niggemann B, Gruber C, Wahn U and Lau S, 2008.
9889 Primary versus secondary immunoglobulin E sensitization to soy and wheat in the Multi-Centre
9890 Allergy Study cohort. Clin Exp Allergy, 38, 493-500.

9891 Matsuda R, Yoshioka Y, Akiyama H, Aburatani K, Watanabe Y, Matsumoto T, Morishita N, Sato H,
9892 Mishima T, Gamo R, Kihira Y and Maitani T, 2006. Interlaboratory evaluation of two enzyme-
9893 linked immunosorbent assay kits for the detection of egg, milk, wheat, buckwheat, and peanut in
9894 foods. J AOAC Int, 89, 1600-1608.

9895 Matsuo H, Morita E, Tatham AS, Morimoto K, Horikawa T, Osuna H, Ikezawa Z, Kaneko S, Kohno
9896 K and Dekio S, 2004. Identification of the IgE-binding epitope in omega-5 gliadin, a major allergen
9897 in wheat-dependent exercise-induced anaphylaxis. J Biol Chem, 279, 12135-12140.

9898 Mattarozzi M, Bignardi C, Elviri L and Careri M, 2012. Rapid Shotgun Proteomic Liquid
9899 Chromatography-Electrospray Ionization-Tandem Mass Spectrometry-Based Method for the Lupin
9900 (Lupinus albus L.) Multi-allergen Determination in Foods. J Agric Food Chem.

9901 Maulitz RM, Pratt DS and Schocket AL, 1979. Exercise-induced anaphylactic reaction to shellfish. J
9902 Allergy Clin Immunol, 63, 433-434.

9903 McCann D, Barrett A, Cooper A, Crumpler D, Dalen L, Grimshaw K, Kitchin E, Lok K, Porteous L,
9904 Prince E, Sonuga-Barke E, Warner JO and Stevenson J, 2007. Food additives and hyperactive
9905 behaviour in 3-year-old and 8/9-year-old children in the community: a randomised, double-blinded,
9906 placebo-controlled trial. Lancet, 370, 1560-1567.

9907 McFeeters RF and Barish AO, 2003. Sulfite analysis of fruits and vegetables by high-performance
9908 liquid chromatography (HPLC) with ultraviolet spectrophotometric detection. J Agric Food Chem,
9909 51, 1513-1517.

9910 Meggs W, Atkins F, Wright R, Fishman M, Kaliner M and Metcalfe D, 1985. Failure of sulphites to
9911 produce clinical responses in patients with systemic mastocytosis or recurrent anaphylaxis: results
9912 of a single-blind study. J Allergy Clin Immunol, 76, 840-846.

9913 Melioli G, Bonifazi F, Bonini S, Maggi E, Mussap M, Passalacqua G, Rossi ER, Vacca A, Canonica
9914 GW and Italian Board for I, 2011. The ImmunoCAP ISAC molecular allergology approach in adult
9915 multi-sensitized Italian patients with respiratory symptoms. Clin Biochem, 44, 1005-1011.

9916 Mena MC, Lombardia M, Hernando A, Mendez E and Albar JP, 2012. Comprehensive analysis of
9917 gluten in processed foods using a new extraction method and a competitive ELISA based on the R5
9918 antibody. Talanta, 91, 33-40.

9919 Menendez-Arias L, Moneo I, Dominguez J and Rodriguez R, 1988. Primary structure of the major
9920 allergen of yellow mustard (Sinapis alba L.) seed, Sin a I. Eur J Biochem, 177, 159-166.

9921 Menendez-Arias L, Dominguez J, Moneo I and Rodriguez R, 1990. Epitope mapping of the major
9922 allergen from yellow mustard seeds, Sin a I. Mol Immunol, 27, 143-150.

9923 Meresse B, Ripoche J, Heyman M and Cerf-Bensussan N, 2009. Celiac disease: from oral tolerance to
9924 intestinal inflammation, autoimmunity and lymphomagenesis. Mucosal Immunol, 2, 8-23.

9925 Mermelstein N, 2008. Testing for allergens. Food Technology, 62,7074.

9926 Metsala J, Lundqvist A, Kaila M, Gissler M, Klaukka T and Virtanen SM, 2010. Maternal and
9927 perinatal characteristics and the risk of cow's milk allergy in infants up to 2 years of age: a case-
9928 control study nested in the Finnish population. Am J Epidemiol, 171, 1310-1316.

9929 Mills EN, Sancho AI, Rigby NM, Jenkins JA and Mackie AR, 2009. Impact of food processing on the
9930 structural and allergenic properties of food allergens. Mol Nutr Food Res, 53, 963-969.

9931 Mine Y and Zhang JW, 2002. Comparative studies on antigenicity and allergenicity of native and
9932 denatured egg white proteins. J Agric Food Chem, 50, 2679-2683.

9933 Mine Y and Yang M, 2008. Recent advances in the understanding of egg allergens: basic, industrial,
9934 and clinical perspectives. J Agric Food Chem, 56, 4874-4900.

9935 Minh Hiep H, Endo T, Kerman K, Chikae M, Kim D-K, Yamamura S, Takamura Y and Tamiya E,
9936 2007. A localized surface plasmon resonance based immunosensor for the detection of casein in
9937 milk. Science and Technology of Advanced Materials, 8, 331-338.

9938 Mirotti L, Florsheim E, Rundqvist L, Larsson G, Spinozzi F, Leite-de-Moraes M, Russo M and
9939 Alcocer M, 2013. Lipids are required for the development of Brazil nut allergy: the role of mouse
9940 and human iNKT cells. Allergy, 68, 74-83.

9941 Mischek D and Krapfenbauer-Cermak C, 2012. Exposure assessment of food preservatives (sulphites,
9942 benzoic and sorbic acid) in Austria. Food Addit Contam Part A Chem Anal Control Expo Risk
9943 Assess, 29, 371-382.

9944 Mistrello G, Falagiani P, Riva G, Gentili M and Antonicelli L, 1992. Cross-reactions between
9945 shellfish and house-dust mite. Allergy, 47, 287.

9946 Mita H, Koketsu A, Ishizaki S and Shiomi K, 2013. Molecular cloning and functional expression of
9947 allergenic sarcoplasmic calcium-binding proteins from Penaeus shrimps. Journal of the Science of
9948 Food and Agriculture, 93, 1737-1742.

9949 Mittag D, Akkerdaas J, Ballmer-Weber BK, Vogel L, Wensing M, Becker W-M, Koppelman SJ,
9950 Knulst AC, Helbling A, Hefle SL, van Ree R and Vieths S, 2004a. Ara h 8, a Bet v 1–homologous
9951 allergen from peanut, is a major allergen in patients with combined birch pollen and peanut allergy.
9952 Journal of Allergy and Clinical Immunology, 114, 1410-1417.

9953 Mittag D, Vieths S, Vogel L, Becker W-M, Rihs H-P, Helbling A, Wüthrich B and Ballmer-Weber
9954 BK, 2004b. Soybean allergy in patients allergic to birch pollen: Clinical investigation and
9955 molecular characterization of allergens. Journal of Allergy and Clinical Immunology, 113, 148-
9956 154.

9957 Moissidis I, Chaidaroon D, Vichyanond P and Bahna SL, 2005. Milk-induced pulmonary disease in
9958 infants (Heiner syndrome). Pediatr Allergy Immunol, 16, 545-552.

9959 Molberg O, Uhlen AK, Jensen T, Flaete NS, Fleckenstein B, Arentz-Hansen H, Raki M, Lundin KE
9960 and Sollid LM, 2005. Mapping of gluten T-cell epitopes in the bread wheat ancestors: implications
9961 for celiac disease. Gastroenterology, 128, 393-401.

9962 Monaci L, Tregoat V, Hengel A and Anklam E, 2006. Milk allergens, their characteristics and their
9963 detection in food: A review. European Food Research and Technology, 223, 149-179.

9964 Monaci L and van Hengel AJ, 2008. Development of a method for the quantification of whey allergen
9965 traces in mixed-fruit juices based on liquid chromatography with mass spectrometric detection.
9966 Journal of Chromatography A, 1192, 113-120.

9967 Monaci L and Visconti A, 2009. Mass spectrometry-based proteomics methods for analysis of food
9968 allergens. TrAC Trends in Analytical Chemistry, 28, 581-591.

9969 Monaci L and Visconti A, 2010. Immunochemical and DNA-based methods in food allergen analysis
9970 and quality assurance perspectives. Trends in Food Science & Technology, 21, 272-283.

9971 Monaci L, Losito I, Palmisano F and Visconti A, 2011. Reliable detection of milk allergens in food
9972 using a high-resolution, stand-alone mass spectrometer. J AOAC Int, 94, 1034-1042.

9973 Monaci L, Losito I, De Angelis E, Pilolli R and Visconti A, 2013. Multi-allergen quantification of
9974 fining-related egg and milk proteins in white wines by high-resolution mass spectrometry. Rapid
9975 Commun Mass Spectrom, 27, 2009-2018.

9976 Mondoulet L, Paty E, Drumare MF, Ah-Leung S, Scheinmann P, Willemot RM, Wal JM and Bernard
9977 H, 2005. Influence of thermal processing on the allergenicity of peanut proteins. J Agric Food
9978 Chem, 53, 4547-4553.

9979 Moneret-Vautrin D and André C, 1983. Immunopathologie d'Allergie Alimentaire et Fausses
9980 Allergies Alimentaires. Masson Paris, 63.

9981 Moneret-Vautrin D and Kanny G, 1995. L'anaphylaxie alimentaire. Nouvelle enquête multicentrique
9982 française. Ann Gastroentrol Hepatol, 31, 256-263.

9983 Moneret-Vautrin D, Kanny G and Parisot L, 2002a. Première enquête sur le 'Réseau d'allergo-
9984 vigilance' en allergie alimentaire. Allerg Immunol (Paris), 34, 194-198.

9985 Moneret-Vautrin D, Kanny G P, P, Denery-Papini S, Morisset M L, V, Parisot L, Beaudouin E,
9986 Croizier A, Guenard L, Sergeant P, Guérin L, Frémont S, Commun N and Battais F, 2003. Étude
9987 prospective 1999-2002 de l'allergie alimentaire à la farine de blé chez l'enfant et chez l'adulte,
9988 comparée à la maladie coeliaque. Association de DR 1 à la l'allergie chez l'enfant. Alim Inter, 8: 2-
9989 8.

9990 Moneret-Vautrin DA, Hatahet R, Kanny G and Ait-Djafer Z, 1991. Allergenic peanut oil in milk
9991 formulas. The Lancet, 338, 1149.

9992 Moneret-Vautrin DA, Hatahet R and Kanny G, 1994. Risks of milk formulas containing peanut oil
9993 contaminated with peanut allergens in infants with atopic dermatitis. Pediatric Allergy and
9994 Immunology, 5, 184-188.

9995 Moneret-Vautrin DA, Guerin L, Kanny G, Flabbee J, Fremont S and Morisset M, 1999. Cross-
9996 allergenicity of peanut and lupine: the risk of lupine allergy in patients allergic to peanuts. J
9997 Allergy Clin Immunol, 104, 883-888.

9998 Moneret-Vautrin DA, 2001. [Current features of food allergies: the need of allergy surveillance]. Bull
9999 Acad Natl Med, 185, 943-957; discussion 958-962.

10000 Moneret-Vautrin DA, Morisset M, Flabbee J, Kanny G, Kirch F and Parisot L, 2002b. Unusual soy oil
10001 allergy. Allergy, 57, 266-267.

10002 Moneret-Vautrin DA, Kanny G, Morisset M, Rance F, Fardeau MF and Beaudouin E, 2004. Severe
10003 food anaphylaxis: 107 cases registered in 2002 by the Allergy Vigilance Network. Eur Ann Allergy
10004 Clin Immunol, 36, 46-51.

10005 Moneret-Vautrin DA and Kanny G, 2004. Update on threshold doses of food allergens: implications
10006 for patients and the food industry. Curr Opin Allergy Clin Immunol, 4, 215-219.

10007 Monreal P, Botey J, Pena M, Marin A and Eseverri JL, 1992. Mustard allergy. Two anaphylactic
10008 reactions to ingestion of mustard sauce. Ann Allergy, 69, 317-320.

10009 Monsalve RI, Gonzalez de la Pena MA, Menendez-Arias L, Lopez-Otin C, Villalba M and Rodriguez
10010 R, 1993. Characterization of a new oriental-mustard (Brassica juncea) allergen, Bra j IE: detection
10011 of an allergenic epitope. Biochem J, 293 (Pt 3), 625-632.

10012 Monsalve RI, Gonzalez de la Pena MA, Lopez-Otin C, Fiandor A, Fernandez C, Villalba M and
10013 Rodriguez R, 1997. Detection, isolation and complete amino acid sequence of an aeroallergenic
10014 protein from rapeseed flour. Clin Exp Allergy, 27, 833-841.

10015 Montesinos E, Martorell A, Felix R and Cerda JC, 2010. Egg white specific IgE levels in serum as
10016 clinical reactivity predictors in the course of egg allergy follow-up. Pediatr Allergy Immunol, 21,
10017 634-639.

10018 Moon A and Kleinman RE, 1995. Allergic gastroenteropathy in children. Ann Allergy Asthma
10019 Immunol, 74, 5-12; quiz 12-16.

10020 Moreno FJ, Maldonado BM, Wellner N and Mills EN, 2005. Thermostability and in vitro digestibility
10021 of a purified major allergen 2S albumin (Ses i 1) from white sesame seeds (Sesamum indicum L.).
10022 Biochim Biophys Acta, 1752, 142-153.

10023 Moreno FJ, 2007. Gastrointestinal digestion of food allergens: Effect on their allergenicity.
10024 Biomedicine & Pharmacotherapy, 61, 50-60.

10025 Morishita N, Kamiya K, Matsumoto T, Sakai S, Teshima R, Urisu A, Moriyama T, Ogawa T,
10026 Akiyama H and Morimatsu F, 2008. Reliable enzyme-linked immunosorbent assay for the
10027 determination of soybean proteins in processed foods. J Agric Food Chem, 56, 6818-6824.

10028 Morisset M, Moneret-Vautrin DA, Kanny G, Guenard L, Beaudouin E, Flabbee J and Hatahet R,
10029 2003a. Thresholds of clinical reactivity to milk, egg, peanut and sesame in immunoglobulin E-
10030 dependent allergies: evaluation by double-blind or single-blind placebo-controlled oral challenges.
10031 Clin Exp Allergy, 33, 1046-1051.

10032 Morisset M, Moneret-Vautrin DA, Maadi F, Fremont S, Guenard L, Croizier A and Kanny G, 2003b.
10033 Prospective study of mustard allergy: first study with double-blind placebo-controlled food
10034 challenge trials (24 cases). Allergy, 58, 295-299.

10035 Morisset M, Moneret-Vautrin DA, Guenard L, Cuny JM, Frentz P, Hatahet R, Hanss C, Beaudouin E,
10036 Petit N and Kanny G, 2007. Oral desensitization in children with milk and egg allergies obtains
10037 recovery in a significant proportion of cases. A randomized study in 60 children with cow's milk
10038 allergy and 90 children with egg allergy. Eur Ann Allergy Clin Immunol, 39, 12-19.

10039 Morita E, Kunie K and Matsuo H, 2007. Food-dependent exercise-induced anaphylaxis. J Dermatol
10040 Sci, 47, 109-117.

10041 Morita E, Chinuki Y, Takahashi H, Nabika T, Yamasaki M and Shiwaku K, 2012. Prevalence of
10042 wheat allergy in Japanese adults. Allergol Int, 61, 101-105.

10043 Moriyama T, Machidori M, Ozasa S, Maebuchi M, Urade R, Takahashi K, Ogawa T and Maruyama
10044 N, 2005. A novel enzyme-linked immunosorbent assay for quantification of soybean beta-
10045 conglycinin, a major soybean storage protein, in soybean and soybean food products. J Nutr Sci
10046 Vitaminol (Tokyo), 51, 34-39.

10047 Moroz LA and Yang WH, 1980. Kunitz soybean trypsin inhibitor: a specific allergen in food
10048 anaphylaxis. N Engl J Med, 302, 1126-1128.

10049 Motoyama K, Ishizaki S, Nagashima Y and Shiomi K, 2006. Cephalopod tropomyosins: identification
10050 as major allergens and molecular cloning. Food Chem Toxicol, 44, 1997-2002.

10051 Motoyama K, Suma Y, Ishizaki S, Nagashima Y, Lu Y, Ushio H and Shiomi K, 2008. Identification of
10052 Tropomyosins as Major Allergens in Antarctic Krill and Mantis Shrimp and Their Amino Acid
10053 Sequence Characteristics. Marine Biotechnology, 10, 709-718.

10054 Mouécoucou J, Villaume C, Sanchez C and Méjean L, 2004. β-Lactoglobulin/polysaccharide
10055 interactions during in vitro gastric and pancreatic hydrolysis assessed in dialysis bags of different
10056 molecular weight cut-offs. Biochimica et Biophysica Acta (BBA) - General Subjects, 1670, 105-
10057 112.

10058 Muccilli V, Lo Bianco M, Cunsolo V, Saletti R, Gallo G and Foti S, 2011. High molecular weight
10059 glutenin subunits in some durum wheat cultivars investigated by means of mass spectrometric
10060 techniques. J Agric Food Chem, 59, 12226-12237.

10061 Mujico JR, Lombardía M, Mena MC, Méndez E and Albar JP, 2011. A highly sensitive real-time PCR
10062 system for quantification of wheat contamination in gluten-free food for celiac patients. Food
10063 Chemistry, 128, 795-801.

10064 Mujoo R, Trinh DT and Ng PKW, 2003. Characterization of storage proteins in different soybean
10065 varieties and their relationship to tofu yield and texture. Food Chemistry, 82, 265-273.

10066 Müller U, Weber W, Hoffmann A, Franke S, Lange R and Vieths S, 1998. Commercial soybean
10067 lecithins: a source of hidden allergens? Zeitschrift für Lebensmitteluntersuchung und -Forschung
10068 A, 207, 341-351.

10069 Mullins RJ, Clark S and Camargo CA, Jr., 2010. Socio-economic status, geographic remoteness and
10070 childhood food allergy and anaphylaxis in Australia. Clin Exp Allergy, 40, 1523-1532.

10071 Musmand JJ, Helbling A and Lehrer SB, 1996. Surimi: something fishy. J Allergy Clin Immunol, 98,
10072 697-699.

10073 Mustafayev R, Civelek E, Orhan F, Yuksel H, Boz AB and Sekerel BE, 2012. Similar prevalence,
10074 different spectrum: IgE-mediated food allergy among Turkish adolescents. Allergol Immunopathol
10075 (Madr).

10076 Mustorp S, Engdahl-Axelsson C, Svensson U and Holck A, 2008. Detection of celery (Apium
10077 graveolens), mustard (Sinapis alba, Brassica juncea, Brassica nigra) and sesame (Sesamum
10078 indicum) in food by real-time PCR. European Food Research and Technology, 226, 771-778.

10079 Mustorp SL, Dromtorp SM and Holck AL, 2011. Multiplex, quantitative, ligation-dependent probe
10080 amplification for determination of allergens in food. J Agric Food Chem, 59, 5231-5239.

10081 Myrmel M, Berg EM, Rimstad E and Grinde B, 2004. Detection of enteric viruses in shellfish from
10082 the Norwegian coast. Appl Environ Microbiol, 70, 2678-2684.

10083 Nakamura A, Watanabe K, Ojima T, Ahn DH and Saeki H, 2005. Effect of maillard reaction on
10084 allergenicity of scallop tropomyosin. J Agric Food Chem, 53, 7559-7564.

10085 Nakano S, Yoshinuma T and Yamada T, 2008. Reactivity of shrimp allergy-related IgE antibodies to
10086 krill tropomyosin. Int Arch Allergy Immunol, 145, 175-181.

10087 Nakayama S, Moncrief ND and Kretsinger RH, 1992. Evolution of EF-hand calcium-modulated
10088 proteins. II. Domains of several subfamilies have diverse evolutionary histories. J Mol Evol, 34,
10089 416-448.

10090 Nassef HM, Bermudo Redondo MC, Ciclitira PJ, Ellis HJ, Fragoso A and O'Sullivan CK, 2008.
10091 Electrochemical immunosensor for detection of celiac disease toxic gliadin in foodstuff. Anal
10092 Chem, 80, 9265-9271.

10093 Nassef HM, Civit L, Fragoso A and O'Sullivan CK, 2009. Amperometric immunosensor for detection
10094 of celiac disease toxic gliadin based on Fab fragments. Anal Chem, 81, 5299-5307.

10095 National Institute for Health and Clinical Excellence, 2011. Food allergy in children and young
10096 people. Diagnosis and assessment of food allergy in children and young people in primary care and
10097 community settings. National Institute for Health and Clinical Excellence, NICE clinical guideline
10098 116.

10099 Navarro MV, Payan MR, Lopez MA, Fernandez-Torres R and Mochon MC, 2010. Rapid flow
10100 injection method for the determination of sulfite in wine using the permanganate-luminol
10101 luminescence system. Talanta, 82, 2003-2006.

10102 Negroni L, Bernard H, Clement G, Chatel JM, Brune P, Frobert Y, Wal JM and Grassi J, 1998. Two-
10103 site enzyme immunometric assays for determination of native and denatured beta-lactoglobulin. J
10104 Immunol Methods, 220, 25-37.

10105 Nelson HS, Lahr J, Rule R, Bock A and Leung D, 1997. Treatment of anaphylactic sensitivity to
10106 peanuts by immunotherapy with injections of aqueous peanut extract. Journal of Allergy and
10107 Clinical Immunology, 99, 744-751.

10108 Nickel R, Kulig M, Forster J, Bergmann R, Bauer CP, Lau S, Guggenmoos-Holzmann I and Wahn U,
10109 1997. Sensitization to hen's egg at the age of twelve months is predictive for allergic sensitization
10110 to common indoor and outdoor allergens at the age of three years. J Allergy Clin Immunol, 99,
10111 613-617.

10112 Nicklas RA, 1989. Sulfites: a review with emphasis on biochemistry and clinical application. Allergy
10113 Proc, 10, 349-356.

10114 Nicolaou N, Poorafshar M, Murray C, Simpson A, Winell H, Kerry G, Härlin A, Woodcock A,
10115 Ahlstedt S and Custovic A, 2010. Allergy or tolerance in children sensitized to peanut: Prevalence
10116 and differentiation using component-resolved diagnostics. Journal of Allergy and Clinical
10117 Immunology, 125, 191-197.e113.

10118 Niemann L, Taylor SL and Hefle SL, 2009. Detection of walnut residues in foods using an enzyme-
10119 linked immunosorbent assay. J Food Sci, 74, T51-57.

10120 Niggemann B, Sielaff B, Beyer K, Binder C and Wahn U, 1999. Outcome of double-blind, placebo-
10121 controlled food challenge tests in 107 children with atopic dermatitis. Clin Exp Allergy, 29, 91-96.

