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# Are alternative proteins increasing food allergies? Trends, drivers and future perspectives☆

C. Kopko[a,*], J.A. Garthoff[b], K. Zhou[a], L. Meunier[b], A.J. O'Sullivan[b], V. Fattori[a]

[a] Food and Agriculture Organization of the United Nations, Rome, Italy
[b] Danone Food Safety Center, Danone Nutricia B.V. Utrecht, the Netherlands

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ABSTRACT

*Background:* **Food allergy** can represent a serious human health issue. The observed rise in regional incidence and global prevalence of food allergies raise, among other, also questions about the risks related to the consumption of new, modified, and **alternative protein** sources.

*Scope and approach:* As we strive towards transforming food systems to match our need for sustainability, food security and adequate nutrition, we cannot lose sight of the importance of food safety. **Population growth**, socioeconomic development, and urbanization, among other factors is putting increasing pressure on the global food supply in general, and on protein sources in particular. New protein sources, such as plant-based meat alternatives and edible insects, while promising to be sustainable protein sources, can also potentially expose allergic and non-allergic consumers to **new food allergens**. Therefore, it is essential to investigate the new drivers and trends influencing the patterns of **protein consumption** while exploring the capacity of existing monitoring and regulatory systems to manage increases in **allergy incidence**, to new and existing food allergens.

*Key findings and conclusions:* This article focuses on key drivers for new food allergy, reviews the latest developments in risk assessment, reporting and monitoring; and outlines possible actions from national authorities, food business operators, clinicians and consumers to proactively address these challenges, ensuring safe food for everyone.

## 1. Food allergy: current understanding of the issue, risk management and regulatory frameworks

Food allergy is an important global human health issue for which no effective cure exists. Food allergy is defined as an adverse human health effect arising from an abnormal immunological response following exposure to certain food proteins. Most reported and confirmed food allergies are categorized as IgE-mediated as they trigger the body's immune system to produce Immunoglobulin E (IgE) antibodies. Symptoms of IgE-mediated allergies can range from mild and transient to severe, including death without proper and timely treatment, and typically develop within minutes to 1–2 h after ingesting very small amounts of the culprit food even after one eating occasion (Remington et al., 2020). For other immune mediated reactions to food, including coeliac disease and other non-IgE mediated reactions, symptoms will often occur with a delay of several hours after exposure and are rarely acute or life-threatening. Despite ongoing investigation, there continues to be limited understanding of the immunopathogenic mechanisms underlying non–IgE-mediated food allergies (Cianferoni, 2020). It must also be acknowledged that although food safety risk management efforts have been mainly directed towards controlling proteinaceous allergens, there are emerging concerns raised for food allergies originating from sensitization to specific carbohydrate structures (e.g., galacto-oligosaccharides, alpha-galactose) (Lee et al., 2022). Such emerging food allergies do remain with very low prevalence worldwide and current knowledge available indicates they have quite limited, specific geographical footprints.

Food allergy arises from a complex interplay between genetic and environmental factors such as diet, microbiota composition and environmental chemical exposure (Shahali & Dadar, 2018). It is not yet clear whether the changing prevalence of allergy relates to an increase in the identification and diagnosis of allergy, an absolute rise in the number of



* Corresponding author. Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153, Rome, Italy.
*E-mail address:* christine.kopko@fao.org (C. Kopko).

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food allergies being reported or the importance of environmental factors in allergic susceptibility (Savage et al., 2016). What is clear is that increases in prevalence have preferentially affected industrialized regions and there is evidence of increasing prevalence in rapidly developing countries in line with rising economic growth (Leung et al., 2018). The prevalence and nature of food allergy in different regions reflect the commonly consumed food allergens in those regions (Loh & Tang, 2018). Research studies have demonstrated how factors like immigration, ethnicity and consumer behavior affect food allergy development (Table 1).

Food allergens are consumed by most of the general population without any adverse effects. However, the health burden of food allergy is non-trivial. It is estimated that there are 220 million food allergy sufferers worldwide (Warren et al., 2020). Up to 3% of the adult population and up to 10% of the pediatric population are allergic as children often outgrow their allergies (Turner et al., 2019). Allergic individuals in Europe and North America report a poorer quality of life and higher healthcare (46% more) and food spending costs (19% more) than their non-allergic peers (Fox et al., 2013; Golding et al., 2021; Warren et al., 2020). Food allergy prevalence appears to be increasing, particularly in children (Houben et al., 2016; Sicherer & Sampson, 2014, 2018), therefore, the $24.8 billion annual cost attributed to food allergy in the United States of America in 2013 (Warren et al., 2020) would be an underestimate of the current situation.