10122 Niggemann B, Reibel S, Roehr CC, Felger D, Ziegert M, Sommerfeld C and Wahn U, 2001.
10123 Predictors of positive food challenge outcome in non-IgE-mediated reactions to food in children
10124 with atopic dermatitis. J Allergy Clin Immunol, 108, 1053-1058.

10125 Niggemann B, Staden U, Rolinck-Werninghaus C and Beyer K, 2006. Specific oral tolerance
10126 induction in food allergy. Allergy, 61, 808-811.

10127 Niggemann B and Beyer K, 2007. Diagnosis of food allergy in children: toward a standardization of
10128 food challenge. J Pediatr Gastroenterol Nutr, 45, 399-404.

10129 Niinimaki A, Bjorksten F, Puukka M, Tolonen K and Hannuksela M, 1989. Spice allergy: results of
10130 skin prick tests and RAST with spice extracts. Allergy, 44, 60-65.

10131 Niinimaki A, Hannuksela M and Makinen-Kiljunen S, 1995. Skin prick tests and in vitro
10132 immunoassays with native spices and spice extracts. Ann Allergy Asthma Immunol, 75, 280-286.

10133 Niinimäki A and Hannuksela M, 1981. Immediate Skin Test Reactions to Spices. Allergy, 36, 487-
10134 493.

10135 Nisbet AD, Saundry RH, Moir AJ, Fothergill LA and Fothergill JE, 1981. The complete amino-acid
10136 sequence of hen ovalbumin. Eur J Biochem, 115, 335-345.

10137 Noorbakhsh R, Mortazavi SA, Sankian M, Shahidi F, Assarehzadegan MA and Varasteh A, 2010a.
10138 Cloning, expression, characterization, and computational approach for cross-reactivity prediction of
10139 manganese superoxide dismutase allergen from pistachio nut. Allergol Int, 59, 295-304.

10140 Noorbakhsh R, Mortazavi SA, Sankian M, Shahidi F, Maleki SJ, Nasiraii LR, Falak R, Sima HR and
10141 Varasteh A, 2010b. Influence of processing on the allergenic properties of pistachio nut assessed in
10142 vitro. J Agric Food Chem, 58, 10231-10235.

10143 Noorbakhsh R, Mortazavi SA, Sankian M, Shahidi F, Tehrani M, Azad FJ, Behmanesh F and Varasteh
10144 A, 2011. Pistachio allergy-prevalence and in vitro cross-reactivity with other nuts. Allergol Int, 60,
10145 425-432.

10146 Nordlee JA, Taylor SL, Townsend JA, Thomas LA and Bush RK, 1996. Identification of a Brazil-nut
10147 allergen in transgenic soybeans. N Engl J Med, 334, 688-692.

10148 Norgaard A and Bindslev-Jensen C, 1992. Egg and milk allergy in adults. Diagnosis and
10149 characterization. Allergy, 47, 503-509.

10150 Norgaard A, Bernard H, Wal JM, Peltre G, Skov IPS, Poulsen LK and Bindslev-Jensen C, 1996. 218
10151 Allergenicity of individual cow milk proteins in DBPCFC-positive milk allergic adults. J Allergy
10152 Clin Immunol, 97, 237.

10153 Novembre E, de Martino M and Vierucci A, 1988. Foods and respiratory allergy. J Allergy Clin
10154 Immunol, 81, 1059-1065.

10155 Novembre E, Moriondo M, Bernardini R, Azzari C, Rossi ME and Vierucci A, 1999. Lupin allergy in
10156 a child. J Allergy Clin Immunol, 103, 1214-1216.

10157 Nowak-Wegrzyn A and Muraro A, 2009. Food protein-induced enterocolitis syndrome. Curr Opin
10158 Allergy Clin Immunol, 9, 371-377.

10159 Nowak-Wegrzyn A and Fiocchi A, 2009. Rare, medium, or well done? The effect of heating and food
10160 matrix on food protein allergenicity. Curr Opin Allergy Clin Immunol, 9, 234-237.

10161 Nowak-Wegrzyn A and Sampson HA, 2011. Future therapies for food allergies. J Allergy Clin
10162 Immunol, 127, 558-573; quiz 574-555.

10163 Nwaru BI and Sheikh A, 2012. Risk factors for the development of egg allergy: progress to date and
10164 future directions. Allergy, 67, 1325-1326.

10165 O'Neil C, Helbling AA and Lehrer SB, 1993. Allergic reactions to fish. Clinical Reviews in Allergy,
10166 11, 183-200.

10167 Oehling A and Cagnani C, 1980. Food allergy and child asthma. Allergol Immunopathol (Madr), 8, 7-
10168 14.

10169 Oehling A, Garcia B, Santos F, Cordoba H, Dieguez I, Fernandez M and Sanz ML, 1992. Food allergy
10170 as a cause of rhinitis and/or asthma. J Investig Allergol Clin Immunol, 2, 78-83.

10171 Ogawa T, Bando N, Tsuji H, Okajima H, Nishikawa K and Sasaoka K, 1991. Investigation of the IgE-
10172 binding proteins in soybeans by immunoblotting with the sera of the soybean-sensitive patients
10173 with atopic dermatitis. J Nutr Sci Vitaminol (Tokyo), 37, 555-565.

10174 Oh HE and Chetty R, 2008. Eosinophilic gastroenteritis: a review. J Gastroenterol, 43, 741-750.

10175 Oh JW, Pyun BY, Choung JT, Ahn KM, Kim CH, Song SW, Son JA, Lee SY and Lee SI, 2004.
10176 Epidemiological change of atopic dermatitis and food allergy in school-aged children in Korea
10177 between 1995 and 2000. J Korean Med Sci, 19, 716-723.

10178 Oliveira SM, Lopes TI, Toth IV and Rangel AO, 2009. Development of a gas diffusion
10179 multicommuted flow injection system for the determination of sulfur dioxide in wines, comparing
10180 malachite green and pararosaniline chemistries. J Agric Food Chem, 57, 3415-3422.

10181 Olszewski A, Pons L, Moutete F, Aimone-Gastin I, Kanny G, Moneret-Vautrin DA and Gueant JL,
10182 1998. Isolation and characterization of proteic allergens in refined peanut oil. Clin Exp Allergy, 28,
10183 850-859.

10184 Oppenheimer JJ, Nelson HS, Bock SA, Christensen F and Leung DYM, 1992. Treatment of peanut
10185 allergy with rush immunotherapy. Journal of Allergy and Clinical Immunology, 90, 256-262.

10186 Orhan F, Karakas T, Cakir M, Aksoy A, Baki A and Gedik Y, 2009. Prevalence of immunoglobulin E-
10187 mediated food allergy in 6-9-year-old urban schoolchildren in the eastern Black Sea region of
10188 Turkey. Clin Exp Allergy, 39, 1027-1035.

10189 Orruño E and Morgan MRA, 2007. Purification and characterisation of the 7S globulin storage protein
10190 from sesame (Sesamum indicum L.). Food Chemistry, 100, 926-934.

10191 Orruño E and Morgan MRA, 2011. Resistance of purified seed storage proteins from sesame
10192 (Sesamum indicum L.) to proteolytic digestive enzymes. Food Chemistry, 128, 923-929.

10193 Ortolani C, Ispano M, Pastorello E, Bigi A and Ansaloni R, 1988. The oral allergy syndrome. Ann
10194 Allergy, 61, 47-52.

10195 Ortolani C, Pastorello EA, Farioli L, Ispano M, Pravettoni V, Berti C, Incorvaia C and Zanussi C,
10196 1993. IgE-mediated allergy from vegetable allergens. Ann Allergy, 71, 470-476.

10197 Ortolani C, 1995. Atlas on mechanisms in adverse reaction to food. Introduction. Allergy, 50, 5.

10198 Ortolani C, Ballmer-Weber BK, Hansen KS, Ispano M, Wuthrich B, Bindslev-Jensen C, Ansaloni R,
10199 Vannucci L, Pravettoni V, Scibilia J, Poulsen LK and Pastorello EA, 2000. Hazelnut allergy: a
10200 double-blind, placebo-controlled food challenge multicenter study. J Allergy Clin Immunol, 105,
10201 577-581.

10202 Osborn DA and Sinn J, 2006. Formulas containing hydrolysed protein for prevention of allergy and
10203 food intolerance in infants. Cochrane Database Syst Rev, CD003664.

10204 Osborne NJ, Koplin JJ, Martin PE, Gurrin LC, Lowe AJ, Matheson MC, Ponsonby AL, Wake M,
10205 Tang ML, Dharmage SC, Allen KJ and HealthNuts I, 2011. Prevalence of challenge-proven IgE-
10206 mediated food allergy using population-based sampling and predetermined challenge criteria in
10207 infants. J Allergy Clin Immunol, 127, 668-676 e661-662.

10208 Ostblom E, Lilja G, Pershagen G, van Hage M and Wickman M, 2008a. Phenotypes of food
10209 hypersensitivity and development of allergic diseases during the first 8 years of life. Clin Exp
10210 Allergy, 38, 1325-1332.

10211 Ostblom E, Wickman M, van Hage M and Lilja G, 2008b. Reported symptoms of food
10212 hypersensitivity and sensitization to common foods in 4-year-old children. Acta Paediatr, 97, 85-
10213 90.

10214 Osterballe M and Bindslev-Jensen C, 2003. Threshold levels in food challenge and specific IgE in
10215 patients with egg allergy: is there a relationship? J Allergy Clin Immunol, 112, 196-201.

10216 Osterballe M, Hansen TK, Mortz CG, Host A and Bindslev-Jensen C, 2005. The prevalence of food
10217 hypersensitivity in an unselected population of children and adults. Pediatr Allergy Immunol, 16,
10218 567-573.

10219 Osterballe M, Mortz CG, Hansen TK, Andersen KE and Bindslev-Jensen C, 2009. The prevalence of
10220 food hypersensitivity in young adults. Pediatr Allergy Immunol, 20, 686-692.

10221 Ou K, Seow TK, Liang RC, Lee BW, Goh DL, Chua KY and Chung MC, 2001. Identification of a
10222 serine protease inhibitor homologue in Bird's Nest by an integrated proteomics approach.
10223 ELECTROPHORESIS, 22, 3589-3595.

10224 Ozol D and Mete E, 2008. Asthma and food allergy. Curr Opin Pulm Med, 14, 9-12.

10225 Pafundo S, Gulli M and Marmiroli N, 2010. Multiplex real-time PCR using SYBR(R) GreenER for
10226 the detection of DNA allergens in food. Anal Bioanal Chem, 396, 1831-1839.

10227 Pafundo S, Gulli M and Marmiroli N, 2011. Comparison of DNA extraction methods and
10228 development of duplex PCR and real-time PCR to detect tomato, carrot, and celery in food. J Agric
10229 Food Chem, 59, 10414-10424.

10230 Pajno GB, La Grutta S, Barberio G, Canonica GW and Passalacqua G, 2002. Harmful effect of
10231 immunotherapy in children with combined snail and mite allergy. J Allergy Clin Immunol, 109,
10232 627-629.

10233 Palle-Reisch M, Wolny M, Cichna-Markl M and Hochegger R, 2013. Development and validation of a
10234 real-time PCR method for the simultaneous detection of black mustard (Brassica nigra) and brown
10235 mustard (Brassica juncea) in food. Food Chem, 138, 348-355.

10236 Palm M, Moneret-Vautrin DA, Kanny G, Denery-Papini S and Fremont S, 1999. Food allergy to egg
10237 and soy lecithins. Allergy, 54, 1116-1117.

10238 Palomares O, Monsalve RI, Rodríguez R and Villalba M, 2002. Recombinant pronapin precursor
10239 produced in Pichia pastoris displays structural and immunologic equivalent properties to its mature
10240 product isolated from rapeseed. European Journal of Biochemistry, 269, 2538-2545.

10241 Palomares O, Cuesta-Herranz J, Rodriguez R and Villalba M, 2005. A recombinant precursor of the
10242 mustard allergen Sin a 1 retains the biochemical and immunological features of the heterodimeric
10243 native protein. Int Arch Allergy Immunol, 137, 18-26.

10244 Palomares O, Vereda A, Cuesta-Herranz J, Villalba M and Rodriguez R, 2007. Cloning, sequencing,
10245 and recombinant production of Sin a 2, an allergenic 11S globulin from yellow mustard seeds. J
10246 Allergy Clin Immunol, 119, 1189-1196.

10247 Palosuo K, Alenius H, Varjonen E, Koivuluhta M, Mikkola J, Keskinen H, Kalkkinen N and Reunala
10248 T, 1999. A novel wheat gliadin as a cause of exercise-induced anaphylaxis. Journal of Allergy and
10249 Clinical Immunology, 103, 912-917.

10250 Palosuo K, Varjonen E, Kekki OM, Klemola T, Kalkkinen N, Alenius H and Reunala T, 2001a. Wheat
10251 omega-5 gliadin is a major allergen in children with immediate allergy to ingested wheat. J Allergy
10252 Clin Immunol, 108, 634-638.

10253 Palosuo K, Alenius H, Varjonen E, Kalkkinen N and Reunala T, 2001b. Rye gamma-70 and gamma-
10254 35 secalins and barley gamma-3 hordein cross-react with omega-5 gliadin, a major allergen in
10255 wheat-dependent, exercise-induced anaphylaxis. Clin Exp Allergy, 31, 466-473.

10256 Palosuo K, Varjonen E, Nurkkala J, Kalkkinen N, Harvima R, Reunala T and Alenius H, 2003.
10257 Transglutaminase-mediated cross-linking of a peptic fraction of omega-5 gliadin enhances IgE
10258 reactivity in wheat-dependent, exercise-induced anaphylaxis. J Allergy Clin Immunol, 111, 1386-
10259 1392.

10260 Panesar SS, Javad S, de Silva D, Nwaru BI, Hickstein L, Muraro A, Roberts G, Worm M, Bilo MB,
10261 Cardona V, Dubois AE, Dunn Galvin A, Eigenmann P, Fernandez-Rivas M, Halken S, Lack G,
10262 Niggemann B, Santos AF, Vlieg-Boerstra BJ, Zolkipli ZQ, Sheikh A, Allergy EF and Anaphylaxis
10263 G, 2013. The epidemiology of anaphylaxis in Europe: a systematic review. Allergy, 68, 1353-1361.

10264 Parisot L, Aparicio C, Moneret-Vautrin DA and Guerin L, 2001. Allergy to lupine flour. Allergy, 56,
10265 918-919.

10266 Park DL, Coates S, Brewer VA, Garber EA, Abouzied M, Johnson K, Ritter B and McKenzie D,
10267 2005. Performance Tested Method multiple laboratory validation study of ELISA-based assays for
10268 the detection of peanuts in food. J AOAC Int, 88, 156-160.

10269 Pascal M, Grishina G, Yang A and Ayuso R, 2012. A sea urchin roe tropomyosin-like protein is
10270 recognized in vitro by shrimp-allergic individuals. J Investig Allergol Clin Immunol, 22, 306-307.

10271 Paschke A, Zunker K, Wigotzki M and Steinhart H, 2001. Determination of the IgE-binding activity
10272 of soy lecithin and refined and non-refined soybean oils. Journal of Chromatography B: Biomedical
10273 Sciences and Applications, 756, 249-254.

10274 Paschke A, 2009. Aspects of food processing and its effect on allergen structure. Mol Nutr Food Res,
10275 53, 959-962.

10276 Pascual C, Martin Esteban M and Crespo JF, 1992. Fish allergy: evaluation of the importance of cross-
10277 reactivity. J Pediatr, 121, S29-34.

10278 Pascual CY, Crespo JF, Martin SS, Ornia N, Ortega N, Caballero T, Muñoz-Pereira M and Martin-
10279 Esteban M, 1997. Cross-reactivity between IgE-binding proteins from Anisakis German cockroach,
10280 and chironomids. Allergy, 52, 514-520.

10281 Pascual CY, Reche M, Fiandor A, Valbuena T, Cuevas T and Esteban MM, 2008. Fish allergy in
10282 childhood. Pediatr Allergy Immunol, 19, 573-579.

10283 Pastorello EA, Farioli L, Pravettoni V, Ispano M, Conti A, Ansaloni R, Rotondo F, Incorvaia C,
10284 Bengtsson A, Rivolta F, Trambaioli C, Previdi M and Ortolani C, 1998. Sensitization to the major
10285 allergen of Brazil nut is correlated with the clinical expression of allergy. Journal of Allergy and
10286 Clinical Immunology, 102, 1021-1027.

10287 Pastorello EA, Farioli L, Pravettoni V, Ispano M, Scibola E, Trambaioli C, Giuffrida MG, Ansaloni R,
10288 Godovac-Zimmermann J, Conti A, Fortunato D and Ortolani C, 2000. The maize major allergen,
10289 which is responsible for food-induced allergic reactions, is a lipid transfer protein. Journal of
10290 Allergy and Clinical Immunology, 106, 744-751.

10291 Pastorello EA and Trambaioli C, 2001a. Isolation of food allergens. J Chromatogr B Biomed Sci Appl,
10292 756, 71-84.

10293 Pastorello EA, Varin E, Farioli L, Pravettoni V, Ortolani C, Trambaioli C, Fortunato D, Giuffrida MG,
10294 Rivolta F, Robino A, Calamari AM, Lacava L and Conti A, 2001b. The major allergen of sesame
10295 seeds (Sesamum indicum) is a 2S albumin. Journal of Chromatography B: Biomedical Sciences
10296 and Applications, 756, 85-93.

10297 Pastorello EA, Vieths S, Pravettoni V, Farioli L, Trambaioli C, Fortunato D, Lüttkopf D, Calamari M,
10298 Ansaloni R, Scibilia J, Ballmer-Weber BK, Poulsen LK, Wütrich B, Hansen KS, Robino AM,
10299 Ortolani C and Conti A, 2002a. Identification of hazelnut major allergens in sensitive patients with
10300 positive double-blind, placebo-controlled food challenge results. Journal of Allergy and Clinical
10301 Immunology, 109, 563-570.

10302 Pastorello EA, Pravettoni V, Calamari AM, Banfi E and Robino AM, 2002b. New plant-origin food
10303 allergens. Allergy, 57, 106-110.

10304 Pastorello EA, Farioli L, Pravettoni V, Robino AM, Scibilia J, Fortunato D, Conti A, Borgonovo L,
10305 Bengtsson A and Ortolani C, 2004. Lipid transfer protein and vicilin are important walnut allergens
10306 in patients not allergic to pollen. J Allergy Clin Immunol, 114, 908-914.

10307 Pastorello EA, Farioli L, Conti A, Pravettoni V, Bonomi S, Iametti S, Fortunato D, Scibilia J,
10308 Bindslev-Jensen C, Ballmer-Weber B, Robino AM and Ortolani C, 2007. Wheat IgE-mediated
10309 food allergy in European patients: alpha-amylase inhibitors, lipid transfer proteins and low-
10310 molecular-weight glutenins. Allergenic molecules recognized by double-blind, placebo-controlled
10311 food challenge. Int Arch Allergy Immunol, 144, 10-22.

10312 Patriarca G, Buonomo A, Roncallo C, Del Ninno M, Pollastrini E, Milani A, De Pasquale T,
10313 Gasbarrini G, Schiavino D and Nucera E, 2002. Oral desensitisation in cow milk allergy:
10314 immunological findings. Int J Immunopathol Pharmacol, 15, 53-58.

10315 Patriarca G, Nucera E, Pollastrini E, Pasquale T, Lombardo C, Buonomo A, Roncallo C, Pecora V,
10316 Musumeci S, Altomonte G, Alonzi C, Schiavino D and Gasbarrini G, 2006. Oral Rush
10317 Desensitization in Peanut Allergy: A Case Report. Dig Dis Sci, 51, 471-473.

10318 Pauli G, Bessot JC, Dietemann-Molard A, Braun PA and Thierry R, 1985. Celery sensitivity: clinical
10319 and immunological correlations with pollen allergy. Clin Allergy, 15, 273-279.

10320 Pearce N, Ait-Khaled N, Beasley R, Mallol J, Keil U, Mitchell E, Robertson C and Group IPTS, 2007.
10321 Worldwide trends in the prevalence of asthma symptoms: phase III of the International Study of
10322 Asthma and Allergies in Childhood (ISAAC). Thorax, 62, 758-766.

10323 Pearson WR and Lipman DJ, 1988. Improved tools for biological sequence comparison. Proc Natl
10324 Acad Sci U S A, 85, 2444-2448.

10325 Pedersen MH, Holzhauser T, Bisson C, Conti A, Jensen LB, Skov PS, Bindslev-Jensen C, Brinch DS
10326 and Poulsen LK, 2008. Soybean allergen detection methods--a comparison study. Mol Nutr Food
10327 Res, 52, 1486-1496.

10328 Pedreschi R, Norgaard J and Maquet A, 2012. Current challenges in detecting food allergens by
10329 shotgun and targeted proteomic approaches: a case study on traces of peanut allergens in baked
10330 cookies. Nutrients, 4, 132-150.

10331 Peeters KA, Nordlee JA, Penninks AH, Chen L, Goodman RE, Bruijnzeel-Koomen CA, Hefle SL,
10332 Taylor SL and Knulst AC, 2007. Lupine allergy: not simply cross-reactivity with peanut or soy. J
10333 Allergy Clin Immunol, 120, 647-653.

10334 Peeters KA, Koppelman SJ, Penninks AH, Lebens A, Bruijnzeel-Koomen CA, Hefle SL, Taylor SL,
10335 van Hoffen E and Knulst AC, 2009. Clinical relevance of sensitization to lupine in peanut-
10336 sensitized adults. Allergy, 64, 549-555.

10337 Pelekis M, Nicolich MJ and Gauthier JS, 2003. Probabilistic framework for the estimation of the adult
10338 and child toxicokinetic intraspecies uncertainty factors. Risk Anal, 23, 1239-1255.

10339 Pelikan Z and Pelikan-Filipek M, 1987. Bronchial response to the food ingestion challenge. Ann
10340 Allergy, 58, 164-172.

10341 Pelkonen AS, Makinen-Kiljunen S, Hilvo S, Siltanen M and Makela MJ, 2011. Severe allergic
10342 reaction to gluten hydrolysate without reaction to wheat. Ann Allergy Asthma Immunol, 106, 343-
10343 344.

10344 Pellegrino L and Tirelli A, 2000. A sensitive HPLC method to detect hen's egg white lysozyme in milk
10345 and dairy products. International Dairy Journal, 10, 435-442.

10346 Penard-Morand C, Raherison C, Kopferschmitt C, Caillaud D, Lavaud F, Charpin D, Bousquet J and
10347 Annesi-Maesano I, 2005. Prevalence of food allergy and its relationship to asthma and allergic
10348 rhinitis in schoolchildren. Allergy, 60, 1165-1171.

10349 Peñas E, Restani P, Ballabio C, Prestamo G, Fiocchi A and Gomez R, 2006a. Evaluation of the
10350 residual antigenicity of dairy whey hydrolysates obtained by combination of enzymatic hydrolysis
10351 and high-pressure treatment. J Food Prot, 69, 1707-1712.

10352 Peñas E, Préstamo G, Polo F and Gomez R, 2006b. Enzymatic proteolysis, under high pressure of
10353 soybean whey: Analysis of peptides and the allergen Gly m 1 in the hydrolysates. Food Chemistry,
10354 99, 569-573.

10355 Peñas E, Gomez R, Frias J, Baeza ML and Vidal-Valverde C, 2011. High hydrostatic pressure effects
10356 on immunoreactivity and nutritional quality of soybean products. Food Chemistry, 125, 423-429.

10357 Pereira B, Venter C, Grundy J, Clayton CB, Arshad SH and Dean T, 2005. Prevalence of sensitization
10358 to food allergens, reported adverse reaction to foods, food avoidance, and food hypersensitivity
10359 among teenagers. J Allergy Clin Immunol, 116, 884-892.

10360 Perez-Calderon R, Gonzalo-Garijo MA, Lamilla-Yerga A, Mangas-Santos R and Moreno-Gaston I,
10361 2007. Recurrent angioedema due to lysozyme allergy. J Investig Allergol Clin Immunol, 17, 264-
10362 266.

10363 Perez-Gordo M, Sanchez-Garcia S, Cases B, Pastor C, Vivanco F and Cuesta-Herranz J, 2008.
10364 Identification of vitellogenin as an allergen in Beluga caviar allergy. Allergy, 63, 479-480.

10365 Permyakov SE, Bakunts AG, Denesyuk AI, Knyazeva EL, Uversky VN and Permyakov EA, 2008.
10366 Apo-parvalbumin as an intrinsically disordered protein. Proteins, 72, 822-836.

10367 Peters RL, Gurrin LC, Dharmage SC, Koplin JJ and Allen KJ, 2013. The natural history of IgE-
10368 mediated food allergy: can skin prick tests and serum-specific IgE predict the resolution of food
10369 allergy? Int J Environ Res Public Health, 10, 5039-5061.

10370 Piboonpocanun S, Jirapongsananuruk O, Tipayanon T, Boonchoo S and Goodman RE, 2011.
10371 Identification of hemocyanin as a novel non-cross-reactive allergen from the giant freshwater
10372 shrimp Macrobrachium rosenbergii. Mol Nutr Food Res, 55, 1492-1498.

10373 Picariello G, Mamone G, Nitride C, Addeo F, Camarca A, Vocca I, Gianfrani C and Ferranti P, 2012.
10374 Shotgun proteome analysis of beer and the immunogenic potential of beer polypeptides. J
10375 Proteomics, 75, 5872-5882.

10376 Pierce RJ, Hillman D, Young IH, O'Donoghue F, Zimmerman PV, West S and Burdon JG, 2005.
10377 Respiratory function tests and their application. Respirology, 10, S1-S19.

10378 Piknova L, Pangallo D and Kuchta T, 2008. A novel real-time polymerase chain reaction (PCR)
10379 method for the detection of hazelnuts in food. European Food Research and Technology, 226,
10380 1155-1158.

10381 Piknová L and Kuchta T, 2007. Detection of cashew nuts in food by real-time polymerase chain
10382 reaction. J Food Nutr Res, 46, 101-104.

10383 Pite H, Prates S, Borrego LM, Matos V, Loureiro V and Leiria-Pinto P, 2012. Resolution of IgE-
10384 mediated fish allergy. Allergol Immunopathol (Madr), 40, 195-197.

10385 Platteau C, De Loose M, De Meulenaer B and Taverniers I, 2011a. Detection of allergenic ingredients
10386 using real-time PCR: a case study on hazelnut (Corylus avellena) and soy (Glycine max). J Agric
10387 Food Chem, 59, 10803-10814.

10388 Platteau C, Cucu T, De Meulenaer B, Devreese B, De Loose M and Taverniers I, 2011b. Effect of
10389 protein glycation in the presence or absence of wheat proteins on detection of soybean proteins by
10390 commercial ELISA. Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 28, 127-
10391 135.

10392 Platteau C, De Loose M, De Meulenaer B and Taverniers I, 2011c. Quantitative detection of hazelnut
10393 (Corylus avellana) in cookies: ELISA versus real-time PCR. J Agric Food Chem, 59, 11395-11402.

10394 Poikonen S, Rance F, Puumalainen TJ, Le Manach G, Reunala T and Turjanmaa K, 2009.
10395 Sensitization and allergy to turnip rape: a comparison between the Finnish and French children
10396 with atopic dermatitis. Acta Paediatr, 98, 310-315.

10397 Polenta G, Godefroy-Benrejeb S, Delahaut P, Weber D and Abbott M, 2010. Development of a
10398 Competitive ELISA for the Detection of Pecan (Carya illinoinensis (Wangenh.) K. Koch) Traces in
10399 Food. Food Analytical Methods, 3, 375-381.

10400 Polenta G, Weber D, Godefroy-Benrejeb S and Abbott M, 2012. Effect of Processing on the
10401 Detectability of Pecan Proteins Assessed by Immunological and Proteomic Tools. Food Analytical
10402 Methods, 5, 216-225.

10403 Pollet J, Delport F, Janssen KP, Tran DT, Wouters J, Verbiest T and Lammertyn J, 2011. Fast and
10404 accurate peanut allergen detection with nanobead enhanced optical fiber SPR biosensor. Talanta,
10405 83, 1436-1441.

10406 Poms R, Lisi C, Summa C, Stroka J and Anklam E, 2003. In-house validation of commercially
10407 available ELISA kits for peanut allergens in foods. Report for the Institute of Reference Materials
10408 and Measurements, Joint Research Center, European commission. EUR 20767 EN.

10409 Poms RE and Anklam E, 2004. Effects of chemical, physical, and technological processes on the
10410 nature of food allergens. J AOAC Int, 87, 1466-1474.

10411 Poms RE, Anklam E and Kuhn M, 2004. Polymerase chain reaction techniques for food allergen
10412 detection. J AOAC Int, 87, 1391-1397.

10413 Poms RE, Klein CL and Anklam E, 2004a. Methods for allergen analysis in food: a review. Food
10414 Addit Contam, 21, 1-31.

10415 Poms RE, Agazzi ME, Bau A, Brohee M, Capelletti C, Norgaard JV and Anklam E, 2005. Inter-
10416 laboratory validation study of five commercial ELISA test kits for the determination of peanut
10417 proteins in biscuits and dark chocolate. Food Addit Contam, 22, 104-112.

10418 Poole JA, Barriga K, Leung DY, Hoffman M, Eisenbarth GS, Rewers M and Norris JM, 2006. Timing
10419 of initial exposure to cereal grains and the risk of wheat allergy. Pediatrics, 117, 2175-2182.

10420 Prausnitz C and Küstner H, 1921. Studien über die Ueberempfindlichkeit. Centr Blad Bakteriol, 86,
10421 160-169.

10422 Pravettoni V, Primavesi L, Farioli L, Brenna OV, Pompei C, Conti A, Scibilia J, Piantanida M,
10423 Mascheri A and Pastorello EA, 2009. Tomato allergy: detection of IgE-binding lipid transfer

10424 proteins in tomato derivatives and in fresh tomato peel, pulp, and seeds. J Agric Food Chem, 57,
10425 10749-10754.

10426 Pravettoni V, Primavesi L and Piantanida M, 2012. Anisakis simplex: current knowledge. Eur Ann
10427 Allergy Clin Immunol, 44, 150-156.

10428 Prenner BM and Stevens JJ, 1976. Anaphylaxis after ingestion of sodium bisulfite. Ann Allergy, 37,
10429 180-182.

10430 Prescott SL, Bouygue GR, Videky D and Fiocchi A, 2010. Avoidance or exposure to foods in
10431 prevention and treatment of food allergy? Curr Opin Allergy Clin Immunol, 10, 258-266.

10432 Prester L, 2011. Biogenic amines in fish, fish products and shellfish: a review. Food Addit Contam
10433 Part A Chem Anal Control Expo Risk Assess, 28, 1547-1560.

10434 Prieto A, Razzak E, Lindo DP, Alvarez-Perea A, Rueda M and Baeza ML, 2010. Recurrent
10435 anaphylaxis due to lupin flour: primary sensitization through inhalation. J Investig Allergol Clin
10436 Immunol, 20, 76-79.

10437 Priftis KN, Mermiri D, Papadopoulou A, Papadopoulos M, Fretzayas A and Lagona E, 2008. Asthma
10438 symptoms and bronchial reactivity in school children sensitized to food allergens in infancy. J
10439 Asthma, 45, 590-595.

10440 Pumphrey RS and Stanworth SJ, 1996. The clinical spectrum of anaphylaxis in north-west England.
10441 Clin Exp Allergy, 26, 1364-1370.

10442 Pumphrey RS, 2000. Lessons for management of anaphylaxis from a study of fatal reactions. Clin Exp
10443 Allergy, 30, 1144-1150.

10444 Pumphrey RS, 2004. Fatal anaphylaxis in the UK, 1992-2001. Novartis Found Symp, 257, 116-128;
10445 discussion 128-132, 157-160, 276-185.

10446 Pumphrey RSH and Gowland MH, 2007. Further fatal allergic reactions to food in the United
10447 Kingdom, 1999-2006. J Allergy Clin Immunol, 119, 1018-1019.

10448 Pundir CS and Rawal R, 2013. Determination of sulfite with emphasis on biosensing methods: a
10449 review. Anal Bioanal Chem, 405, 3049-3062.

10450 Pyrhonen K, Nayha S, Kaila M, Hiltunen L and Laara E, 2009. Occurrence of parent-reported food
10451 hypersensitivities and food allergies among children aged 1-4 yr. Pediatr Allergy Immunol, 20,
10452 328-338.

10453 Quaresma RR, Viseu R, Martins LM, Tomaz E and Inacio F, 2007. Allergic primary sensitization to
10454 lupine seed. Allergy, 62, 1473-1474.

10455 Quirce S, Marañón F, Umpiérrez A, De Las Heras M, Fernández-Caldas E and Sastre J, 2001. Chicken
10456 serum albumin (Gal d 5*) is a partially heat-labile inhalant and food allergen implicated in the bird-
10457 egg syndrome. Allergy, 56, 754-762.

10458 Radauer C and Breiteneder H, 2006. Pollen allergens are restricted to few protein families and show
10459 distinct patterns of species distribution. Journal of Allergy and Clinical Immunology, 117, 141-147.

10460 Radauer C, Willerroider M, Fuchs H, Hoffmann-Sommergruber K, Thalhamer J, Ferreira F, Scheiner
10461 O and Breiteneder H, 2006. Cross-reactive and species-specific immunoglobulin E epitopes of
10462 plant profilins: an experimental and structure-based analysis. Clin Exp Allergy, 36, 920-929.

10463 Radauer C and Breiteneder H, 2007. Evolutionary biology of plant food allergens. Journal of Allergy
10464 and Clinical Immunology, 120, 518-525.

10465 Rancé F and Dutau G, 1997. Labial food challenge in children with food allergy. Pediatr Allergy
10466 Immunol, 8, 41-44.

10467 Rancé F, Kanny G, Dutau G and Moneret-Vautrin D, 1998. Clinical features in food allergy. Rev
10468 Franc Allergol Immunol Clin, 38(10), 900-905.

10469 Rancé F, Kanny G, Dutau G and Moneret-Vautrin DA, 1999. Food hypersensitivity in children:
10470 clinical aspects and distribution of allergens. Pediatr Allergy Immunol, 10, 33-38.

10471 Rancé F, Dutau G and Abbal M, 2000. Mustard allergy in children. Allergy, 55, 496-500.

10472 Rancé F, Abbal M and Dutau G, 2001. Mustard allergy in children. Pediatr Pulmonol, Suppl 23, 44-
10473 45.

10474 Rancé F, Abbal M and Lauwers-Cances V, 2002. Improved screening for peanut allergy by the
10475 combined use of skin prick tests and specific IgE assays. J Allergy Clin Immunol, 109, 1027-1033.

10476 Rancé F and Dutau G, 2002. [Asthma and food allergy: report of 163 pediatric cases]. Arch Pediatr, 9
10477 Suppl 3, 402s-407s.

10478 Rancé F, Grandmottet X and Grandjean H, 2005. Prevalence and main characteristics of
10479 schoolchildren diagnosed with food allergies in France. Clin Exp Allergy, 35, 167-172.

10480 Rangsithienchai P, Zhuang Y, Hansen K and Dreskin SC, 2013. Determining the Most Potent
10481 Allergens of Walnut. J Allergy Clin Immunol, 131, AB18.

10482 Raulf-Heimsoth M, Kespohl S, Crespo JF, Rodriguez J, Feliu A, Bruning T and Rihs HP, 2007.
10483 Natural rubber latex and chestnut allergy: cross-reactivity or co-sensitization? Allergy, 62, 1277-
10484 1281.

10485 Real A, Comino I, de Lorenzo L, Merchan F, Gil-Humanes J, Gimenez MJ, Lopez-Casado MA,
10486 Torres MI, Cebolla A, Sousa C, Barro F and Piston F, 2012. Molecular and immunological
10487 characterization of gluten proteins isolated from oat cultivars that differ in toxicity for celiac
10488 disease. PLoS One, 7, e48365.

10489 Redl G, Husain FT, Bretbacher IE, Nemes A and Cichna-Markl M, 2010. Development and validation
10490 of a sandwich ELISA for the determination of potentially allergenic sesame (Sesamum indicum) in
10491 food. Anal Bioanal Chem, 398, 1735-1745.

10492 Reese G, Ayuso R and Lehrer SB, 1999. Tropomyosin: an invertebrate pan-allergen. Int Arch Allergy
10493 Immunol, 119, 247-258.

10494 Rehbein H and Lopata AL, 2011. Presence of parvalbumin in different tissues of three sturgeon
10495 species (Acipenser baeri, A. gueldenstaedtii, A. ruthenus). Journal of Applied Ichthyology, 27,
10496 219-225.

10497 Remington B, 2013. Risk Assessment of Trace and Undeclared Allergens in Processed Foods.
10498 Dissertations & Theses in Food Science and Technology, Paper 32.

10499 Rencova E, Kostelnikova D and Tremlova B, 2013. Detection of allergenic parvalbumin of Atlantic
10500 and Pacific herrings in fish products by PCR. Food Addit Contam Part A Chem Anal Control Expo
10501 Risk Assess, 30, 1679-1683.

10502 Reschiglian P and Moon MH, 2008. Flow field-flow fractionation: A pre-analytical method for
10503 proteomics. J Proteomics, 71, 265-276.

10504 Resta D, Brambilla F and Arnoldi A, 2012. HPLC-Chip-Multiple Reaction Monitoring (MRM)
10505 method for the label-free absolute quantification of γ-conglutin in lupin: Proteotypic peptides and
10506 standard addition method. Food Chemistry, 131, 126-133.

10507 Restani P, Velona T, Plebani A, Ugazio AG, Poiesi C, Muraro A and Galli CL, 1995. Evaluation by
10508 SDS-PAGE and immunoblotting of residual antigenicity in hydrolysed protein formulas. Clin Exp
10509 Allergy, 25, 651-658.

10510 Restani P, Fiocchi A, Beretta B, Velona T, Giovannini M and Galli CL, 1997. Meat allergy: III--
10511 Proteins involved and cross-reactivity between different animal species. J Am Coll Nutr, 16, 383-
10512 389.

10513 Restani P, Gaiaschi A, Plebani A, Beretta B, Cavagni G, Fiocchi A, Poiesi C, Velona T, Ugazio AG
10514 and Galli CL, 1999. Cross-reactivity between milk proteins from different animal species. Clin Exp
10515 Allergy, 29, 997-1004.

10516 Restani P, Beretta B, Fiocchi A, Ballabio C and Galli CL, 2002. Cross-reactivity between mammalian
10517 proteins. Ann Allergy Asthma Immunol, 89, 11-15.

10518 Restani P, Ballabio C, Cattaneo A, Isoardi P, Terracciano L and Fiocchi A, 2004. Characterization of
10519 bovine serum albumin epitopes and their role in allergic reactions. Allergy, 59 Suppl 78, 21-24.

10520 Restani P, Ballabio C and Fiocchi A, 2006. Milk allergens: chemical characterization, structure
10521 modifications and associated clinical aspects. In: Immunochemistry in dairy research. Ed Pizzano
10522 R. Research Signpost, Kerala, 61-76.

10523 Restani P, Ballabio C, Tripodi S and Fiocchi A, 2009. Meat allergy. Curr Opin Allergy Clin Immunol,
10524 9, 265-269.

10525 Restani P, Uberti F, Tarantino C, Ballabio C, Gombac F, Bastiani E, Bolognini L, Pavanello F and
10526 Danzi R, 2012. Validation by a Collaborative Interlaboratory Study of an ELISA Method for the
10527 Detection of Caseinate Used as a Fining Agent in Wine. Food Analytical Methods, 5, 480-486.

10528 Rihs H-P, Chen Z, Ruëff F, Petersen A, Rozynek P, Heimanna H and Baur X, 1999. IgE binding of the
10529 recombinant allergen soybean profilin (rGly m 3) is mediated by conformational epitopes. Journal
10530 of Allergy and Clinical Immunology, 104, 1293-1301.

10531 Rinaldi M, Harnack L, Oberg C, Schreiner P, St Sauver J and Travis LL, 2012. Peanut allergy
10532 diagnoses among children residing in Olmsted County, Minnesota. J Allergy Clin Immunol, 130,
10533 945-950.

10534 Rivas R N, Dench JE and Caygill JC, 1981. Nitrogen extractability of sesame (Sesamum indicum L.)
10535 seed and the preparation of two protein isolates. Journal of the Science of Food and Agriculture,
10536 32, 565-571.

10537 Ro AD, Saunes M, Smidesang I, Storro O, Oien T, Moen T and Johnsen R, 2012. Agreement of
10538 specific IgE and skin prick test in an unselected cohort of two-year-old children. Eur J Pediatr, 171,
10539 479-484.

10540 Roberts G, Peckitt C, Northstone K, Strachan D, Lack G, Henderson J, Golding J and Team AS, 2005.
10541 Relationship between aeroallergen and food allergen sensitization in childhood. Clin Exp Allergy,
10542 35, 933-940.

10543 Robotham JM, Teuber SS, Sathe SK and Roux KH, 2002. Linear IgE epitope mapping of the English
10544 walnut (Juglans regia) major food allergen, Jug r 1. J Allergy Clin Immunol, 109, 143-149.

10545 Robotham JM, Wang F, Seamon V, Teuber SS, Sathe SK, Sampson HA, Beyer K, Seavy M and Roux
10546 KH, 2005. Ana o 3, an important cashew nut (Anacardium occidentale L.) allergen of the 2S
10547 albumin family. J Allergy Clin Immunol, 115, 1284-1290.

10548 Robotham JM, Xia L, Willison LN, Teuber SS, Sathe SK and Roux KH, 2010. Characterization of a
10549 cashew allergen, 11S globulin (Ana o 2), conformational epitope. Mol Immunol, 47, 1830-1838.

10550 Röder M, Vieths S and Holzhauser T, 2009. Commercial lateral flow devices for rapid detection of
10551 peanut (Arachis hypogaea) and hazelnut (Corylus avellana) cross-contamination in the industrial
10552 production of cookies. Anal Bioanal Chem, 395, 103-109.

10553 Röder M, Filbert H and Holzhauser T, 2010. A novel, sensitive and specific real-time PCR for the
10554 detection of traces of allergenic Brazil nut (Bertholletia excelsa) in processed foods. Anal Bioanal
10555 Chem, 398, 2279-2288.

10556 Röder M, Kleiner K, Sachs A, Keil N and Holzhauser T, 2013. Detectability of Lupine Seeds by
10557 ELISA and PCR May Be Strongly Influenced by Potential Differences between Cultivars. J Agric
10558 Food Chem, 61, 5936-5945.

10559 Rodríguez-Del Rio P, Sanchez-Lopez J, Robledo Echarren T, Martinez-Cocera C and Fernandez-
10560 Rivas M, 2009. Selective allergy to Venus antiqua clam. Allergy, 64, 815.

10561 Rodríguez-Perez R, Fernandez-Rivas M, Gonzalez-Mancebo E, Sanchez-Monge R, Diaz-Perales A
10562 and Salcedo G, 2003. Peach profilin: cloning, heterologous expression and cross-reactivity with
10563 Bet v 2. Allergy, 58, 635-640.

10564 Rodríguez J, Reaño M, Vives R, Canto G, Daroca P, Crespo JF, Vila C, Villarreal O and Bensabat Z,
10565 1997. Occupational asthma caused by fish inhalation. Allergy, 52, 866-869.

10566 Rodríguez J, Crespo JF, Burks W, Rivas-Plata C, Fernandez-Anaya S, Vives R and Daroca P, 2000.
10567 Randomized, double-blind, crossover challenge study in 53 subjects reporting adverse reactions to
10568 melon (Cucumis melo). J Allergy Clin Immunol, 106, 968-972.

10569 Roehr CC, Edenharter G, Reimann S, Ehlers I, Worm M, Zuberbier T and Niggemann B, 2004. Food
10570 allergy and non-allergic food hypersensitivity in children and adolescents. Clin Exp Allergy, 34,
10571 1534-1541.

10572 Rolinck-Werninghaus C, Niggemann B, Grabenhenrich L, Wahn U and Beyer K, 2012. Outcome of
10573 oral food challenges in children in relation to symptom-eliciting allergen dose and allergen-specific
10574 IgE. Allergy, 67, 951-957.

10575 Rolland JM, Apostolou E, de Leon MP, Stockley CS and O'Hehir RE, 2008. Specific and sensitive
10576 enzyme-linked immunosorbent assays for analysis of residual allergenic food proteins in
10577 commercial bottled wine fined with egg white, milk, and nongrape-derived tannins. J Agric Food
10578 Chem, 56, 349-354.

10579 Rona RJ, Keil T, Summers C, Gislason D, Zuidmeer L, Sodergren E, Sigurdardottir ST, Lindner T,
10580 Goldhahn K, Dahlstrom J, McBride D and Madsen C, 2007. The prevalence of food allergy: a
10581 meta-analysis. J Allergy Clin Immunol, 120, 638-646.

10582 Ronchetti R, Jesenak M, Trubacova D, Pohanka V and Villa MP, 2008. Epidemiology of atopy patch
10583 tests with food and inhalant allergens in an unselected population of children. Pediatr Allergy
10584 Immunol, 19, 599-604.

10585 Ronning SB, Berdal KG, Andersen CB and Holst-Jensen A, 2006. Novel reference gene, PKABA1,
10586 used in a duplex real-time polymerase chain reaction for detection and quantitation of wheat- and
10587 barley-derived DNA. J Agric Food Chem, 54, 682-687.