Allergens can occur in food products as part of the ingredients or through unintended cross-contamination. Allergen risk management of commercial packaged foods is ultimately implemented through appropriate labeling to inform allergic consumers of the specific “presence” of the allergen so they can avoid foods that would put them at risk. However, before a product reaches the final consumers, it requires the ability of Food Business Operators (FBOs) to accurately identify and manage allergens in the supply chain through appropriate disclosures, traceability, good manufacturing and handling practices and proper labelling. Weaknesses or gaps in allergen management can in the most severe cases represent life-threatening risks for the consumer. In general, precautionary (advisory) allergen labeling (also referred to as PAL) which includes statements such as “may contain” may be applied voluntarily by FBO to inform and protect consumers with allergies from products with a potential unintended allergen presence (UAP). The current research on precautionary allergen statements suggests that they are often confusing for consumers and ineffective due to their over-use on pre-packaged food products. It is also recognized that a harmonized global approach to PAL could improve consumers trust and understanding of these statements (Allen & Taylor, 2018; Fiocchi et al., 2021; Holleman et al., 2021).

The Codex Alimentarius Commission (CAC) is undertaking a review of allergen labelling provisions, which includes developing international guidelines on the proper use of PAL. This work is underpinned by the deliberations of expert committees convened through ad hoc Joint FAO/WHO meetings for scientific advice. The FAO/WHO expert committee reached consensus on the priority allergens (FAO & WHO, 2022a), their threshold levels (FAO & WHO, 2021b; 2022b) and recommendation on PAL (FAO & WHO, 2021c). CAC has also recently adopted a Code of Practice on the management of allergens throughout the supply chain to support industry compliance. Best practices in allergen management developed over the last 25 years by the food industry to support accurate allergen declarations, prevent allergen cross contamination and validate the control measures being taken, have been consolidated into a harmonized practice on food allergen management for FBOs (FAO & WHO, 2020) including primary producers. However, there are indications that the shortfall in implementation of best practices as well as the further need for clarity of labelling and education for consumers represents a continued vulnerability in the system (FAO, 2021a). The risk of undeclared allergens cannot be completely avoided, and consequently recalls due to allergens continue to be amongst the top food safety related recalls (Do et al., 2018).

Currently there is limited consensus amongst jurisdictions on regional priority allergen lists of public health relevance as dietary habits and consequently allergen exposures can differ vastly. Some national and regional regulatory authorities have prioritized allergenic foods responsible for most of the food allergy national public health burden based on clear scientific criteria (Houben et al., 2016) while others have adopted the list of foods and ingredients known to cause hypersensitivities internationally included in the CAC labelling standards (FAO & WHO, 2018), particularly for the labelling of foods for export. It is generally observed that it takes time to capture the rise in incidence of new or emerging allergens and include these in allergen management practices, since sufficient scientific information needs to be available to assess the public health burden (allergen severity, potency and prevalence). Not many countries have a system for reporting food allergens, and for those that do have monitoring and surveillance programs they tend to focus on known allergens.

Fig. 1 aims to provide an overview of the four key drivers that impact risk for human health posed by new or revised proteins: different hazard characteristics, type of exposures, approaches to risk assessment, management and communication but also the individual vulnerability towards the development of food allergy.

**Table 1**
Examples of how different factors affect food allergy development.

| Key findings | References |
|---|---|
| • Survey in Singapore showed that irrespective of ethnicity, those born in Asia had lower risk of peanut and tree nut allergies compared to those born in Western countries. | Sicherer et al. (2000) |
| • Migration from Asia after the early infant period appears protective for the development of nut allergy.<br>• Additionally, rural regions have lower rates of nut allergy than urban areas.<br>• The gene-environment interactions are likely to underline the etiology of food allergic disease. | Warren et al., 2020; Panjari et al., 2016 |
| • Children of East Asian or African descent born in a Western environment are at higher risk of food allergy compared to Caucasian children. | Loh & Tang (2018) |
| • First-generation immigrants have a lower allergy prevalence compared to the native population.<br>• Second-generation immigrants have a higher allergy prevalence compared to first-generation immigrants and second-generation immigrants with two foreign-born parents have a lower allergy prevalence than those with only one foreign born parent. | Tham et al. (2018) |
| • An increase in peanut allergy prevalence in South Africans.<br>• Peanut allergy rates were significantly higher in mixed race patients. | Basera et al., 2015; Gray et al., 2015; Leung et al., 2018 |
| • A changing pattern of food anaphylaxis in the cohort of Singaporean children with peanut emerging as most commonly reported food trigger.<br>• This is contrast to zero peanut food triggers 15 years ago. | Liew et al. (2013) |
| • Increasing number of buckwheat allergy cases in Asia as buckwheat is used as a substitute for wheat in gluten free products. This trend is expected to continue as Japanese food popularizes globally. | Lee et al. (2013) |
| • Food allergy time-trends confirm the rising prevalence in Asia, and a gradient of food allergy with progressive economic development also provides indirect evidence that food allergy is associated with westernization. | Prescott et al. (2013) |