10588 Rossi S, Scaravelli E, Germini A, Corradini R, Fogher C and Marchelli R, 2006. A PNA-array
10589 platform for the detection of hidden allergens in foodstuffs. Eur Food Res Tech, 223, 1-6.

10590 Roth-Walter F, Berin MC, Arnaboldi P, Escalante CR, Dahan S, Rauch J, Jensen-Jarolim E and Mayer
10591 L, 2008. Pasteurization of milk proteins promotes allergic sensitization by enhancing uptake
10592 through Peyer's patches. Allergy, 63, 882-890.

10593 Roux KH, Teuber SS and Sathe SK, 2003. Tree nut allergens. Int Arch Allergy Immunol, 131, 234-
10594 244.

10595 Rozenfeld P, Docena GH, Anon MC and Fossati CA, 2002. Detection and identification of a soy
10596 protein component that cross-reacts with caseins from cow's milk. Clin Exp Immunol, 130, 49-58.

10597 Rubio-Tapia A, Kyle RA, Kaplan EL, Johnson DR, Page W, Erdtmann F, Brantner TL, Kim WR,
10598 Phelps TK, Lahr BD, Zinsmeister AR, Melton LJ, 3rd and Murray JA, 2009. Increased prevalence
10599 and mortality in undiagnosed celiac disease. Gastroenterology, 137, 88-93.

10600 Rudikoff D and Lebwohl M, 1998. Atopic dermatitis. Lancet, 351, 1715-1721.

10601 Rudolf J, Ansari P, Kern C, Ludwig T and Baumgartner S, 2012. Effects of different extraction buffers
10602 on peanut protein detectability and lateral flow device (LFD) performance. Food Addit Contam
10603 Part A Chem Anal Control Expo Risk Assess, 29, 1-11.

10604 Ruiter B, Tregoat V, M'Rabet L, Garssen J, Bruijnzeel-Koomen CA, Knol EF and Hoffen E, 2006.
10605 Characterization of T cell epitopes in alphas1-casein in cow's milk allergic, atopic and non-atopic
10606 children. Clin Exp Allergy, 36, 303-310.

10607 Ruiter B, Knol EF, van Neerven RJ, Garssen J, Bruijnzeel-Koomen CA, Knulst AC and van Hoffen E,
10608 2007. Maintenance of tolerance to cow's milk in atopic individuals is characterized by high levels
10609 of specific immunoglobulin G4. Clin Exp Allergy, 37, 1103-1110.

10610 Ruiz-Capillas C and Jiménez-Colmenero F, 2009. Application of flow injection analysis for
10611 determining sulphites in food and beverages: A review. Food Chemistry

10612 112, Issue 2, 487–493.

10613 Saarinen KM, Juntunen-Backman K, Jarvenpaa AL, Kuitunen P, Lope L, Renlund M, Siivola M and
10614 Savilahti E, 1999. Supplementary feeding in maternity hospitals and the risk of cow's milk allergy:
10615 A prospective study of 6209 infants. J Allergy Clin Immunol, 104, 457-461.

10616 Sabbah A, Drouet M, Bonneau JC and Le Sellin J, 1987. [Reactions to metabisulfites in aspirin-
10617 induced asthma]. Allerg Immunol (Paris), 19, 25-28.

10618 Sahabudin S, Misnan R, Yadzir ZH, Mohamad J, Abdullah N, Bakhtiar F and Murad S, 2011.
10619 Identification of Major and Minor Allergens of Black Tiger Prawn (Penaeus monodon) and King
10620 Prawn (Penaeus latisulcatus). Malays J Med Sci, 18, 27-32.

10621 Sai XY, Zheng YS, Zhao JM and Hao W, 2011. [A cross sectional survey on the prevalence of food
10622 intolerance and its determinants in Beijing, China]. Zhonghua Liu Xing Bing Xue Za Zhi, 32, 302-
10623 305.

10624 Sakaguchi M, Hori H, Hattori S, Irie S, Imai A, Yanagida M, Miyazawa H, Toda M and Inouye S,
10625 1999. IgE reactivity to alpha1 and alpha2 chains of bovine type 1 collagen in children with bovine
10626 gelatin allergy. J Allergy Clin Immunol, 104, 695-699.

10627 Sakaguchi M, Toda M, Ebihara T, Irie S, Hori H, Imai A, Yanagida M, Miyazawa H, Ohsuna H,
10628 Ikezawa Z and Inouye S, 2000. IgE antibody to fish gelatin (type I collagen) in patients with fish
10629 allergy. J Allergy Clin Immunol, 106, 579-584.

10630 Sakai S, Adachi R, Akiyama H, Teshima R, Doi H and Shibata H, 2010. Determination of walnut
10631 protein in processed foods by enzyme-linked immunosorbent assay: interlaboratory study. J AOAC
10632 Int, 93, 1255-1261.

10633 Sakellariou A, Zannikos K, Tzannis K, Michopoulou C, Emmanouil E, Vassilopoulou E, Sinaniotis A,
10634 Saxoni-Papageorgiou P and Papadopoulos N, 2008. The prevalence of perceived food
10635 hypersensitivity in adults in the city of Athens. Allergy, 63, 583-583.

10636 Sampson HA, Mendelson L and Rosen JP, 1992. Fatal and near-fatal anaphylactic reactions to food in
10637 children and adolescents. N Engl J Med, 327, 380-384.

10638 Sampson HA and James JM, 1992. Respiratory reactions induced by food challenges in children with
10639 atopic dermatitis. Pediatric Allergy and Immunology, 3, 195-200.

10640 Sampson HA, 1997. Food sensitivity and the pathogenesis of atopic dermatitis. J R Soc Med, 90 Suppl
10641 30, 2-8.

10642 Sampson HA, 2000. Food anaphylaxis. Br Med Bull, 56, 925-935.

10643 Sampson HA, 2001. Utility of food-specific IgE concentrations in predicting symptomatic food
10644 allergy. J Allergy Clin Immunol, 107, 891-896.

10645 Sampson HA, 2004. Update on food allergy. J Allergy Clin Immunol, 113, 805-819; quiz 820.

10646 Sampson HA, 2006. Anaphylaxis: persistent enigma. Emerg Med Australas, 18, 101-102.

10647 Samson KT, Chen FH, Miura K, Odajima Y, Iikura Y, Naval Rivas M, Minoguchi K and Adachi M,
10648 2004. IgE binding to raw and boiled shrimp proteins in atopic and nonatopic patients with adverse
10649 reactions to shrimp. Int Arch Allergy Immunol, 133, 225-232.

10650 San Miguel-Moncin M, Pineda F, Llamas E, Amat P, Garcia R, Garcia-Rubio I, Lluch M and Malet
10651 M, 2007. Octopus hypersensitivity. Allergy, 62, 167–551.

10652 Sánchez-Martinez ML, Aguilar-Caballos MP and Gomez-Hens A, 2009. Homogeneous immunoassay
10653 for soy protein determination in food samples using gold nanoparticles as labels and light scattering
10654 detection. Anal Chim Acta, 636, 58-62.

10655 Sánchez-Monge R, Blanco C, Perales AD, Collada C, Carrillo T, Aragoncillo C and Salcedo G, 2000.
10656 Class I chitinases, the panallergens responsible for the latex-fruit syndrome, are induced by
10657 ethylene treatment and inactivated by heating. J Allergy Clin Immunol, 106, 190-195.

10658 Sánchez-Monge R, Blanco C, López-Torrejón G, Cumplido J, Recas M, Figueroa J, Carrillo T and
10659 Salcedo G, 2006. Differential allergen sensitization patterns in chestnut allergy with or without
10660 associated latex-fruit syndrome. Journal of Allergy and Clinical Immunology, 118, 705-710.

10661 Sancho AI and Mills EN, 2010. Proteomic approaches for qualitative and quantitative characterisation
10662 of food allergens. Regul Toxicol Pharmacol, 58, S42-46.

10663 Sandberg M, Lundberg L, Ferm M and Malmheden Yman I, 2003. Real Time PCR for the detection
10664 and discrimination of cereal contamination in gluten free foods. European Food Research and
10665 Technology, 217, 344-349.

10666 Sander I, Raulf-Heimsoth M, Duser M, Flagge A, Czuppon AB and Baur X, 1997. Differentiation
10667 between cosensitization and cross-reactivity in wheat flour and grass pollen-sensitized subjects. Int
10668 Arch Allergy Immunol, 112, 378-385.

10669 Sander I, Rozynek P, Rihs HP, van Kampen V, Chew FT, Lee WS, Kotschy-Lang N, Merget R,
10670 Bruning T and Raulf-Heimsoth M, 2011. Multiple wheat flour allergens and cross-reactive
10671 carbohydrate determinants bind IgE in baker's asthma. Allergy, 66, 1208-1215.

10672 Sanz ML, de Las Marinas MD, Fernandez J and Gamboa PM, 2010. Lupin allergy: a hidden killer in
10673 the home. Clin Exp Allergy, 40, 1461-1466.

10674 Sasaki S, Arikawa Y, Shimomura M, Ikebukuro K and Karube I, 1997. Measurement of sulfite using
10675 sulfite oxidase and luminol chemiluminescence. Analytical Communications, 34, 299-301.

10676 Sastre J, 2010. Molecular diagnosis in allergy. Clin Exp Allergy, 40, 1442-1460.

10677 Sathe SK, Wolf WJ, Roux KH, Teuber SS, Venkatachalam M and Sze-Tao KW, 2002. Biochemical
10678 characterization of amandin, the major storage protein in almond (Prunus dulcis L.). J Agric Food
10679 Chem, 50, 4333-4341.

10680 Sato R, Takeyama H, Tanaka T and Matsunaga T, 2001. Development of high-performance and rapid
10681 immunoassay for model food allergen lysozyme using antibody-conjugated bacterial magenetic
10682 particles and fully automated system. Applied Biochemistry and Biotechnology, 91-93, 109-116.

10683 Savage JH, Matsui EC, Skripak JM and Wood RA, 2007. The natural history of egg allergy. J Allergy
10684 Clin Immunol, 120, 1413-1417.

10685 Savage JH, Kaeding AJ, Matsui EC and Wood RA, 2010. The natural history of soy allergy. J Allergy
10686 Clin Immunol, 125, 683-686.

10687 Savilahti E, 2000. Food-induced malabsorption syndromes. J Pediatr Gastroenterol Nutr, 30 Suppl,
10688 S61-66.

10689 Scarafoni A, Ronchi A and Duranti M, 2009. A real-time PCR method for the detection and
10690 quantification of lupin flour in wheat flour-based matrices. Food Chemistry, 115, 1088-1093.

10691 Scaravelli E, Brohée M, Marchelli R and Hengel A, 2008. Development of three real-time PCR assays
10692 to detect peanut allergen residue in processed food products. European Food Research and
10693 Technology, 227, 857-869.

10694 Scaravelli E, Brohée M, Marchelli R and Hengel A, 2009. The effect of heat treatment on the
10695 detection of peanut allergens as determined by ELISA and real-time PCR. Anal Bioanal Chem,
10696 395, 127-137.

10697 SCF (Scientific Committee for Foods), 1994. Opinion on sulphur dioxide and other sulphiting agents
10698 used as food preservatives. Reports of the Scientific Committee for Foods, Thirty-fifth series.

10699 Schafer T, Kramer U, Dockery D, Vieluf D, Behrendt H and Ring J, 1999. What makes a child
10700 allergic? Analysis of risk factors for allergic sensitization in preschool children from East and West
10701 Germany. Allergy Asthma Proc, 20, 23-27.

10702 Schafer T, Bohler E, Ruhdorfer S, Weigl L, Wessner D, Heinrich J, Filipiak B, Wichmann HE and
10703 Ring J, 2001. Epidemiology of food allergy/food intolerance in adults: associations with other
10704 manifestations of atopy. Allergy, 56, 1172-1179.

10705 Scharf A, Kasel U, Wichmann G and Besler M, 2013. Performance of ELISA and PCR methods for
10706 the determination of allergens in food: an evaluation of six years of proficiency testing for soy
10707 (Glycine max L.) and wheat gluten (Triticum aestivum L.). J Agric Food Chem, 61, 10261-10272.

10708 Scheibe B, Weiss W, Rueff F, Przybilla B and Gorg A, 2001. Detection of trace amounts of hidden
10709 allergens: hazelnut and almond proteins in chocolate. J Chromatogr B Biomed Sci Appl, 756, 229-
10710 237.

10711 Schein CH, Ivanciuc O and Braun W, 2007. Bioinformatics Approaches to Classifying Allergens and
10712 Predicting Cross-Reactivity. Immunology and Allergy Clinics of North America, 27, 1-27.

10713 Scheurer S, Wangorsch A, Haustein D and Vieths S, 2000. Cloning of the minor allergen Api g 4
10714 profilin from celery (Apium graveolens) and its cross-reactivity with birch pollen profilin Bet v 2.
10715 Clin Exp Allergy, 30, 962-971.

10716 Scheurer S, Wangorsch A, Nerkamp J, Skov PS, Ballmer-Weber B, Wuthrich B, Haustein D and
10717 Vieths S, 2001. Cross-reactivity within the profilin panallergen family investigated by comparison
10718 of recombinant profilins from pear (Pyr c 4), cherry (Pru av 4) and celery (Api g 4) with birch
10719 pollen profilin Bet v 2. J Chromatogr B Biomed Sci Appl, 756, 315-325.

10720 Schiller D, Hellmuth M, Gubesch M, Ballmer-Weber B, Bindslev-Jensen C, Niggemann B, Scibillia J,
10721 Hanschmann K-M, Kuhne Y, Reuter A, Vieths S, Wangorsch A and Holzhauser T, 2014. Soybean
10722 allergy: IgE epitopes of glycinin (Gly m 6), an important soybean allergen. Clin Transl Allergy, 4,
10723 O2.

10724 Schimek EM, Zwölfer B, Briza P, Jahn-Schmid B, Vogel L, Vieths S, Ebner C and Bohle B, 2005.
10725 Gastrointestinal digestion of Bet v 1–homologous food allergens destroys their mediator-releasing,
10726 but not T cell–activating, capacity. Journal of Allergy and Clinical Immunology, 116, 1327-1333.

10727 Schirmer T, Hoffimann-Sommergrube K, Susani M, Breiteneder H and Marković-Housley Z, 2005.
10728 Crystal Structure of the Major Celery Allergen Api g 1: Molecular Analysis of Cross-reactivity. J
10729 Mol Biol, 351, 1101-1109.

10730 Schmitt DA, Cheng H, Maleki SJ and Burks AW, 2004. Competitive inhibition ELISA for
10731 quantification of Ara h 1 and Ara h 2, the major allergens of peanuts. J AOAC Int, 87, 1492-1497.

10732 Schneider N, Becker C-M and Pischetsrieder M, 2010a. Analysis of lysozyme in cheese by
10733 immunocapture mass spectrometry. Journal of Chromatography B, 878, 201-206.

10734 Schneider N, Weigel I, Werkmeister K and Pischetsrieder M, 2010b. Development and validation of
10735 an enzyme-linked immunosorbent assay (ELISA) for quantification of lysozyme in cheese. J Agric
10736 Food Chem, 58, 76-81.

10737 Schocker F, Luttkopf D, Muller U, Thomas P, Vieths S and Becker WM, 2000. IgE binding to unique
10738 hazelnut allergens: identification of non pollen-related and heat-stable hazelnut allergens eliciting
10739 severe allergic reactions. Eur J Nutr, 39, 172-180.

10740 Schöll I and Jensen-Jarolim E, 2004. Allergenic Potency of Spices: Hot, Medium Hot, or Very Hot. Int
10741 Arch Allergy Immunol, 135, 247-261.

10742 Schoringhumer K and Cichna-Markl M, 2007. Development of a real-time PCR method to detect
10743 potentially allergenic sesame (Sesamum indicum) in food. J Agric Food Chem, 55, 10540-10547.

10744 Schoringhumer K, Redl G and Cichna-Markl M, 2009. Development and validation of a duplex real-
10745 time PCR method to simultaneously detect potentially allergenic sesame and hazelnut in food. J
10746 Agric Food Chem, 57, 2126-2134.

10747 Schrander JJ, van den Bogart JP, Forget PP, Schrander-Stumpel CT, Kuijten RH and Kester AD,
10748 1993. Cow's milk protein intolerance in infants under 1 year of age: a prospective epidemiological
10749 study. Eur J Pediatr, 152, 640-644.

10750 Schubert-Ullrich P, Rudolf J, Ansari P, Galler B, Führer M, Molinelli A and Baumgartner S, 2009.
10751 Commercialized rapid immunoanalytical tests for determination of allergenic food proteins: an
10752 overview. Anal Bioanal Chem, 395, 69-81.

10753 Schulmeister U, Hochwallner H, Swoboda I, Focke-Tejkl M, Geller B, Nystrand M, Harlin A,
10754 Thalhamer J, Scheiblhofer S, Keller W, Niggemann B, Quirce S, Ebner C, Mari A, Pauli G, Herz
10755 U, Valenta R and Spitzauer S, 2009. Cloning, expression, and mapping of allergenic determinants
10756 of alphaS1-casein, a major cow's milk allergen. J Immunol, 182, 7019-7029.

10757 Schulten V, Nagl B, Scala E, Bernardi ML, Mari A, Ciardiello MA, Lauer I, Scheurer S, Briza P,
10758 Jurets A, Ferreira F, Jahn-Schmid B, Fischer GF and Bohle B, 2011. Pru p 3, the nonspecific lipid
10759 transfer protein from peach, dominates the immune response to its homolog in hazelnut. Allergy,
10760 66, 1005-1013.

10761 Schuppan D, Junker Y and Barisani D, 2009. Celiac disease: from pathogenesis to novel therapies.
10762 Gastroenterology, 137, 1912-1933.

10763 Schwartz H, 1984. Observations on the uses and effects of sulfating agents in foods and drugs.
10764 Immunol Allergy Prac, 6.29.

10765 Schwartz HJ, 1983. Sensitivity to ingested metabisulfite: variations in clinical presentation. J Allergy
10766 Clin Immunol, 71, 487-489.

10767 Scibilia J, Pastorello EA, Zisa G, Ottolenghi A, Bindslev-Jensen C, Pravettoni V, Scovena E, Robino
10768 A and Ortolani C, 2006. Wheat allergy: a double-blind, placebo-controlled study in adults. J
10769 Allergy Clin Immunol, 117, 433-439.

10770 Sealey-Voyksner JA, Khosla C, Voyksner RD and Jorgenson JW, 2010. Novel aspects of quantitation
10771 of immunogenic wheat gluten peptides by liquid chromatography-mass spectrometry/mass
10772 spectrometry. J Chromatogr A, 1217, 4167-4183.

10773 Seidel M and Niessner R, 2008. Automated analytical microarrays: a critical review. Anal Bioanal
10774 Chem, 391, 1521-1544.

10775 Seiki K, Oda H, Yoshioka H, Sakai S, Urisu A, Akiyama H and Ohno Y, 2007. A reliable and
10776 sensitive immunoassay for the determination of crustacean protein in processed foods. J Agric
10777 Food Chem, 55, 9345-9350.

10778 Seo JH, Kim JH, Lee JW, Yoo YC, Kim MR, Park KS and Byun MW, 2007. Ovalbumin modified by
10779 gamma irradiation alters its immunological functions and allergic responses. Int
10780 Immunopharmacol, 7, 464-472.

10781 Shafique RH, Inam M, Ismail M and Chaudhary FR, 2012. Group 10 allergens (tropomyosins) from
10782 house-dust mites may cause covariation of sensitization to allergens from other invertebrates.
10783 Allergy Rhinol (Providence), 3, e74-90.

10784 Shan L, Molberg O, Parrot I, Hausch F, Filiz F, Gray GM, Sollid LM and Khosla C, 2002. Structural
10785 basis for gluten intolerance in celiac sprue. Science, 297, 2275-2279.

10786 Shanti KN, Martin BM, Nagpal S, Metcalfe DD and Rao PV, 1993. Identification of tropomyosin as
10787 the major shrimp allergen and characterization of its IgE-binding epitopes. J Immunol, 151, 5354-
10788 5363.

10789 Sharma GM, Roux KH and Sathe SK, 2009. A sensitive and robust competitive enzyme-linked
10790 immunosorbent assay for Brazil nut (Bertholletia excelsa L.) detection. J Agric Food Chem, 57,
10791 769-776.

10792 Sharma GM, Irsigler A, Dhanarajan P, Ayuso R, Bardina L, Sampson HA, Roux KH and Sathe SK,
10793 2011a. Cloning and characterization of an 11S legumin, Car i 4, a major allergen in pecan. J Agric
10794 Food Chem, 59, 9542-9552.

10795 Sharma GM, Irsigler A, Dhanarajan P, Ayuso R, Bardina L, Sampson HA, Roux KH and Sathe SK,
10796 2011b. Cloning and characterization of 2S albumin, Car i 1, a major allergen in pecan. J Agric
10797 Food Chem, 59, 4130-4139.

10798 Sharp MF and Lopata AL, 2013. Fish Allergy: In Review. Clin Rev Allergy Immunol.

10799 Shaw J, Roberts G, Grimshaw K, White S and Hourihane J, 2008. Lupin allergy in peanut-allergic
10800 children and teenagers. Allergy, 63, 370-373.

10801 Shefcheck KJ and Musser SM, 2004. Confirmation of the allergenic peanut protein, Ara h 1, in a
10802 model food matrix using liquid chromatography/tandem mass spectrometry (LC/MS/MS). J Agric
10803 Food Chem, 52, 2785-2790.

10804 Shefcheck KJ, Callahan JH and Musser SM, 2006. Confirmation of peanut protein using peptide
10805 markers in dark chocolate using liquid chromatography-tandem mass spectrometry (LC-MS/MS). J
10806 Agric Food Chem, 54, 7953-7959.

10807 Shek LP, Soderstrom L, Ahlstedt S, Beyer K and Sampson HA, 2004. Determination of food specific
10808 IgE levels over time can predict the development of tolerance in cow's milk and hen's egg allergy. J
10809 Allergy Clin Immunol, 114, 387-391.

10810 Shek LP, Cabrera-Morales EA, Soh SE, Gerez I, Ng PZ, Yi FC, Ma S and Lee BW, 2010. A
10811 population-based questionnaire survey on the prevalence of peanut, tree nut, and shellfish allergy in
10812 2 Asian populations. J Allergy Clin Immunol, 126, 324-331, 331 e321-327.

10813 Shen HW, Cao MJ, Cai QF, Ruan MM, Mao HY, Su WJ and Liu GM, 2012. Purification, cloning, and
10814 immunological characterization of arginine kinase, a novel allergen of Octopus fangsiao. J Agric
10815 Food Chem, 60, 2190-2199.

10816 Sheppard D, Wong WS, Uehara CF, Nadel JA and Boushey HA, 1980. Lower threshold and greater
10817 bronchomotor responsiveness of asthmatic subjects to sulfur dioxide. Am Rev Respir Dis, 122,
10818 873-878.

10819 Shi X, Guo R, White BL, Yancey A, Sanders TH, Davis JP, Burks AW and Kulis M, 2013. Allergenic
10820 properties of enzymatically hydrolyzed peanut flour extracts. Int Arch Allergy Immunol, 162, 123-
10821 130.

10822 Shibahara Y, Oka M, Tominaga K, Ii T, Umeda M, Uneo N, Abe A, Ohashi E, Ushio H and Shiomi K,
10823 2007. Determination of Crustacean Allergen in Food Products by Sandwich ELISA. Nippon
10824 Shokuhin Kagaku Kogaku Kaishi, 54, 280-286.

10825 Shibahara Y, Uesaka Y, Abe A, Yamada S, Ushio H and Shiomi K, 2010. Detection of Cephalopod
10826 Allergen in Food Products by ELISA. Nippon Shokuhin Kagaku Kogaku Kaishi, 57, 198-204.

10827 Shibahara Y, Uesaka Y, Wang J, Yamada S and Shiomi K, 2013. A sensitive enzyme-linked
10828 immunosorbent assay for the determination of fish protein in processed foods. Food Chem, 136,
10829 675-681.

10830 Shim YY and Wanasundara JP, 2008. Quantitative detection of allergenic protein Sin a 1 from yellow
10831 mustard (Sinapis alba L.) seeds using enzyme-linked immunosorbent assay. J Agric Food Chem,
10832 56, 1184-1192.

10833 Shimizu Y, Nakamura A, Kishimura H, Hara A, Watanabe K and Saeki H, 2009. Major allergen and
10834 its IgE cross-reactivity among salmonid fish roe allergy. J Agric Food Chem, 57, 2314-2319.

10835 Shin M, Han Y and Ahn K, 2013. The influence of the time and temperature of heat treatment on the
10836 allergenicity of egg white proteins. Allergy Asthma Immunol Res, 5, 96-101.

10837 Shiomi K, Sato Y, Hamamoto S, Mita H and Shimakura K, 2008. Sarcoplasmic Calcium-Binding
10838 Protein: Identification as a New Allergen of the Black Tiger Shrimp Penaeus monodon. Int
10839 Arch Allergy Immunol, 146, 91-98.

10840 Shoji M, 2009. Egg allergen detection. In: Molecular Biological and Immunological Techniques and
10841 Applications for Food Chemists. Eds Popping B, Diaz-Amigo C, Hoenicke K. John Wiley & Sons,
10842 NJ, 311-334.

10843 Shreffler WG, Charlop-Powers Z and Sicherer SH, 2006. Lack of association of HLA class II alleles
10844 with peanut allergy. Ann Allergy Asthma Immunol, 96, 865-869.

10845 Shriver-Lake LC, Taitt CR and Ligler FS, 2004. Applications of array biosensor for detection of food
10846 allergens. J AOAC Int, 87, 1498-1502.

10847 Shriver S, Yang W, Chung SY and Percival S, 2011. Pulsed ultraviolet light reduces immunoglobulin
10848 E binding to Atlantic white shrimp (Litopenaeus setiferus) extract. Int J Environ Res Public Health,
10849 8, 2569-2583.

10850 Sicherer SH, Munoz-Furlong A, Burks AW and Sampson HA, 1999. Prevalence of peanut and tree nut
10851 allergy in the US determined by a random digit dial telephone survey. J Allergy Clin Immunol,
10852 103, 559-562.

10853 Sicherer SH, Morrow EH and Sampson HA, 2000a. Dose-response in double-blind, placebo-
10854 controlled oral food challenges in children with atopic dermatitis. J Allergy Clin Immunol, 105,
10855 582-586.

10856 Sicherer SH, Sampson HA and Burks AW, 2000b. Peanut and soy allergy: a clinical and therapeutic
10857 dilemma. Allergy, 55, 515-521.

10858 Sicherer SH, Furlong TJ, Munoz-Furlong A, Burks AW and Sampson HA, 2001. A voluntary registry
10859 for peanut and tree nut allergy: characteristics of the first 5149 registrants. J Allergy Clin Immunol,
10860 108, 128-132.

10861 Sicherer SH, 2001. Clinical implications of cross-reactive food allergens. J Allergy Clin Immunol,
10862 108, 881-890.

10863 Sicherer SH, 2002. Clinical update on peanut allergy. Ann Allergy Asthma Immunol, 88, 350-361;
10864 quiz 361-352, 394.

10865 Sicherer SH, Muñoz-Furlong A and Sampson HA, 2003. Prevalence of peanut and tree nut allergy in
10866 the United States determined by means of a random digit dial telephone survey: A 5-year follow-up
10867 study. Journal of Allergy and Clinical Immunology, 112, 1203-1207.

10868 Sicherer SH, Munoz-Furlong A and Sampson HA, 2004. Prevalence of seafood allergy in the United
10869 States determined by a random telephone survey. J Allergy Clin Immunol, 114, 159-165.

10870 Sicherer SH, 2005. Food protein-induced enterocolitis syndrome: case presentations and management
10871 lessons. J Allergy Clin Immunol, 115, 149-156.

10872 Sicherer SH, Muñoz-Furlong A, Godbold JH and Sampson HA, 2010. US prevalence of self-reported
10873 peanut, tree nut, and sesame allergy: 11-year follow-up. J Allergy Clin Immunol, 125, 1322-1326.

10874 Sicherer SH and Leung DY, 2011. Advances in allergic skin disease, anaphylaxis, and hypersensitivity
10875 reactions to foods, drugs, and insects in 2010. J Allergy Clin Immunol, 127, 326-335.

10876 Sicherer SH and Sampson HA, 2013. Food allergy: Epidemiology, pathogenesis, diagnosis, and
10877 treatment. J Allergy Clin Immunol.

10878 Siegel M, Schnur K, Boernsen B, Pietsch K and Waiblinger H-U, 2012. First ring-trial validation of
10879 real-time PCR methods for the quantification of allergenic food ingredients. European Food
10880 Research and Technology, 235, 619-630.

10881 Silva R, Gomes E, Cunha L and Falcao H, 2012. Anaphylaxis in children: a nine years retrospective
10882 study (2001-2009). Allergol Immunopathol (Madr), 40, 31-36.

10883 Simon R, 1998. Update on sulphite sensitivity. Allergy, 53 (Suppl), 78-79.

10884 Simon RA, 1989. Sulfite challenge for the diagnosis of sensitivity. Allergy Proc, 10, 357-362.

10885 Simon RA, 2003. Adverse reactions to food additives. Curr Allergy Asthma Rep, 3, 62-66.

10886 Simonato B, De Lazzari F, Pasini G, Polato F, Giannattasio M, Gemignani C, Peruffo AD, Santucci B,
10887 Plebani M and Curioni A, 2001a. IgE binding to soluble and insoluble wheat flour proteins in
10888 atopic and non-atopic patients suffering from gastrointestinal symptoms after wheat ingestion. Clin
10889 Exp Allergy, 31, 1771-1778.

10890 Simonato B, Pasini G, Giannattasio M, Peruffo AD, De Lazzari F and Curioni A, 2001b. Food allergy
10891 to wheat products: the effect of bread baking and in vitro digestion on wheat allergenic proteins. A
10892 study with bread dough, crumb, and crust. J Agric Food Chem, 49, 5668-5673.

10893 Simonato B, Mainente F, Tolin S and Pasini G, 2011. Immunochemical and mass spectrometry
10894 detection of residual proteins in gluten fined red wine. J Agric Food Chem, 59, 3101-3110.

10895 Sirtori E, Resta D, Brambilla F, Zacherl C and Arnoldi A, 2010. The effects of various processing
10896 conditions on a protein isolate from Lupinus angustifolius. Food Chemistry, 120, 496-504.

10897 Sirtori E, Resta D, Arnoldi A, Savelkoul HFJ and Wichers HJ, 2011. Cross-reactivity between peanut
10898 and lupin proteins. Food Chemistry, 126, 902-910.

10899 Sirvent S, Palomares O, Vereda A, Villalba M, Cuesta-Herranz J and Rodriguez R, 2009. nsLTP and
10900 profilin are allergens in mustard seeds: cloning, sequencing and recombinant production of Sin a 3
10901 and Sin a 4. Clin Exp Allergy, 39, 1929-1936.

10902 Sirvent S, Akotenou M, Cuesta-Herranz J, Vereda A, Rodriguez R, Villalba M and Palomares O,
10903 2012. The 11S globulin Sin a 2 from yellow mustard seeds shows IgE cross-reactivity with
10904 homologous counterparts from tree nuts and peanut. Clin Transl Allergy, 2, 23.

10905 Skamstrup Hansen K and Poulsen LK, 2010. Component resolved testing for allergic sensitization.
10906 Curr Allergy Asthma Rep, 10, 340-348.

10907 Skerritt JH and Hill AS, 1991. Enzyme immunoassay for determination of gluten in foods:
10908 collaborative study. J Assoc Off Anal Chem, 74, 257-264.

10909 Skolnick HS, Conover-Walker MK, Koerner CB, Sampson HA, Burks W and Wood RA, 2001. The
10910 natural history of peanut allergy. J Allergy Clin Immunol, 107, 367-374.

10911 Skripak JM, Matsui EC, Mudd K and Wood RA, 2007. The natural history of IgE-mediated cow's
10912 milk allergy. J Allergy Clin Immunol, 120, 1172-1177.

10913 Skripak JM, Nash SD, Rowley H, Brereton NH, Oh S, Hamilton RG, Matsui EC, Burks AW and
10914 Wood RA, 2008. A randomized, double-blind, placebo-controlled study of milk oral
10915 immunotherapy for cow's milk allergy. J Allergy Clin Immunol, 122, 1154-1160.

10916 Skypala I, 2011. Adverse Food Reactions—An Emerging Issue for Adults. J Am Diet Assoc, 111,
10917 1877-1891.

10918 Sletten G, Van Do T, Lindvik H, Egaas E and Florvaag E, 2010. Effects of industrial processing on the
10919 immunogenicity of commonly ingested fish species. Int Arch Allergy Immunol, 151, 223-236.

10920 Smith WB, Gillis D and Kette FE, 2004. Lupin: a new hidden food allergen. Med J Aust, 181, 219-
10921 220.

10922 Snégaroff J, Bouchez-Mahiout I, Pecquet C, Branlard G and Laurière M, 2006. Study of IgE Antigenic
10923 Relationships in Hypersensitivity to Hydrolyzed Wheat Proteins and Wheat-Dependent Exercise-
10924 Induced Anaphylaxis. Int Arch Allergy Immunol, 139, 201-208.

10925 Soares S, Mafra I, Amaral JS and Oliveira MBPP, 2010. A PCR assay to detect trace amounts of
10926 soybean in meat sausages. International Journal of Food Science & Technology, 45, 2581-2588.

10927 Solensky R, 2003. Resolution of fish allergy: a case report. Ann Allergy Asthma Immunol, 91, 411-
10928 412.

10929 Soller L, Ben-Shoshan M, Harrington DW, Fragapane J, Joseph L, St Pierre Y, Godefroy SB, La
10930 Vieille S, Elliott SJ and Clarke AE, 2012. Overall prevalence of self-reported food allergy in
10931 Canada. J Allergy Clin Immunol, 130, 986-988.

10932 Sollid LM, 2002. Coeliac disease: dissecting a complex inflammatory disorder. Nat Rev Immunol, 2,
10933 647-655.

10934 Sollid LM and Khosla C, 2011. Novel therapies for coeliac disease. J Intern Med, 269, 604-613.

10935 Somssich IE, Schmelzer E, Kawalleck P and Hahlbrock K, 1988. Gene structure and in situ transcript
10936 localization of pathogenesis-related protein 1 in parsley. Mol Gen Genet, 213, 93-98.

10937 Song YS, Frias J, Martinez-Villaluenga C, Vidal-Valdeverde C and de Mejia EG, 2008.
10938 Immunoreactivity reduction of soybean meal by fermentation, effect on amino acid composition
10939 and antigenicity of commercial soy products. Food Chemistry, 108, 571-581.

10940 Sonin L and Patterson R, 1985. Metabisulfite challenge in patients with idiopathic anaphylaxis. J
10941 Allergy Clin Immunol, 75, 67-69.

10942 Sormus de Castro Pinto SE, Neves VA and Machado de Medeiros BM, 2009. Enzymatic hydrolysis of
10943 sweet lupin, chickpea, and lentil 11S globulins decreases their antigenic activity. J Agric Food
10944 Chem, 57, 1070-1075.

10945 Sorva R, Makinen-Kiljunen S and Juntunen-Backman K, 1994. Beta-lactoglobulin secretion in human
10946 milk varies widely after cow's milk ingestion in mothers of infants with cow's milk allergy. J
10947 Allergy Clin Immunol, 93, 787-792.

10948 Sotkovsky P, Hubalek M, Hernychova L, Novak P, Havranova M, Setinova I, Kitanovicova A, Fuchs
10949 M, Stulik J and Tuckova L, 2008. Proteomic analysis of wheat proteins recognized by IgE
10950 antibodies of allergic patients. Proteomics, 8, 1677-1691.

10951 Spanjersberg MQ, Kruizinga AG, Rennen MA and Houben GF, 2007. Risk assessment and food
10952 allergy: the probabilistic model applied to allergens. Food Chem Toxicol, 45, 49-54.

10953 Spergel JM and Paller AS, 2003. Atopic dermatitis and the atopic march. J Allergy Clin Immunol,
10954 112, S118-127.

10955 Speroni F, Elviri L, Careri M and Mangia A, 2010. Magnetic particles functionalized with PAMAM-
10956 dendrimers and antibodies: a new system for an ELISA method able to detect Ara 3/4 peanut
10957 allergen in foods. Anal Bioanal Chem, 397, 3035-3042.

10958 Spricigo R, Richter C, Leimkuhler S, Gorton L, Scheller FW and Wollenberger U, 2010. Sulfite
10959 biosensor based on osmium redox polymer wired sulfite oxidase. Colloids and Surfaces a-
10960 Physicochemical and Engineering Aspects, 354, 314-319.

10961 Spuergin P, Walter M, Schiltz E, Deichmann K, Forster J and Mueller H, 1997. Allergenicity of alpha-
10962 caseins from cow, sheep, and goat. Allergy, 52, 293-298.

10963 Srivastava KD, Qu C, Zhang T, Goldfarb J, Sampson HA and Li X-M, 2009. Food Allergy Herbal
10964 Formula-2 silences peanut-induced anaphylaxis for a prolonged posttreatment period via IFN-γ–
10965 producing CD8+ T cells. J Allergy Clin Immunol, 123, 443-451.

10966 Staden U, Rolinck-Werninghaus C, Brewe F, Wahn U, Niggemann B and Beyer K, 2007. Specific oral
10967 tolerance induction in food allergy in children: efficacy and clinical patterns of reaction. Allergy,
10968 62, 1261-1269.

10969 Staswick PE, Hermodson MA and Nielsen NC, 1981. Identification of the acidic and basic subunit
10970 complexes of glycinin. J Biol Chem, 256, 8752-8755.

10971 Stephan O, Möller N, Lehmann S, Holzhauser T and Vieths S, 2002. Development and validation of
10972 two dipstick type immunoassays for determination of trace amounts of peanut and hazelnut in
10973 processed foods. European Food Research and Technology, 215, 431-436.

10974 Stephan O and Vieths S, 2004. Development of a real-time PCR and a sandwich ELISA for detection
10975 of potentially allergenic trace amounts of peanut (Arachis hypogaea) in processed foods. J Agric
10976 Food Chem, 52, 3754-3760.

10977 Stephan O, Weisz N, Vieths S, Weiser T, Rabe B and Vatterott W, 2004. Protein quantification,
10978 sandwich ELISA, and real-time PCR used to monitor industrial cleaning procedures for
10979 contamination with peanut and celery allergens. J AOAC Int, 87, 1448-1457.

10980 Stern M, Ciclitira PJ, van Eckert R, Feighery C, Janssen FW, Mendez E, Mothes T, Troncone R and
10981 Wieser H, 2001. Analysis and clinical effects of gluten in coeliac disease. Eur J Gastroenterol
10982 Hepatol, 13, 741-747.

10983 Stevenson D and Simon R, 1984. Sulphites and asthma (editorial). J Allergy Clin Immunol, 74:469.

10984 Stevenson DD and Simon RA, 1981. Sensitivity to ingested metabisulfites in asthmatic subjects. J
10985 Allergy Clin Immunol, 68, 26-32.

10986 Stewart AG and Ewan PW, 1996. The incidence, aetiology and management of anaphylaxis presenting
10987 to an accident and emergency department. QJM, 89, 859-864.

10988 Strannegard O and Strannegard IL, 2001. The causes of the increasing prevalence of allergy: is atopy a
10989 microbial deprivation disorder? Allergy, 56, 91-102.

10990 Straumann A, Conus S, Grzonka P, Kita H, Kephart G, Bussmann C, Beglinger C, Smith DA, Patel J,
10991 Byrne M and Simon HU, 2010. Anti-interleukin-5 antibody treatment (mepolizumab) in active
10992 eosinophilic oesophagitis: a randomised, placebo-controlled, double-blind trial. Gut, 59, 21-30.

10993 Stumr F, Gabrovska D, Rysova J, Hanak P, Plicka J, Tomkova K, Cuhra P, Kubik M, Barsova S,
10994 Karsulinovi L, Bulawova H and Brychta J, 2009. Enzyme-linked immunosorbent assay kit for beta-
10995 lactoglobulin determination: interlaboratory study. J AOAC Int, 92, 1519-1525.

10996 Stutius LM, Sheehan WJ, Rangsithienchai P, Bharmanee A, Scott JE, Young MC, Dioun AF,
10997 Schneider LC and Phipatanakul W, 2010. Characterizing the relationship between sesame, coconut,
10998 and nut allergy in children. Pediatr Allergy Immunol, 21, 1114-1118.

10999 Su M, Venkatachalam M, Teuber SS, Roux KH and Sathe SK, 2004. Impact of γ-irradiation and
11000 thermal processing on the antigenicity of almond, cashew nut and walnut proteins. Journal of the
11001 Science of Food and Agriculture, 84, 1119-1125.

11002 Sugita K, Kabashima K, Nakashima D and Tokura Y, 2007. Oral allergy syndrome caused by raw fish
11003 in a Japanese sushi bar worker. Contact Dermatitis, 56, 369-370.

11004 Suma Y, Ishizaki S, Nagashima Y, Lu Y, Ushio H and Shiomi K, 2007. Comparative analysis of
11005 barnacle tropomyosin: Divergence from decapod tropomyosins and role as a potential allergen.
11006 Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology, 147, 230-
11007 236.

11008 Summers CW, Pumphrey RS, Woods CN, McDowell G, Pemberton PW and Arkwright PD, 2008.
11009 Factors predicting anaphylaxis to peanuts and tree nuts in patients referred to a specialist center. J
11010 Allergy Clin Immunol, 121, 632-638 e632.

11011 Sun M, Liang C, Gao H, Lin C and Deng M, 2009. Detection of parvalbumin, a common fish allergen
11012 gene in food, by real-time polymerase chain reaction. J AOAC Int, 92, 234-240.

11013 Sun X, Guan L, Shan X, Zhang Y and Li Z, 2012. Electrochemical detection of peanut allergen Ara h
11014 1 using a sensitive DNA biosensor based on stem-loop probe. J Agric Food Chem, 60, 10979-
11015 10984.

11016 Susanna S and Prabhasankar P, 2011. A comparative study of different bio-processing methods for
11017 reduction in wheat flour allergens. European Food Research and Technology, 233, 999-1006.

11018 Sutherland MF, O'Hehir RE, Czarny D and Suphioglu C, 1999. Macadamia nut anaphylaxis:
11019 demonstration of specific IgE reactivity and partial cross-reactivity with hazelnut. J Allergy Clin
11020 Immunol, 104, 889-890.

11021 Sutton R, Hill DJ, Baldo BA and Wrigley CW, 1982. Immunoglobulin E antibodies to ingested cereal
11022 flour components: studies with sera from subjects with asthma and eczema. Clin Allergy, 12, 63-
11023 74.

11024 Swoboda I, Bugajska-Schretter A, Verdino P, Keller W, Sperr WR, Valent P, Valenta R and Spitzauer
11025 S, 2002. Recombinant carp parvalbumin, the major cross-reactive fish allergen: a tool for diagnosis
11026 and therapy of fish allergy. J Immunol, 168, 4576-4584.

11027 Szajewska H and Horvath A, 2010. Meta-analysis of the evidence for a partially hydrolyzed 100%
11028 whey formula for the prevention of allergic diseases. Curr Med Res Opin, 26, 423-437.

11029 Szepfalusi Z, Ebner C, Pandjaitan R, Orlicek F, Scheiner O, Boltz-Nitulescu G, Kraft D and Ebner H,
11030 1994. Egg yolk alpha-livetin (chicken serum albumin) is a cross-reactive allergen in the bird-egg
11031 syndrome. J Allergy Clin Immunol, 93, 932-942.

11032 Tack GJ, Verbeek WH, Schreurs MW and Mulder CJ, 2010. The spectrum of celiac disease:
11033 epidemiology, clinical aspects and treatment. Nat Rev Gastroenterol Hepatol, 7, 204-213.

11034 Taguchi H, Watanabe S, Temmei Y, Hirao T, Akiyama H, Sakai S, Adachi R, Sakata K, Urisu A and
11035 Teshima R, 2011. Differential detection of shrimp and crab for food labeling using polymerase
11036 chain reaction. J Agric Food Chem, 59, 3510-3519.

11037 Tai SS, Wu LS, Chen EC and Tzen JT, 1999. Molecular cloning of 11S globulin and 2S albumin, the
11038 two major seed storage proteins in sesame. J Agric Food Chem, 47, 4932-4938.

11039 Tai SSK, Lee TTT, Tsai CCY, Yiu T-J and Tzen JTC, 2001. Expression pattern and deposition of
11040 three storage proteins, 11S globulin, 2S albumin and 7S globulin in maturing sesame seeds. Plant
11041 Physiology and Biochemistry, 39, 981-992.

11042 Takahashi Y, Ichikawa S, Aihara Y and Yokota S, 1998. [Buckwheat allergy in 90,000 school children
11043 in Yokohama]. Arerugi, 47, 26-33.

11044 Tanner GJ, Colgrave ML, Blundell MJ, Goswami HP and Howitt CA, 2013. Measuring hordein
11045 (gluten) in beer--a comparison of ELISA and mass spectrometry. PLoS One, 8, e56452.

11046 Tariq SM, Stevens M, Matthews S, Ridout S, Twiselton R and Hide DW, 1996. Cohort study of
11047 peanut and tree nut sensitisation by age of 4 years. BMJ, 313, 514-517.