## 2. New drivers and trends in food consumption

The world population is growing; it is estimated to increase by one third by 2050, so, the problem of how to feed this increasing population

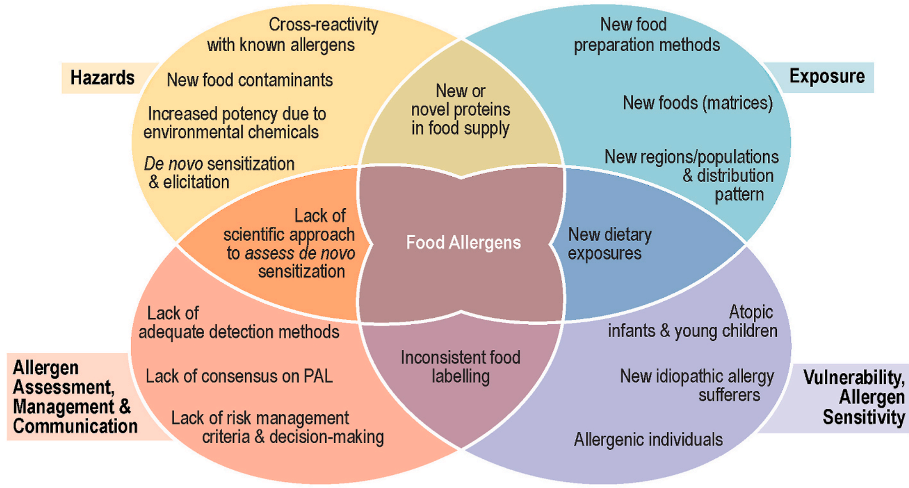



**Fig. 1.** Risk factors driving the emergence of new food allergies.

while preserving the planet remains to be solved and was the focus of the 2021 United Nations Food Systems Summit (UN-FSS). The UN-FSS challenged all stakeholders (academia, private sector, healthcare, farmers, etc.) to bring about tangible, positive changes to transform the way the world produces, process, consumes and thinks about food. New and alternative sources of protein that are scalable, economically viable and cost competitive can represent a clear opportunity to address this gap (UN, 2021).

As new foods enter the food system, it is essential that the potential risks to consumers be identified and assessed, since human health should not be compromised in the process. One such risk is the inadvertent introduction of allergens into the diet through new exposures, new or altered proteins or allergen cross-reactivity. The adoption of plant-based diets through vegetarianism, veganism and variants of these continue to trend upwards and is propelling advancements in the plant-based alternatives industry (McClements & Grossmann, 2021). While consumers are reducing their consumption of animal-based products for various reasons, they still desire the texture, mouthfeel and feeling of satiety often associated with various animal-derived products. This has led to the development of various plant-based alternatives that mimic the taste and experience of consuming animal-based products (He et al., 2020). The protein sources typically used in plant-based alternatives range from legumes to nuts, seeds, cereals and tubers (Sha & Xiong, 2020), many of which are foods known to be responsible for the majority of food allergies.

Food processing technologies are being used to create protein isolates and concentrates from novel sources such as pea, potato, seaweed, fava bean and chickpea. Functional ingredients formulated from these novel sources, can be added to various foods as a plant-based high-protein source without the allergen management implications associated with wheat and soy, the more traditional sources (Webb et al., 2020). These crops can be scaled up to meet the demand; however, the allergenic or cross-reactivity potential of these protein sources should not be overlooked. While potato protein appears to be allergen-free (Hussain et al., 2021), for legumes there is a high rate of cross-reactivity among different types with individuals allergic to one showing sensitivity to others, but not necessarily to all (Bessada et al., 2019; Kakleas et al., 2020). Foods of plant origin are the major source of food allergy in adults, which is not unexpected given that plant proteins are more likely to be recognized as non-self when compared to animal proteins (Masilamani et al., 2012; Shahali & Dadar, 2018). Emerging plant-based foods with increasing popularity, such as legumes (e.g. lentils, chickpeas) and seeds (e.g. poppy and pumpkin seeds), warrant proper clinical investigations as the reported number of allergic consumers increase (Soller et al., 2021).