11048 Tariq SM, Matthews SM, Hakim EA and Arshad SH, 2000. Egg allergy in infancy predicts respiratory
11049 allergic disease by 4 years of age. Pediatr Allergy Immunol, 11, 162-167.

11050 Tatham AS and Shewry PR, 2008. Allergens to wheat and related cereals. Clin Exp Allergy, 38, 1712-
11051 1726.

11052 Tawde P, Venkatesh YP, Wang F, Teuber SS, Sathe SK and Roux KH, 2006. Cloning and
11053 characterization of profilin (Pru du 4), a cross-reactive almond (Prunus dulcis) allergen. J Allergy
11054 Clin Immunol, 118, 915-922.

11055 Taylor S, Bush R and Nordlee J, 1997. Sulphites. In: Food Allergy: Adverse reactions to foods and
11056 food additives. Eds Metcalfe D, Sampson H, Simon R. Blackwell Scientific, Boston.

11057 Taylor SL, Higley NA and Bush RK, 1986. Sulfites in foods: uses, analytical methods, residues, fate,
11058 exposure assessment, metabolism, toxicity, and hypersensitivity. Adv Food Res, 30, 1-76.

11059 Taylor SL, Hefle SL, Bindslev-Jensen C, Bock SA, Burks AW, Jr., Christie L, Hill DJ, Host A,
11060 Hourihane JO, Lack G, Metcalfe DD, Moneret-Vautrin DA, Vadas PA, Rance F, Skrypec DJ,
11061 Trautman TA, Yman IM and Zeiger RS, 2002. Factors affecting the determination of threshold
11062 doses for allergenic foods: how much is too much? J Allergy Clin Immunol, 109, 24-30.

11063 Taylor SL, Hefle SL, Bindslev-Jensen C, Atkins FM, Andre C, Bruijnzeel-Koomen C, Burks AW,
11064 Bush RK, Ebisawa M, Eigenmann PA, Host A, Hourihane JO, Isolauri E, Hill DJ, Knulst A, Lack
11065 G, Sampson HA, Moneret-Vautrin DA, Rance F, Vadas PA, Yunginger JW, Zeiger RS, Salminen
11066 JW, Madsen C and Abbott P, 2004. A consensus protocol for the determination of the threshold
11067 doses for allergenic foods: how much is too much? Clin Exp Allergy, 34, 689-695.

11068 Taylor SL, 2008. Molluscan shellfish allergy. Adv Food Nutr Res, 54, 139-177.

11069 Taylor SL, Gendel SM, Houben GF and Julien E, 2009a. The Key Events Dose-Response Framework:
11070 a foundation for examining variability in elicitation thresholds for food allergens. Crit Rev Food
11071 Sci Nutr, 49, 729-739.

11072 Taylor SL, Crevel RW, Sheffield D, Kabourek J and Baumert J, 2009b. Threshold dose for peanut:
11073 risk characterization based upon published results from challenges of peanut-allergic individuals.
11074 Food Chem Toxicol, 47, 1198-1204.

11075 Taylor SL, Moneret-Vautrin DA, Crevel RW, Sheffield D, Morisset M, Dumont P, Remington BC and
11076 Baumert JL, 2010. Threshold dose for peanut: Risk characterization based upon diagnostic oral
11077 challenge of a series of 286 peanut-allergic individuals. Food Chem Toxicol, 48, 814-819.

11078 Taylor SL, Baumert JL, Kruizinga AG, Remington BC, Crevel RW, Brooke-Taylor S, Allen KJ, The
11079 Allergen Bureau of A, New Z and Houben G, 2013. Establishment of Reference Doses for residues
11080 of allergenic foods: Report of the VITAL Expert Panel. Food Chem Toxicol, 63C, 9-17.

11081 Terzi V, Infascelli F, Tudisco R, Russo G, Stanca M and Faccioli P, 2004. Quantitative detection of
11082 Secale cereale by real-time PCR amplification. Lebensm.-Wiss. u.-Technol., 37, 239-246.

11083 Teuber SS, Brown RL and Haapanen LA, 1997. Allergenicity of gourmet nut oils processed by
11084 different methods. J Allergy Clin Immunol, 99, 502-507.

11085 Teuber SS, Dandekar AM, Peterson WR and Sellers CL, 1998. Cloning and sequencing of a gene
11086 encoding a 2S albumin seed storage protein precursor from English walnut (Juglans regia), a major
11087 food allergen. Journal of Allergy and Clinical Immunology, 101, 807-814.

11088 Teuber SS, Jarvis KC, Dandekar AM, Peterson WR and Ansari AA, 1999. Identification and cloning
11089 of a complementary DNA encoding a vicilin-like proprotein, Jug r 2, from English walnut kernel
11090 (Juglans regia), a major food allergen. Journal of Allergy and Clinical Immunology, 104, 1311-
11091 1320.

11092 Theisen S, Hansch R, Kothe L, Leist U and Galensa R, 2010. A fast and sensitive HPLC method for
11093 sulfite analysis in food based on a plant sulfite oxidase biosensor. Biosens Bioelectron, 26, 175-
11094 181.

11095 Thompson T and Mendez E, 2008. Commercial assays to assess gluten content of gluten-free foods:
11096 why they are not created equal. J Am Diet Assoc, 108, 1682-1687.

11097 Thong BY, Cheng YK, Leong KP, Tang CY and Chng HH, 2005. Anaphylaxis in adults referred to a
11098 clinical immunology/allergy centre in Singapore. Singapore Med J, 46, 529-534.

11099 Tobias A, Soriano JB, Chinn S, Anto JM, Sunyer J, Burney P and European Community Respiratory
11100 Health S, 2001. Symptoms of asthma, bronchial responsiveness and atopy in immigrants and
11101 emigrants in Europe. European Community Respiratory Health Survey. Eur Respir J, 18, 459-465.

11102 Tolin S, Pasini G, Simonato B, Mainente F and Arrigoni G, 2012a. Analysis of commercial wines by
11103 LC-MS/MS reveals the presence of residual milk and egg white allergens. Food Control, 28, 321-
11104 326.

11105 Tolin S, Pasini G, Curioni A, Arrigoni G, Masi A, Mainente F and Simonato B, 2012b. Mass
11106 spectrometry detection of egg proteins in red wines treated with egg white. Food Control, 23, 87-
11107 94.

11108 Tomm JM, van Do T, Jende C, Simon JC, Treudler R, von Bergen M and Averbeck M, 2013.
11109 Identification of new potential allergens from Nile perch (Lates niloticus) and cod (Gadus morhua).
11110 J Investig Allergol Clin Immunol, 23, 159-167.

11111 Toniolo R, Pizzariello A, Susmel S, Dossi N and Bontempelli G, 2010. A sensor based on electrodes
11112 supported on ion-exchange membranes for the flow-injection monitoring of sulphur dioxide in
11113 wines and grape juices. Talanta, 80, 1809-1815.

11114 Torp AM, Olesen A, Sten E, Stahl Skov P, Bindslev-Jensen U, Poulsen LK, Bindslev-Jensen C and
11115 Andersen SB, 2006. Specific, semi-quantitative detection of the soybean allergen Gly m Bd 30K
11116 DNA by PCR. Food Control, 17, 30-36.

11117 Torres Borrego J, Martinez Cuevas JF and Tejero Garcia J, 2003. [Cross reactivity between fish and
11118 shellfish]. Allergol Immunopathol (Madr), 31, 146-151.

11119 Tortajada-Genaro LA, Santiago-Felipe S, Morais S, Gabaldon JA, Puchades R and Maquieira A, 2012.
11120 Multiplex DNA detection of food allergens on a digital versatile disk. J Agric Food Chem, 60, 36-
11121 43.

11122 Touraine F, Ouzeau J, Boullaud C, Dalmay F and Bonnaud F, 2002. Survey on the prevalence of food
11123 allergy in school children. Rev Franc Allerg Immunol Clin, 42, 763-768.

11124 Tranquet O, Larré C and Denery-Papini S, 2012. Selection of a monoclonal antibody for detection of
11125 gliadins and glutenins: A step towards reliable gluten quantification. Journal of Cereal Science, 56,
11126 760-763.

11127 Trashin SA, Cucu T, Devreese B, Adriaens A and De Meulenaer B, 2011. Development of a highly
11128 sensitive and robust Cor a 9 specific enzyme-linked immunosorbent assay for the detection of
11129 hazelnut traces. Anal Chim Acta, 708, 116-122.

11130 Tregoat V and van Hengel A, 2010. Allergens. In: Safety Analysis of Foods of Animal Origin. Eds
11131 Nollet L, Toldrà F. CRC press, 951-958.

11132 Treudler R, Werner M, Thiery J, Kramer S, Gebhardt C, Averbeck M, Suess A and Simon JC, 2008.
11133 High risk of immediate-type reactions to soy drinks in 50 patients with birch pollinosis. J Investig
11134 Allergol Clin Immunol, 18, 483-484.

11135 Trucksess MW, Brewer VA, Williams KM, Westphal CD and Heeres JT, 2004. Preparation of Peanut
11136 Butter Suspension for Determination of Peanuts Using Enzyme-Linked Immunoassay Kits. J
11137 AOAC Int, 87, 424-428.

11138 Tsabouri S, Triga M, Makris M, Kalogeromitros D, Church MK and Priftis KN, 2012. Fish and
11139 shellfish allergy in children: Review of a persistent food allergy. Pediatric Allergy and
11140 Immunology, 23, 608-615.

11141 Tsiougkos N and Vovolis V, 2013. Repeated anaphylactic episodes to orange and apple. Eur Ann
11142 Allergy Clin Immunol, 45, 113-115.

11143 Tsujimura Y, Obata K, Mukai K, Shindou H, Yoshida M, Nishikado H, Kawano Y, Minegishi Y,
11144 Shimizu T and Karasuyama H, 2008. Basophils play a pivotal role in immunoglobulin-G-mediated
11145 but not immunoglobulin-E-mediated systemic anaphylaxis. Immunity, 28, 581-589.

11146 Turjanmaa K, Darsow U, Niggemann B, Rance F, Vanto T and Werfel T, 2006. EAACI/GA2LEN
11147 position paper: present status of the atopy patch test. Allergy, 61, 1377-1384.

11148 Tzvetkova I, Dalgalarrondo M, Danova S, Iliev I, Ivanova I, Chobert J-M and HaertlÉ T, 2007.
11149 Hydrolysis of major dairy proteins by lactic acid bacteria from Bulgarian yogurts. Journal of Food
11150 Biochemistry, 31, 680-702.

11151 University of Portsmouth, 2013. Literature searches and reviews related to the prevalence of food
11152 allergy in Europe. Project developed as part of procurement project CFT/EFSA/NUTRI/2012/02.
11153 343 pp.

11154 Unsel M, Sin AZ, Ardeniz O, Erdem N, Ersoy R, Gulbahar O, Mete N and Kokuludag A, 2007. New
11155 onset egg allergy in an adult. J Investig Allergol Clin Immunol, 17, 55-58.

11156 Untersmayr E, Focke M, Kinaciyan T, Poulsen LK, Boltz-Nitulescu G, Scheiner O and Jensen-Jarolim
11157 E, 2002. Anaphylaxis to Russian Beluga caviar. J Allergy Clin Immunol, 109, 1034-1035.

11158 Untersmayr E, Vestergaard H, Malling HJ, Jensen LB, Platzer MH, Boltz-Nitulescu G, Scheiner O,
11159 Skov PS, Jensen-Jarolim E and Poulsen LK, 2007. Incomplete digestion of codfish represents a risk
11160 factor for anaphylaxis in patients with allergy. J Allergy Clin Immunol, 119, 711-717.

11161 Urisu A, Ando H, Morita Y, Wada E, Yasaki T, Yamada K, Komada K, Torii S, Goto M and
11162 Wakamatsu T, 1997. Allergenic activity of heated and ovomucoid-depleted egg white. J Allergy
11163 Clin Immunol, 100, 171-176.

11164 Usui M, Harada A, Ishimaru T, Sakumichi E, Saratani F, Sato-Minami C, Azakami H, Miyasaki T and
11165 Hanaoka K, 2013. Contribution of structural reversibility to the heat stability of the tropomyosin
11166 shrimp allergen. Biosci Biotechnol Biochem, 77, 948-953.

11167 Vadas P, Wai Y, Burks W and Perelman B, 2001. Detection of peanut allergens in breast milk of
11168 lactating women. JAMA, 285, 1746-1748.

11169 Vader W, Kooy Y, Van Veelen P, De Ru A, Harris D, Benckhuijsen W, Pena S, Mearin L, Drijfhout
11170 JW and Koning F, 2002. The gluten response in children with celiac disease is directed toward
11171 multiple gliadin and glutenin peptides. Gastroenterology, 122, 1729-1737.

11172 Vahl JM and Converse JE, 1980. Ripper Procedure for Determining Sulfur-Dioxide in Wine -
11173 Collaborative Study. Journal of the Association of Official Analytical Chemists, 63, 194-201.

11174 Valdes I, Garcia E, Llorente M and Mendez E, 2003. Innovative approach to low-level gluten
11175 determination in foods using a novel sandwich enzyme-linked immunosorbent assay protocol. Eur
11176 J Gastroenterol Hepatol, 15, 465-474.

11177 Valenta R, Duchene M, Ebner C, Valent P, Sillaber C, Deviller P, Ferreira F, Tejkl M, Edelmann H,
11178 Kraft D and et al., 1992. Profilins constitute a novel family of functional plant pan-allergens. J Exp
11179 Med, 175, 377-385.

11180 Vallier P, DeChamp C, Valenta R, Vial O and Deviller P, 1992. Purification and characterization of an
11181 allergen from celery immunochemically related to an allergen present in several other plant species.
11182 Identification as a profilin. Clin Exp Allergy, 22, 774-782.

11183 Vally H, Carr A, El-Saleh J and Thompson P, 1999. Wine-induced asthma: a placebo-controlled
11184 assessment of its pathogenesis. J Allergy Clin Immunol, 103, 41-46.

11185 Vally H, Thompson PJ and Misso NL, 2007. Changes in bronchial hyperresponsiveness following
11186 high- and low-sulphite wine challenges in wine-sensitive asthmatic patients. Clin Exp Allergy, 37,
11187 1062-1066.

11188 Vally H, Misso NL and Madan V, 2009. Clinical effects of sulphite additives. Clin Exp Allergy, 39,
11189 1643-1651.

11190 van Bilsen JH, Ronsmans S, Crevel RW, Rona RJ, Przyrembel H, Penninks AH, Contor L and Houben
11191 GF, 2011. Evaluation of scientific criteria for identifying allergenic foods of public health
11192 importance. Regul Toxicol Pharmacol, 60, 281-289.

11193 van Boxtel EL, van den Broek LA, Koppelman SJ and Gruppen H, 2008. Legumin allergens from
11194 peanuts and soybeans: effects of denaturation and aggregation on allergenicity. Mol Nutr Food Res,
11195 52, 674-682.

11196 van de Wal Y, Kooy YM, van Veelen PA, Pena SA, Mearin LM, Molberg O, Lundin KE, Sollid LM,
11197 Mutis T, Benckhuijsen WE, Drijfhout JW and Koning F, 1998. Small intestinal T cells of celiac

11198 disease patients recognize a natural pepsin fragment of gliadin. Proc Natl Acad Sci U S A, 95,
11199 10050-10054.

11200 Van Do T, Elsayed S, Florvaag E, Hordvik I and Endresen C, 2005. Allergy to fish parvalbumins:
11201 Studies on the cross-reactivity of allergens from 9 commonly consumed fish. Journal of Allergy
11202 and Clinical Immunology, 116, 1314-1320.

11203 van Eckert R, Berghofer E, Ciclitira PJ, Chirdo F, Denery-Papini S, Ellis HJ, Ferranti P, Goodwin P,
11204 Immer U, Mamone G, Méndez E, Mothes T, Novalin S, Osman A, Rumbo M, Stern M, Thorell L,
11205 Whim A and Wieser H, 2006. Towards a new gliadin reference material–isolation and
11206 characterisation. Journal of Cereal Science, 43, 331-341.

11207 van Eckert R, Bond J, Rawson P, Klein CL, Stern M and Jordan TW, 2010. Reactivity of gluten
11208 detecting monoclonal antibodies to a gliadin reference material. Journal of Cereal Science, 51, 198-
11209 204.

11210 van Hengel AJ, Capelletti C, Brohee M and Anklam E, 2006. Validation of two commercial lateral
11211 flow devices for the detection of peanut proteins in cookies: interlaboratory study. J AOAC Int, 89,
11212 462-468.

11213 van Hengel AJ, 2007. Food allergen detection methods and the challenge to protect food-allergic
11214 consumers. Anal Bioanal Chem, 389, 111-118.

11215 van Hoffen E, Peeters KABM, van Neerven RJJ, van der Tas CWH, Zuidmeer L, van Ieperen-van
11216 Dijk AG, Bruijnzeel-Koomen CAFM, Knol EF, van Ree R and Knulst AC, 2011. Effect of birch
11217 pollen–specific immunotherapy on birch pollen–related hazelnut allergy. J Allergy Clin Immunol,
11218 127, 100-101.e103.

11219 Van Kleef FS, 1986. Thermally induced protein gelation: gelation and rheological characterization of
11220 highly concentrated ovalbumin and soybean protein gels. Biopolymers, 25, 31-59.

11221 van Ree R, Antonicelli L, Akkerdaas JH, Pajno GB, Barberio G, Corbetta L, Ferro G, Zambito M,
11222 Garritani MS, Aalberse RC and Bonifazi F, 1996a. Asthma after consumption of snails in house-
11223 dust-mite-allergic patients: a case of IgE cross-reactivity. Allergy, 51, 387-393.

11224 van Ree R, Antonicelli L, Akkerdaas JH, Garritani MS, Aalberse RC and Bonifazi F, 1996b. Possible
11225 induction of food allergy during mite immunotherapy. Allergy, 51, 108-113.

11226 van Zuuren EJ, Terreehorst I, Tupker RA, Hiemstra PS and Akkerdaas JH, 2010. Anaphylaxis after
11227 consuming soy products in patients with birch pollinosis. Allergy, 65, 1348-1349.

11228 Vandevijvere S, Temme E, Andjelkovic M, De Wil M, Vinkx C, Goeyens L and Van Loco J, 2010.
11229 Estimate of intake of sulfites in the Belgian adult population. Food Addit Contam Part A Chem
11230 Anal Control Expo Risk Assess, 27, 1072-1083.

11231 Vang B, Mæhre HK, Jensen I-J and Olsen RL, 2013. Detection of tropomyosin and determination of
11232 proteins in crustacean oils. Food Chemistry, 141, 72-76.

11233 Varjonen E, Vainio E and Kalimo K, 2000. Antigliadin IgE--indicator of wheat allergy in atopic
11234 dermatitis. Allergy, 55, 386-391.

11235 Vautrin S and Zhang D, 2007. Real-time polymerase chain reaction assay for endogenous reference
11236 gene for specific detection and quantification of common wheat-derived DNA (Triticum aestivum
11237 L.). J AOAC Int, 90, 794-801.

11238 Veledo MT, de Frutos M and Diez-Masa JC, 2005. Development of a method for quantitative analysis
11239 of the major whey proteins by capillary electrophoresis with on-capillary derivatization and laser-
11240 induced fluorescence detection. Journal of Separation Science, 28, 935-940.

11241 Venkatachalam M, Teuber SS, Peterson WR, Roux KH and Sathe SK, 2006. Antigenic stability of
11242 pecan [Carya illinoinensis (Wangenh.) K. Koch] proteins: effects of thermal treatments and in vitro
11243 digestion. J Agric Food Chem, 54, 1449-1458.

11244 Venkatachalam M, Monaghan EK, Kshirsagar HH, Robotham JM, O'Donnell SE, Gerber MS, Roux
11245 KH and Sathe SK, 2008. Effects of processing on immunoreactivity of cashew nut (Anacardium
11246 occidentale L.) seed flour proteins. J Agric Food Chem, 56, 8998-9005.

11247 Venter C, Pereira B, Grundy J, Clayton CB, Arshad SH and Dean T, 2006a. Prevalence of
11248 sensitization reported and objectively assessed food hypersensitivity amongst six-year-old children:
11249 a population-based study. Pediatr Allergy Immunol, 17, 356-363.

11250 Venter C, Pereira B, Grundy J, Clayton CB, Roberts G, Higgins B and Dean T, 2006b. Incidence of
11251 parentally reported and clinically diagnosed food hypersensitivity in the first year of life. J Allergy
11252 Clin Immunol, 117, 1118-1124.

11253 Venter C, Pereira B, Voigt K, Grundy J, Clayton CB, Higgins B, Arshad SH and Dean T, 2008.
11254 Prevalence and cumulative incidence of food hypersensitivity in the first 3 years of life. Allergy,
11255 63, 354-359.

11256 Vereda A, Sirvent S, Villalba M, Rodriguez R, Cuesta-Herranz J and Palomares O, 2011a.
11257 Improvement of mustard (Sinapis alba) allergy diagnosis and management by linking clinical
11258 features and component-resolved approaches. J Allergy Clin Immunol, 127, 1304-1307.

11259 Vereda A, van Hage M, Ahlstedt S, Ibanez MD, Cuesta-Herranz J, van Odijk J, Wickman M and
11260 Sampson HA, 2011b. Peanut allergy: Clinical and immunologic differences among patients from 3
11261 different geographic regions. J Allergy Clin Immunol, 127, 603-607.

11262 Verweij MM, Hagendorens MM, De Knop KJ, Bridts CH, De Clerck LS, Stevens WJ and Ebo DG,
11263 2011. Young infants with atopic dermatitis can display sensitization to Cor a 9, an 11S legumin-
11264 like seed-storage protein from hazelnut (Corylus avellana). Pediatric Allergy and Immunology, 22,
11265 196-201.

11266 Verweij MM, Hagendorens MM, Trashin S, Cucu T, De Meulenaer B, Devreese B, Bridts CH, De
11267 Clerck LS and Ebo DG, 2012. Age-dependent sensitization to the 7S-vicilin-like protein Cor a 11
11268 from hazelnut (Corylus avellana) in a birch-endemic region. J Investig Allergol Clin Immunol, 22,
11269 245-251.

11270 Vickery BP, Chin S and Burks AW, 2011. Pathophysiology of food allergy. Pediatr Clin North Am,
11271 58, 363-376, ix-x.

11272 Victorino CC and Gauthier AH, 2009. The social determinants of child health: variations across health
11273 outcomes - a population-based cross-sectional analysis. BMC Pediatr, 9, 53.

11274 Vidal ML, Gautron J and Nys Y, 2005. Development of an ELISA for quantifying lysozyme in hen
11275 egg white. J Agric Food Chem, 53, 2379-2385.

11276 Vieira T, Lopes C, Pereira AM, Araujo L, Moreira A and Delgado L, 2012. Microarray based IgE
11277 detection in poly-sensitized allergic patients with suspected food allergy - an approach in four
11278 clinical cases. Allergol Immunopathol (Madr), 40, 172-180.

11279 Vierk KA, Koehler KM, Fein SB and Street DA, 2007. Prevalence of self-reported food allergy in
11280 American adults and use of food labels. J Allergy Clin Immunol, 119, 1504-1510.

11281 Vieths S, Jankiewicz A, Wuthrich B and Baltes W, 1995. Immunoblot study of IgE binding allergens
11282 in celery roots. Ann Allergy Asthma Immunol, 75, 48-55.

11283 Vighi G, Marcucci F, Sensi L, Di Cara G and Frati F, 2008. Allergy and the gastrointestinal system.
11284 Clin Exp Immunol, 153 Suppl 1, 3-6.

11285 Vila L, Beyer K, Jarvinen KM, Chatchatee P, Bardina L and Sampson HA, 2001. Role of
11286 conformational and linear epitopes in the achievement of tolerance in cow's milk allergy. Clin Exp
11287 Allergy, 31, 1599-1606.

11288 Virta LJ, Kaukinen K and Collin P, 2009. Incidence and prevalence of diagnosed coeliac disease in
11289 Finland: results of effective case finding in adults. Scand J Gastroenterol, 44, 933-938.

11290 Vissers YM, Jansen AP, Ruinemans-Koerts J, Wichers HJ and Savelkoul HF, 2011. IgE component-
11291 resolved allergen profile and clinical symptoms in soy and peanut allergic patients. Allergy, 66,
11292 1125-1127.

11293 Volta U and Villanacci V, 2011. Celiac disease: diagnostic criteria in progress. Cell Mol Immunol, 8,
11294 96-102.

11295 von Berg A, Filipiak-Pittroff B, Kramer U, Hoffmann B, Link E, Beckmann C, Hoffmann U,
11296 Reinhardt D, Grubl A, Heinrich J, Wichmann HE, Bauer CP, Koletzko S, Berdel D and group GIs,
11297 2013. Allergies in high-risk schoolchildren after early intervention with cow's milk protein
11298 hydrolysates: 10-year results from the German Infant Nutritional Intervention (GINI) study. J
11299 Allergy Clin Immunol, 131, 1565-1573.

11300 Vu Huu T and Shibasaki K, 1978. Major proteins of soybean seeds. Subunit structure of .beta.-
11301 conglycinin. J Agric Food Chem, 26, 692-695.

11302 Wagner S, Radauer C, Bublin M, Hoffmann-Sommergruber K, Kopp T, Greisenegger EK, Vogel L,
11303 Vieths S, Scheiner O and Breiteneder H, 2008. Naturally occurring hypoallergenic Bet v 1 isoforms
11304 fail to induce IgE responses in individuals with birch pollen allergy. J Allergy Clin Immunol, 121,
11305 246-252.

11306 Wainstein BK, Studdert J, Ziegler M and Ziegler JB, 2010. Prediction of anaphylaxis during peanut
11307 food challenge: usefulness of the peanut skin prick test (SPT) and specific IgE level. Pediatric
11308 Allergy and Immunology, 21, 603-611.

11309 Wal JM, Bernard H, Creminon C, Hamberger C, David B and Peltre G, 1995. Cow's milk allergy: the
11310 humoral immune response to eight purified allergens. Adv Exp Med Biol, 371B, 879-881.

11311 Wal JM, 2002. Cow's milk proteins/allergens. Ann Allergy Asthma Immunol, 89, 3-10.

11312 Wal JM, 2003. Thermal processing and allergenicity of foods. Allergy, 58, 727-729.

11313 Walker-Smith J and Walker WA, 2003. The development of pediatric gastroenterology: a historical
11314 overview. Pediatr Res, 53, 706-715.

11315 Walker-Smith JA, 1992. Cow milk-sensitive enteropathy: predisposing factors and treatment. J
11316 Pediatr, 121, S111-115.

11317 Walley AJ, Chavanas S, Moffatt MF, Esnouf RM, Ubhi B, Lawrence R, Wong K, Abecasis GR, Jones
11318 EY, Harper JI, Hovnanian A and Cookson WO, 2001. Gene polymorphism in Netherton and
11319 common atopic disease. Nat Genet, 29, 175-178.

11320 Wallowitz M, Peterson WR, Uratsu S, Comstock SS, Dandekar AM and Teuber SS, 2006a. Jug r 4, a
11321 legumin group food allergen from walnut (Juglans regia Cv. Chandler). J Agric Food Chem, 54,
11322 8369-8375.

11323 Wallowitz ML, Teuber S, Beyer K, Sampson HA, Roux KH, Sathe SK, Wang F and Robotham J,
11324 2004. Cross-reactivity of walnut, cashew, and hazelnut legumin proteins in tree nut allergic
11325 patients. Journal of Allergy and Clinical Immunology, 113, S156.

11326 Wallowitz ML, Chen RJY, Tzen JTC and Teuber SS, 2006b. Using Human Basophil Donors to Assess
11327 the Clinical Relevance of Sesame 11S Globulin, Ses i 6. J Allergy Clin Immunol, 117, S50.

11328 Wallowitz ML, Chen RJ, Tzen JT and Teuber SS, 2007. Ses i 6, the sesame 11S globulin, can activate
11329 basophils and shows cross-reactivity with walnut in vitro. Clin Exp Allergy, 37, 929-938.

11330 Walsh BJ, Baldo BA, Bass DJ, Clancy R, Musk AW and Wrigley CW, 1987. Insoluble and soluble
11331 allergens from wheat grain and wheat dust: detection of IgE binding in inhalant and ingestion
11332 allergy. N Engl Reg Allergy Proc, 8, 27-33.

11333 Wan K and Chiu W, 2012. Food hypersensitivity in primary school children in Taiwan: relationship
11334 with asthma. Food and Agricultural Immunology, 23, 247-254.

11335 Wang F, Robotham JM, Teuber SS, Tawde P, Sathe SK and Roux KH, 2002. Ana o 1, a cashew
11336 (Anacardium occidental) allergen of the vicilin seed storage protein family. J Allergy Clin
11337 Immunol, 110, 160-166.

11338 Wang F, Robotham JM, Teuber SS, Sathe SK and Roux KH, 2003. Ana o 2, a major cashew
11339 (Anacardium occidentale L.) nut allergen of the legumin family. Int Arch Allergy Immunol, 132,
11340 27-39.

11341 Wang H, Li G, Wu J and Chen Y, 2011a. Detection of the allergenic celery protein component (Api g
11342 1.01) in foods by immunoassay. European Food Research and Technology, 233, 1023-1028.

11343 Wang J, Lin J, Bardina L, Goldis M, Nowak-Wegrzyn A, Shreffler WG and Sampson HA, 2010.
11344 Correlation of IgE/IgG4 milk epitopes and affinity of milk-specific IgE antibodies with different
11345 phenotypes of clinical milk allergy. J Allergy Clin Immunol, 125, 695-702, 702 e691-702 e696.

11346 Wang W, Li Y, Zhao F, Chen Y and Ge Y, 2011b. Optical thin-film biochips for multiplex detection
11347 of eight allergens in food. Food Research International, 44, 3229-3234.

11348 Wangorsch A, Ballmer-Weber BK, Rosch P, Holzhauser T and Vieths S, 2007. Mutational epitope
11349 analysis and cross-reactivity of two isoforms of Api g 1, the major celery allergen. Mol Immunol,
11350 44, 2518-2527.

11351 Waserman S and Watson W, 2011. Food allergy. Allergy Asthma Clin Immunol, 7 Suppl 1, S7.

11352 Watanabe T, Akiyama H, Maleki S, Yamakawa H, Iijima KEN, Yamazaki F, Matsumoto T, Futo S,
11353 Arakawa F, Watai M and Maitani T, 2006. A specific qualitative detection method for peanut
11354 (Arachis hypogaea) in foods using Polymerase Chain Reaction. Journal of Food Biochemistry, 30,
11355 215-233.

11356 Watanabe Y, Aburatani K, Mizumura T, Sakai M, Muraoka S, Mamegosi S and Honjoh T, 2005.
11357 Novel ELISA for the detection of raw and processed egg using extraction buffer containing a
11358 surfactant and a reducing agent. J Immunol Methods, 300, 115-123.

11359 Webber CM and England RW, 2010. Oral allergy syndrome: a clinical, diagnostic, and therapeutic
11360 challenge. Ann Allergy Asthma Immunol, 104, 101-108; quiz 109-110, 117.

11361 Weber D, Cleroux C and Godefroy SB, 2009a. Emerging analytical methods to determine gluten
11362 markers in processed foods--method development in support of standard setting. Anal Bioanal
11363 Chem, 395, 111-117.

11364 Weber P, Steinhart H and Paschke A, 2007. Investigation of the allergenic potential of wines fined
11365 with various proteinogenic fining agents by ELISA. J Agric Food Chem, 55, 3127-3133.

11366 Weber P, Steinhart H and Paschke A, 2009b. Competitive indirect ELISA for the determination of
11367 parvalbumins from various fish species in food grade fish gelatins and isinglass with PARV-19
11368 anti-parvalbumin antibodies. J Agric Food Chem, 57, 11328-11334.

11369 Weber P, Steinhart H and Paschke A, 2010. Characterization, antigenicity and detection of fish
11370 gelatine and isinglass used as processing aids in wines. Food Addit Contam Part A Chem Anal
11371 Control Expo Risk Assess, 27, 273-282.

11372 Wei Y, Sathe SK, Teuber SS and Roux KH, 2003. A sensitive sandwich ELISA for the detection of
11373 trace amounts of cashew (Anacardium occidentale L.) nut in foods. J Agric Food Chem, 51, 3215-
11374 3221.

11375 Weichel M, Vergoossen NJ, Bonomi S, Scibilia J, Ortolani C, Ballmer-Weber BK, Pastorello EA and
11376 Crameri R, 2006. Screening the allergenic repertoires of wheat and maize with sera from double-
11377 blind, placebo-controlled food challenge positive patients. Allergy, 61, 128-135.

11378 Weidinger S, Baurecht H, Wagenpfeil S, Henderson J, Novak N, Sandilands A, Chen H, Rodriguez E,
11379 O'Regan GM, Watson R, Liao H, Zhao Y, Barker JNWN, Allen M, Reynolds N, Meggitt S,
11380 Northstone K, Smith GD, Strobl C, Stahl C, Kneib T, Klopp N, Bieber T, Behrendt H, Palmer
11381 CNA, Wichmann HE, Ring J, Illig T, McLean WHI and Irvine AD, 2008. Analysis of the

individual and aggregate genetic contributions of previously identified serine peptidase inhibitor Kazal type 5 (SPINK5), kallikrein-related peptidase 7 (KLK7), and filaggrin (FLG) polymorphisms to eczema risk. J Allergy Clin Immunol, 122, 560-568.e564.

Welch AA, Lund E, Amiano P, Dorronsoro M, Brustad M, Kumle M, Rodriguez M, Lasheras C, Janzon L, Jansson J, Luben R, Spencer EA, Overvad K, Tjonneland A, Clavel-Chapelon F, Linseisen J, Klipstein-Grobusch K, Benetou V, Zavitsanos X, Tumino R, Galasso R, Bueno-De-Mesquita HB, Ocke MC, Charrondiere UR and Slimani N, 2002. Variability of fish consumption within the 10 European countries participating in the European Investigation into Cancer and Nutrition (EPIC) study. Public Health Nutr, 5, 1273-1285.

Wen H-W, Borejsza-Wysocki W, DeCory T and Durst R, 2005. Development of a competitive liposome-based lateral flow assay for the rapid detection of the allergenic peanut protein Ara h1. Anal Bioanal Chem, 382, 1217-1226.

Wennberg M, Tornevi A, Johansson I, Hornell A, Norberg M and Bergdahl IA, 2012. Diet and lifestyle factors associated with fish consumption in men and women: a study of whether gender differences can result in gender-specific confounding. Nutr J, 11, 101.

Wensing M, Penninks AH, Hefle SL, Akkerdaas JH, van Ree R, Koppelman SJ, Bruijnzeel-Koomen CA and Knulst AC, 2002a. The range of minimum provoking doses in hazelnut-allergic patients as determined by double-blind, placebo-controlled food challenges. Clin Exp Allergy, 32, 1757-1762.

Wensing M, Penninks AH, Hefle SL, Koppelman SJ, Bruijnzeel-Koomen CAFM and Knulst AC, 2002b. The distribution of individual threshold doses eliciting allergic reactions in a population with peanut allergy. Journal of Allergy and Clinical Immunology, 110, 915-920.

Wensing M, Knulst AC, Piersma S, O'Kane F, Knol EF and Koppelman SJ, 2003. Patients with anaphylaxis to pea can have peanut allergy caused by cross-reactive IgE to vicilin (Ara h 1). J Allergy Clin Immunol, 111, 420-424.

Werfel SJ, Cooke SK and Sampson HA, 1997. Clinical reactivity to beef in children allergic to cow's milk. J Allergy Clin Immunol, 99, 293-300.

Werner MT, Faeste CK and Egaas E, 2007. Quantitative sandwich ELISA for the determination of tropomyosin from crustaceans in foods. J Agric Food Chem, 55, 8025-8032.

Wershil BK, Butzner D, Sabra A, Savilahti E, Seidman E, Strobel S and Yamashiro Y, 2002. Allergy and immunologic disease: Working Group Report of the First World Congress of Pediatric Gastroenterology, Hepatology, and Nutrition. J Pediatr Gastroenterol Nutr, 35 Suppl 2, S74-77.

Westphal CD, Pereira MR, Raybourne RB and Williams KM, 2004. Evaluation of extraction buffers using the current approach of detecting multiple allergenic and nonallergenic proteins in food. J AOAC Int, 87, 1458-1465.

Whitaker TB, Williams KM, Trucksess MW and Slate AB, 2005. Immunochemical analytical methods for the determination of peanut proteins in foods. J AOAC Int, 88, 161-174.

WHO (World Health Organisation), 1975. Manual of the International Statistical Classification of Diseases, Injuries and Causes of Death.

Wieser H, Antes S and Seilmeier W, 1998. Quantitative Determination of Gluten Protein Types in Wheat Flour by Reversed-Phase High-Performance Liquid Chromatography. Cereal Chemistry Journal, 75, 644-650.

Wieser H and Koehler P, 2008. The Biochemical Basis of Celiac Disease. Cereal Chemistry Journal, 85, 1-13.

Wigotzki M, Schubert S, Steinhart H and Paschke A, 2000. Effects of in vitro digestion on the IgE-binding activity of proteins from hazelnus (Corylus avellana). Internet Symposium on Food Allergens, 2, 1-8.

11428 Williams WR, Pawlowicz A and Davies BH, 1989. Aspirin-like effects of selected food additives and
11429 industrial sensitizing agents. Clin Exp Allergy, 19, 533-537.

11430 Willison LN, Tawde P, Robotham JM, Penney RMt, Teuber SS, Sathe SK and Roux KH, 2008.
11431 Pistachio vicilin, Pis v 3, is immunoglobulin E-reactive and cross-reacts with the homologous
11432 cashew allergen, Ana o 1. Clin Exp Allergy, 38, 1229-1238.

11433 Willison LN, Tripathi P, Sharma G, Teuber SS, Sathe SK and Roux KH, 2011. Cloning, Expression
11434 and Patient IgE Reactivity of Recombinant Pru du 6, an 11S Globulin from Almond. Int Arch
11435 Allergy Immunol, 156, 267-281.

11436 Witteman AM, Akkerdaas JH, van Leeuwen J, van der Zee JS and Aalberse RC, 1994. Identification
11437 of a cross-reactive allergen (presumably tropomyosin) in shrimp, mite and insects. Int Arch Allergy
11438 Immunol, 105, 56-61.

11439 Wolff N, Cogan U, Admon A, Dalal I, Katz Y, Hodos N, Karin N and Yannai S, 2003. Allergy to
11440 sesame in humans is associated primarily with IgE antibody to a 14 kDa 2S albumin precursor.
11441 Food Chem Toxicol, 41, 1165-1174.

11442 Wolff N, Yannai S, Karin N, Levy Y, Reifen R, Dalal I and Cogan U, 2004. Identification and
11443 characterization of linear B-cell epitopes of beta-globulin, a major allergen of sesame seeds. J
11444 Allergy Clin Immunol, 114, 1151-1158.

11445 Wood RA, Sicherer SH, Vickery BP, Jones SM, Liu AH, Fleischer DM, Henning AK, Mayer L, Burks
11446 AW, Grishin A, Stablein D and Sampson HA, 2013. The natural history of milk allergy in an
11447 observational cohort. J Allergy Clin Immunol, 131, 805-812.

11448 Woods RK, Abramson M, Raven JM, Bailey M, Weiner JM and Walters EH, 1998. Reported food
11449 intolerance and respiratory symptoms in young adults. Eur Respir J, 11, 151-155.

11450 Woods RK, Abramson M, Bailey M and Walters EH, 2001. International prevalences of reported food
11451 allergies and intolerances. Comparisons arising from the European Community Respiratory Health
11452 Survey (ECRHS) 1991-1994. Eur J Clin Nutr, 55, 298-304.

11453 Woods RK, Stoney RM, Raven J, Walters EH, Abramson M and Thien FC, 2002. Reported adverse
11454 food reactions overestimate true food allergy in the community. Eur J Clin Nutr, 56, 31-36.

11455 Worm M, Hompes S, Fiedler EM, Illner AK, Zuberbier T and Vieths S, 2009. Impact of native, heat-
11456 processed and encapsulated hazelnuts on the allergic response in hazelnut-allergic patients. Clin
11457 Exp Allergy, 39, 159-166.

11458 Worth A and Sheikh A, 2010. Food allergy and atopic eczema. Curr Opin Allergy Clin Immunol, 10,
11459 226-230.

11460 Wu AY and Williams GA, 2004. Clinical characteristics and pattern of skin test reactivities in
11461 shellfish allergy patients in Hong Kong. Allergy Asthma Proc, 25, 237-242.

11462 Wu TC, Tsai TC, Huang CF, Chang FY, Lin CC, Huang IF, Chu CH, Lau BH, Wu L, Peng HJ and
11463 Tang RB, 2012. Prevalence of food allergy in Taiwan: a questionnaire-based survey. Intern Med J,
11464 42, 1310-1315.

11465 Wuthrich B and Dietschi R, 1985. [The celery-carrot-mugwort-condiment syndrome: skin test and
11466 RAST results]. Schweiz Med Wochenschr, 115, 258-264.

11467 Wuthrich B, Stager J and Johansson SG, 1990. Celery allergy associated with birch and mugwort
11468 pollinosis. Allergy, 45, 566-571.

11469 Wuthrich B and Johansson SG, 1995. Allergy to cheese produced from sheep's and goat's milk but not
11470 to cheese produced from cow's milk. J Allergy Clin Immunol, 96, 270-273.

11471 Wuthrich B, 2000. Lethal or life-threatening allergic reactions to food. J Investig Allergol Clin
11472 Immunol, 10, 59-65.

11473 Wuthrich B and Ballmer-Weber BK, 2001. Food-induced anaphylaxis. Allergy, 56 Suppl 67, 102-104.

11474 Wüthrich B and Straumann F, 1997. Pollen cross-reactivity. Can we establish a link between the in
11475 vitro results and the clinical situation? Allergy, 52, 1187-1193.

11476 Xiulan S, Yinzhi Z, Jingdong S, Liyan S, He Q and Weijuan Z, 2010. A quartz crystal microbalance-
11477 based Immunosensor for Shrimp Allergen Determination in Food. European Food Research and
11478 Technology, 231, 563-570.

11479 Xue B, Soeria-Atmadja D, Gustafsson MG, Hammerling U, Dunker AK and Uversky VN, 2011.
11480 Abundance and functional roles of intrinsic disorder in allergenic proteins and allergen
11481 representative peptides. Proteins, 79, 2595-2606.

11482 Yadzir ZH, Misnan R, Abdullah N, Bakhtiar F, Arip M and Murad S, 2010. Identification of Ige-
11483 binding proteins of raw and cooked extracts of Loligo edulis (white squid). Southeast Asian J Trop
11484 Med Public Health, 41, 653-659.

11485 Yadzir ZH, Misnan R, Abdullah N, Bakhtiar F, Arip M and Murad S, 2012. Identification of the major
11486 allergen of Macrobrachium rosenbergii (giant freshwater prawn). Asian Pac J Trop Biomed, 2, 50-
11487 54.

11488 Yamada S, Nolte H and Zychlinsky E, 1999. Identification and characterization of allergens in two
11489 species of tuna fish. Ann Allergy Asthma Immunol, 82, 395-400.

11490 Yamakawa Y, Ohsuna H, Aihara M, Tsubaki K and Ikezawa Z, 2001. Contact urticaria from rice.
11491 Contact Dermatitis, 44, 91-93.

11492 Yang W, Shriver S, Chung S-y, Percival S, Correll M and Rababah T, 2012. In Vitro Gastric and
11493 Intestinal Digestions of Pulsed Light-Treated Shrimp Extracts. Applied Biochemistry and
11494 Biotechnology, 166, 1409-1422.

11495 Yaqoob M, Nabi A, Waseem A and Masoom-Yasinzai M, 2004. Determination of sulphite using an
11496 immobilized enzyme with flow injection chemiluminescence detection. Luminescence, 19, 26-30.

11497 Yeung JM, Newsome WH and Abbott MA, 2000. Determination of egg proteins in food products by
11498 enzyme immunoassay. J AOAC Int, 83, 139-143.

11499 Yman IM, Eriksson A, Johansson MA and Hellenas KE, 2006. Food allergen detection with biosensor
11500 immunoassays. J AOAC Int, 89, 856-861.

11501 You J, Li D, Qiao S, Wang Z, He P, Ou D and Dong B, 2008. Development of a monoclonal antibody-
11502 based competitive ELISA for detection of β-conglycinin, an allergen from soybean. Food
11503 Chemistry, 106, 352-360.

11504 Young E, Stoneham MD, Petruckevitch A, Barton J and Rona R, 1994. A population study of food
11505 intolerance. Lancet, 343, 1127-1130.

11506 Yu CJ, Lin YF, Chiang BL and Chow LP, 2003. Proteomics and immunological analysis of a novel
11507 shrimp allergen, Pen m 2. J Immunol, 170, 445-453.

11508 Yu H-L, Cao M-J, Cai Q-F, Weng W-Y, Su W-J and Liu G-M, 2011. Effects of different processing
11509 methods on digestibility of Scylla paramamosain allergen (tropomyosin). Food and Chemical
11510 Toxicology, 49, 791-798.

11511 Yunginger JW, Sweeney KG, Sturner WQ, Giannandrea LA, Teigland JD, Bray M, Benson PA, York
11512 JA, Biedrzycki L, Squillace DL and et al., 1988. Fatal food-induced anaphylaxis. JAMA, 260,
11513 1450-1452.

11514 Zacharisen MC, Elms NP and Kurup VP, 2002. Severe tomato allergy (Lycopersicon esculentum).
11515 Allergy Asthma Proc, 23, 149-152.

11516 Zannikos K, Sakellariou A, Emmanouil E, Tzannis K, Michopoulou C, Sinaniotis A, Xepapadaki P,
11517 Saxoni-Papegeorgiou P and Papadopoulos N, 2008. The prevalence of parentally perceived food
11518 hypersensitivity in Greek schoolchildren. Allergy, 63, 318-318.

11519 Zeiger RS, Sampson HA, Bock SA, Burks AW, Jr., Harden K, Noone S, Martin D, Leung S and
11520 Wilson G, 1999. Soy allergy in infants and children with IgE-associated cow's milk allergy. J
11521 Pediatr, 134, 614-622.

11522 Zeiger RS, 2003. Food allergen avoidance in the prevention of food allergy in infants and children.
11523 Pediatrics, 111, 1662-1671.

11524 Zeleny R and Schimmel H, 2010. Towards comparability of ELISA results for peanut proteins in food:
11525 A feasibility study. Food Chemistry, 123, 1343-1351.

11526 Zeltner D, Glomb M and Maede D, 2009. Real-time PCR systems for the detection of the gluten-
11527 containing cereals wheat, spelt, kamut, rye, barley and oat. European Food Research and
11528 Technology, 228, 321-330.

11529 Zhang H, Lu Y, Ushio H and Shiomi K, 2014. Development of sandwich ELISA for detection and
11530 quantification of invertebrate major allergen tropomyosin by a monoclonal antibody. Food Chem,
11531 150, 151-157.

11532 Zheng LN, Lin H, Pawar R, Li ZX and Li MH, 2011. Mapping IgE binding epitopes of major shrimp
11533 (Penaeus monodon) allergen with immunoinformatics tools. Food Chem Toxicol, 49, 2954-2960.

11534 Zhenxing L, Yiqun Z, Hong L, Haider S and Jie J, 2010. Quantitative analysis of shrimp allergen in
11535 food matrices using a protein chip based on sandwich immunoassay. European Food Research and
11536 Technology, 231, 47-54.

11537 Zhong ZX, Li GK, Zhu BH, Luo ZB, Huang L and Wu XM, 2012. A rapid distillation method coupled
11538 with ion chromatography for the determination of total sulphur dioxide in foods. Food Chemistry,
11539 131, 1044-1050.

11540 Zoumpoulakis P, Sinanoglou VJ, Batrinou A, Strati IF, Miniadis-Meimaroglou S and Sflomos K,
11541 2012. A combined methodology to detect γ-irradiated white sesame seeds and evaluate the effects
11542 on fat content, physicochemical properties and protein allergenicity. Food Chemistry, 131, 713-
11543 721.

11544 Zuberbier T, Edenharter G, Worm M, Ehlers I, Reimann S, Hantke T, Roehr CC, Bergmann KE and
11545 Niggemann B, 2004. Prevalence of adverse reactions to food in Germany - a population study.
11546 Allergy, 59, 338-345.

11547 Zuidmeer L, Goldhahn K, Rona RJ, Gislason D, Madsen C, Summers C, Sodergren E, Dahlstrom J,
11548 Lindner T, Sigurdardottir ST, McBride D and Keil T, 2008. The prevalence of plant food allergies:
11549 a systematic review. J Allergy Clin Immunol, 121, 1210-1218 e1214.

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APPENDICES

A. POPULATION THRESHOLDS CALCULATED FOR SOME ALLERGENIC FOODS/INGREDIENTS[1].

Food	No. of patients (population)	Objective symptoms			Any symptom			Reference
		ED_{01} (95 % CI)	ED_{05} (95 % CI)	ED_{10} (95 % CI)	ED_{01} (95 % CI)	ED_{05} (95% CI)	ED_{10} (95% CI)	
Hen's egg	53 (children)	0.07 (0.01-0.79)	1.51 (0.3-7.7)	5.82 (1.6-21.4)	0.04 (0.005-0.35)	0.75 (0.2-3.3)	2.75 (0.8-9.2)	(Blom et al., 2013)
	> 200 (mostly children)	0.03 (NR)	-	-	-	-	-	(Allen et al., 2013)
		0.0043-0.056[2] (NA)	0.21-0.44[2] (NA)	1.2-1.6 [2] (NA)	-	-	-	(Remington, 2013)
	206 (mostly children)	0.12-0.13[3] (NR)	0.66-0.69[3,4] (NR)	-	-	-	-	(Taylor et al., 2013)
		0.2-0.21[5] (NR)	0.62[4,5] (NR)	-	-	-	-	
		0.03-0.045[6] (NR)	0.31-0.38[4,6] (NR)	-	-	-	-	
	155 (mostly children)	-	2.08 (1.1-4.0)	5.36 (3.0-9.6)	-	-	-	(Eller et al., 2012)
Cow's milk	93 (children)	0.05 (0.01-0.30)	1.07 (0.3-3.8)	4.24 (1.6-11.6)	0.007 (0.001-0.06)	0.27 (0.1-1.1)	1.31 (0.4-4.2)	(Blom et al., 2013)
	> 200 (mostly children)	0.1 (NR)	1.3-3.6[7] (NR)	2.6 -13.0[7] (NR)	-	-	-	(Allen et al., 2013)
		0.016-0.14[2] (NA)	0.57-1.9[2] (NA)	2.8-5.1[2] (NA)	-	-	-	(Remington, 2013)
	351 (mostly children)	0.081-0.14[3] (NR)	-	-	-	-	-	(Taylor et al., 2013)
		0.21-0.34[5] (NR)	-	-	-	-	-	
	42 (mostly children)	-	59.3 (29.1-109.9)	100.2 (52.7-190.5)	-	-	-	(Eller et al., 2012)

Food	No. of patients (population)	Objective symptoms			Any symptom			Reference
		ED_{01} (95 % CI)	ED_{05} (95 % CI)	ED_{10} (95 % CI)	ED_{01} (95 % CI)	ED_{05} (95% CI)	ED_{10} (95% CI)	
Peanut	135 (children)	0.15 (0.04-0.51)	1.56 (0.7 - 3.6)	4.42 (2.3-8.5)	0.007 (0.002-0.03)	0.14 (0.1-0.4)	0.52 (0.2-1.2)	(Blom et al., 2013)
	> 200 (adults/children)	0.2 (NR)	0.4-2[2] (NR)	-	-	-	-	(Allen et al., 2013)
		0.015-0.13[2] (NA)	0.5-1.5[2] (NA)	2.3-4.1[2] (NA)				(Remington, 2013)
	750 (adults/children)	0.1-0.13[3] (NR)						(Taylor et al., 2013)
		0.22-0.28[5] (NR)						
	149 (mostly children)		18.9 (13.0-27.6)	32.9 (23.6-45.9)				(Eller et al., 2012)
Hazelnut	28 (children)	0.01 (0.00-0.56)	0.29 (0.0-4.6)	1.38 (0.2-12.0)	0.001 (0-0.05)	0.05 (0.0-0.6)	0.22 (0.0-1.8)	(Blom et al., 2013)
	202 (adults/children)	0.1 (NR)	-	-	-	-	-	(Allen et al., 2013)
		0.038-0.42[2] (NA)	1.2-2.6[2] (NA)	5.2-7.9[2] (NA)	-	-	-	(Remington, 2013)
		0.11-0.21[3] (NR)	0.69-1.3[3,4] (NR)	-	-	-	-	
		0.25-0.42[5] (NR)	0.84-1.4[4,5] (NR)	-	-	-	-	(Taylor et al., 2013)
		0.017-0.038[6] (NR)	0.23-0.46[5,6] (NR)	-	-	-	-	
	59 (mostly children)	-	8.7 (4.5-16.8)	15.9 (8.9-28.4)	-	-	-	(Eller et al., 2012)

Food	No. of patients (population)	Objective symptoms			Any symptom			Reference
		ED_{01} (95 % CI)	**ED_{05} (95 % CI)**	**ED_{10} (95 % CI)**	**ED_{01} (95 % CI)**	**ED_{05} (95% CI)**	**ED_{10} (95% CI)**	
Cashew	31 (children)	1.30 (0.18 - 9.57)	7.41 (1.9 - 28.7)	16.0 (5.4 - 47.4)	0.02 (0.002-0.25)	0.32 (0.1-1.8)	1.07 (0.3-4.5)	(Blom et al., 2013)
		1.4-2.8[2] (NA)	8.9-11.5[2] (NA)	16.8-22.7[2] (NA)	-	-	-	(Remington, 2013)
		-	3.0-3.3[3,4] (NR)	-	-	-	-	
		-	2.6-3.0[4,5] (NR)	-	-	-	-	(Taylor et al., 2013)
		-	1.9-2.1[5,6] (NR)	-	-	-	-	
Soy	80 (adults/children)	0.078-3.1[2] (NA)	4.7-22.2[2] (NA)	28.2-63.4[2] (NA)	-	-	-	(Remington, 2013)
		-	1.0-2.9[3,4] (NR)	-	-	-	-	
		-	2.3-5.5[4,5] (NR)	-	-	-	-	(Taylor et al., 2013)
		-	1.15-0.5[5,6] (NR)	-	-	-	-	
	23 (adults/children)	37.2 (NR)	-	-	0.37 (NR)	-	-	(Ballmer-Weber et al., 2007)
Wheat	40 (adults/children)	0.14-1.1[2] (NA)	2.0-4.3[2] (NA)	6.6-10.2[2] (NA)	-	-	-	(Remington, 2013)
		-	1.3-1.5[3,4] (NR)	-	-	-	-	
		-	1.4-1.6[4,5] (NR)	-	-	-	-	(Taylor et al., 2013)
		-	0.41-0.44[5,6] (NR)	-	-	-	-	

Food	No. of patients (population)	Objective symptoms			Any symptom			Reference
		ED_{01} (95 % CI)	ED_{05} (95 % CI)	ED_{10} (95 % CI)	ED_{01} (95 % CI)	ED_{05} (95% CI)	ED_{10} (95% CI)	
Mustard	33 (adults/children)	0.022-0.097[2] (NA)	0.32-0.46[2] (NA)	1.0-1.2[2] (NA)	-	-	-	(Remington, 2013)
		-	0.09-0.1[3,4] (NR)	-	-	-	-	
		-	0.11-0.12[4,5] (NR)	-	-	-	-	(Taylor et al., 2013)
		-	0.046-0.052[5,6] (NR)	-	-	-	-	
Lupin	24 (adults/children)	0.83-3.7[2] (NA)	7.8-19.1[2] (NA)	20.8-33[2] (NA)	-	-	-	(Remington, 2013)
		-	4.5-4.8[3,4] (NR)		-	-	-	
		-	0.61-0.65[4,5] (NR)		-	-	-	(Taylor et al., 2013)
Sesame	21 (adults/children)	0.10-0.67[2] (NA)	2.1-3.8[2] (NA)	7.6-10.6[2] (NA)	-	-	-	(Remington, 2013)
		-	0.45-0.56[3,4] (NR)	-	-	-	-	
		-	0.49-0.61[4,5] (NR)	-	-	-	-	(Taylor et al., 2013)
		-	0.13-0.18[5,6] (NR)	-	-	-	-	
Shrimp	48 (adults)	3.7-6.1[2] (NA)	73.6-127[2] (NA)	284-500[2] (NA)	-	-	-	(Remington, 2013)
		-	17.6-19.1[3,4] (NR)	-	-	-	-	
		-	10.4-12.1[4,5] (NR)	-	-	-	-	(Taylor et al., 2013)
		-	13.1-13.9[5,6] (NR)	-	-	-	-	

[1] Expressed as mg of total protein from the allergenic food, unless otherwise specified;
[2] Depending on the distribution model used (e.g. log-logistic, log-normal or Weibull);
[3] Depending on whether discrete or cumulative trigger doses were used for analysis, Log-logistic;
[4] 95 % lower confidence interval of ED_{05};

[5] Depending on whether discrete or cumulative trigger doses were used for analysis, Log-normal;
[6] Depending on whether discrete or cumulative trigger doses were used for analysis, Weibull;
[7] Depending on the studies used to derive the minimum observed eliciting doses (e.g. food challenges for immunotherapy, threshold-finding or diagnostic purposes);
NR = not reported; NA = not available numerically, reported only graphically in the original publication

GLOSSARY AND ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
1DE	1-dimensional electrophoresis
2DE	2-dimensional electrophoresis
2D-SDS-PAGE	Two dimensional Sodium Dodecyl Sulphate-PolyAcrylamide Gel-Electrophoresis
Absolute LOD	For DNA-based methods, LOD expressed as absolute amounts of DNA detected (e.g. in pg, ng, or number of DNA copies)
ALA	α-lactalbumin
Allergen	Proteins or peptides responsible for the allergenicity of allergenic foods/ingredients
Allergenic food	Substances listed under Annex IIIa of Directive when considered as such
Allergenic ingredient	Substances listed under Annex IIIa of Directive when considered as part of complex foods
Allergenicity	Ability to induce immune-mediated clinical reactions
Antigenicity	Ability to induce the synthesis of specific IgE antibodies
AOAC	Association of Analytical Communities
AQUA	Absolute quantification of proteins using stable isotope labelled peptides by MS
Atopy	Familial tendency to produce IgE antibodies in response to low doses of allergens
BIA	Biosensor ImmunoAssay
BLAST	Basic Local Alignment Search Algorithm
BLG	β-lactoglobulin
BMD	Bench Mark Dose
BSA	Bovine Serum Albumin
CAS	Casein
CAP (or ImmunoCAP)	A brand name of a test for the diagnosis of atopy in patients with allergy-like symptoms. It measures specific IgE antibodies in human serum.

CAP-FEIA	CAP-FluorEnzymeImmunoAssay
CAP-RAST	CAP-RadioAllergoSorbent Test
CCDs	Cross-reactive Carbohydrate Determinants
CD	Circular Dichroism
CE	Capillary Electrophoresis
CI	Confidence Interval
CITP-CZE	Capillary Isotachophoresis-Capillary Zone Electrophoresis
CMA	Cow's milk allergy
CMP	Cow's milk proteins
Coeliac disease	Autoimmune adverse reaction to food triggered by the ingestion of gluten and related to prolamins found in wheat, barley and rye
CRIE	Cross RadioImmunoElectrophoresis
CRM	Certified Reference Material
DAS-ELISA	Double Antibody Sandwich-Enzyme Linked Immunosorbent Assay
DBPCFC	Double Blind Placebo Controlled Food Challenge
DIGE	Difference Gel Electrophoresis
DLLME	Dispersive Liquid–Liquid MicroExtraction
DNA	Deoxyribonucleic Acid
Dot-blot	Dot-immunoblotting
EAST	Enzyme-AllergoSorbent test
ED	Population-based Eliciting Dose
EIS	Electrochemical Impedance Spectroscopy
ELISA	Enzyme Linked Immunosorbent Assay
ESI	ElectroSpray Ionisation
ESI-MS	ElectroSpray Ionisation-Mass Spectrometry
EU	European Union
FAPAS	Food Analysis Proficiency Assessment Scheme
FARRP	Food Allergen Research and Resource Program

FDEIA	Food-Dependent Exercise-Induced Anaphylaxis
FFF	Field-Flow Fractionation
FIA	Flow Injection Analysis
Food allergy	Adverse health effect arising from a specific immune-mediated response that occurs reproducibly on oral exposure to a given food, which can be mediated by food-specific immunoglobulin class E (IgE) antibodies or not
Food intolerance	Non immune-mediated adverse reactions to food
FPIES	Food protein-induced enterocolitis syndrome
FT-ICR	Fourier Transform Ion-Cyclotron Resonance
FTIR	Fourier Transform Infrared Spectroscopy
GC	Gas Chromatography
GD	Gas Diffusion
GLP	Germin-Like Proteins
GNPs	Gold NanoParticles
HHP	High Hydrostatic Pressure
HMW	High Molecular Weight
HPLC	High Performance Liquid Chromatography
HPLC/ESI-MS/MS	High Performance Liquid Chromatography-Electro Spray Ionisation-Tandem Mass Spectrometry
HR-MS	High-Resolution Mass Spectrometry
HS-GC	Head-Space Gas Chromatography
Ig	Immunoglobulin
IgG	Immunoglobulin class G antibodies
IgE	Immunoglobulin class E antibodies
IC	Ion-exclusion Chromatography
ICD	International Classification of Diseases
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
ICSA	Interval-Censoring Survival Analysis. Method used to determine individual thresholds when the exact dose that provokes a reaction in an individual is not known but it is known to fall into a particular

	interval. Individuals reacting to the first dose in a challenge trial are left-censored: the NOAEL is set to zero with the LOAEL is set as that first dose. Individuals not experiencing a reaction after the largest challenge dose are right-censored: the NOAEL is set to that largest challenge dose and the LOAEL is set to infinity. In all other cases, interval-censoring occurs bounded by the NOAEL and LOAEL.
IEF	IsoElectric Focusing
Incurred sample	A sample in which a known amount of the authentic specimen is added before treatment (cooking or any industrial process)
IPC	Internal Positive Control
IRMM	Institute for Reference Materials and Measurements
ISAAC	International Study of Asthma and Allergies in Childhood
IT	Ion Trap
IUIS	International Union of Immunological Societies
KDS	Potassium Dodecyl Sulphate
LAB	Lactic Acid Bacteria
LC	Liquid Chromatography
LC-ESI-MS	Liquid Chromatography-ElectroSpray Ionisation-Mass Spectrometry
LC-ESI-MS/MS	Liquid Chromatography-ElectroSpray Ionisation-Tandem Mass Spectrometry
LC-ESI-IT-MS/MS	Liquid Chromatography-ElectroSpray Ionisation-Ion traps-Tandem Mass Spectrometry
LC-ESI-QqQ-MS/MS	Liquid Chromatography-ElectroSpray Ionisation-Triple Quadrupoles-Tandem Mass Spectrometry
LC-ESI-Q-TOF-MS/MS	Liquid Chromatography-ElectroSpray Ionisation-Quadrupole-Time Of Flight-Tandem Mass Spectrometry
LC/HR-MS	Liquid Chromatography-High-Resolution Mass Spectrometry
LC-LIT-MS	Liquid Chromatography-Linear Ion Trap-Mass Spectrometry
LC-LIT-MS/MS	Liquid Chromatography-Linear Ion Trap-Tandem Mass Spectrometry
LC-MS/MS	Liquid Chromatography-Tandem Mass Spectrometry
LC-QpQ-MS/MS	Liquid Chromatography-Triple Quadrupoles-Tandem Mass Spectrometry

LF	LactoFerrin
LFD	Lateral Flow Device
LMW	Low Molecular Weight
LIT	Linear Ion Trap
LOAEL	Lowest Observed Adverse Effect Level
LOD	Limit Of Detection
LOQ	Limit Of Quantification
LSPR	Localised Surface Plasmon Resonance
LTP	Lipid Transfer Proteins
mAb	Monoclonal Antibody
MALDI	Matrix Assisted Laser Desorption Ionisation
MALDI-TOF	Matrix Assisted Laser Desorption Ionisation-Time Of Flight
MED	Minimal Eliciting Dose
MIM	Multiple Ion Monitoring
MLC	Myosin Light Chain
MLPA	Multiplex Ligation-dependent Probe Amplification
MnSOD	Manganese SuperOxide Dismutase
MoE	Margin of Exposure
MOED	Minimal Observed Eliciting Dose
MRM	Multiple Reaction Monitoring
MRM-MS	Multiple Reaction Monitoring-Mass Spectrometry
MS	Mass Spectrometry
MS/MS	Tandem Mass Spectrometry
MW	Molecular Weight
NCBI	National Center for Biotechnology Information
NIST	National Institute of Standards and Technology
NMR	Nuclear Magnetic Resonance
NOAEL	No-Observed Adverse-Effect Level

NOE	Nuclear Overhauser Effect
NSAID	Non-Steroid Anti-Inflammatory Drug
nsLTP	non specific Lipid Transfer Proteins
OAS	Oral Allergy Syndrome is an IgE-mediated immediate type allergic reaction characterised by symptoms within several minutes after contact with food, involving the mouth and the pharynx
OFC	Open label Food Challenge
OMW	Optimised Monier-Williams method
qPCR	quantitative Polymerase Chain Reaction
QpQ	Triple Quadrupole
Q-TOF	Quadrupole-Time Of Flight
PAD	Pulsed Amperometric Detection
Panallergens	Usually classified as minor allergens, are homologous molecules that originate from a multitude of organisms and cause IgE cross-reactivity between evolutionary unrelated species
PBS	Phosphate Buffer Saline
PCR	Polymerase Chain Reaction
PCR-RFLP	Polymerase Chain Reaction-Restriction Fragment Length Polymorphism
PFF	Peptide Fragment Fragmentation
PFU	PCR Forming Units
PMF	Peptide Mass Fingerprinting
PNA	Peptide Nucleic Acid
PR proteins	Pathogenesis-Related proteins
PUV	Pulsed UltraViolet light
PVDF	PolyVinylidene DiFluoride
PWG	Prolamin Working Group
RAST	RadioAllergoSorbent Test
REA	Resonance Enhanced Absorption
Real Time-PCR	Real-Time Polymerase Chain Reaction

RIE	Rocket Immuno Electrophoresis
RP-HPLC	Reversed-Phase High Performance Liquid Chromatography
RT-PCR	Reverse Transcriptase- Polymerase Chain Reaction
SBPCFC	Single Blind Placebo Controlled Food Challenge
SCBP	Sarcoplasmic Calcium-Binding Protein
SCORAD	SCORing Atopic Dermatitis
SDAP	Structural Database of Allergenic Proteins
SDS-PAGE	Sodium Dodecyl Sulphate-PolyAcrylamide Gel-Electrophoresis
SEC	Size-Exclusion Chromatography
SELDI	Surface-Enhanced Laser Desorption Ionization
SELDI-TOF/MS	Surface-Enhanced Laser Desorption Ionization-Time Of Flight-Mass Spectrometry
Sensitisation	Positive SPTs or high levels of specific IgE to the offending food
SGF	Simulated Gastric Fluid
SLIT	SubLingual ImmunoTherapy
SOTI	Systemic Oral Tolerance Induction
SPI	Soybean protein isolates
Spiked sample	A sample in which a known amount of the authentic specimen is added before the analysis.
SPF	Soy Protein-based Formula
SPR	Surface Plasmon Resonance
SPRI	Surface Plasmon Resonance Imaging
SPT	Skin Prick Test
SRM	Selective Reaction Monitoring
TLP	Thaumatin-Like Proteins
TOF	Time Of Flight
TOF^2	TandemTime Of Flight
TRFIA	Time-Resolved FluoroImmunoAssay

UK	United Kingdom
US	United States
WDEIA	Wheat-Dependent Exercise-Induced Anaphylaxis
WHO	World Health Organisation