Another consideration is the potential risk of hidden or undeclared allergens that can occur during food product formulation and production when plant-based sources are replaced or mixed with others due to drivers such as supply shortages, healthier alternatives (e.g., pea protein versus lupine or soy) or cost reductions. In some cases, ingredients do no need to be identified when present at less than 2% in finished products if the source is not recognized as major allergen. Undeclared or hidden allergens could potentially result in a serious health risk (Lavine and Ben-Shoshan, 2019; Martin-Munoz et al., 2017; Skypala, 2019) and could be rapidly revealed by new developments in the area of proteomics technologies for protein identification and quality control (Carrera et al., 2018; Khan et al., 2021).

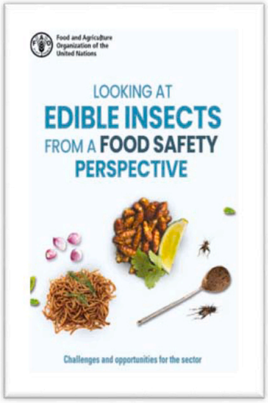
Other dietary trends where new proteins exposure may occur are based on animal sources like edible insects and cell-based meat/seafood (also known as *in vitro*, lab-grown, or cultured meat) derived from animal stem cells that are cultivated in controlled setting. Although meat allergies are rare, cell-based meat and seafood would represent the same risk to those allergic to regular meat, fish and crustacean products, therefore the information to consumers should fully disclose the origin of the products (Bryant, 2020; Watson, 2021). Edible insects are undoubtedly possible new allergen sources (EFSA NDA Panel et al., 2021; FAO 2021b). Although more research is needed to fully understand the allergenicity of certain insects and the effects of thermal processing, there is an established allergen cross reactivity with crustaceans and dust mites, as reflected in Box 1 (Hadi & Brightwell, 2021).

Fortunately, in this race for innovation, many regulatory systems now include requirements for pre-market authorization to assess ingredient safety. This includes the consideration of the potential allergenicity for new/novel proteins designed to safeguard consumers.

## 3. Risk factors driving allergic response

Factors known to affect sensitization to proteins and the development of protein allergy are embedded in three major considerations: the subject (intrinsic and immediate environmental factors), exposure routes, and the allergen itself. The susceptibility of the individual is driven largely by the possession of an atopic phenotype (genetic or epigenetic). Atopy being defined as a tendency to produce chronic IgE antibody responses and symptoms when exposed to low dose allergens. Atopy appears to show a strong hereditary component, especially on the maternal side, and to be influenced by factors such as gender, ethnicity, socioeconomic status, childhood care and feeding status (Blumenthal, 2005; EC, 2021). The age of the subject at time of exposure to allergens is also important as sensitization to protein is most likely to occur during infancy or even in utero, particular at times when severe infection or

**Box 1**
Edible insects as new allergen source




Edible insects are good food and alternative protein sources that are nutritious and environmentally sustainable, but food safety considerations need thorough investigation. The recent FAO report *Looking at edible insects from a food safety perspective* (FAO, 2021b) describes these aspects, including the allergenic potential of edible insects, in depth. Insects, like crustaceans (e.g., shrimp) belong to the arthropod family, hence, individuals already allergic to shellfish are particularly vulnerable to developing allergic reactions to edible insects, due to allergen cross-reactivity. There is also evidence that new hypersensitivities to insect proteins can arise in those with no allergic predisposition. Further research is needed to gain a better understanding of the potential allergenic risk associated with consuming and producing edible insects and processed insect-based foods.

other factors transiently disturb normal immune mechanisms. There is substantial evidence that environmental disturbances to the gut microbiome of an infant can affect digestion and immunity and may play a critical role in food allergy development (Eisenstein, 2020; Rachid et al., 2021).

Gender also appears to play a role in some allergies as boys appear to be at higher risk than girls with the reverses happening after puberty and in adulthood, with women being more susceptible than men, suggesting an endocrinologic influence (Chen et al., 2008). Also, other health factors are reported to play a role in sensitization susceptibility, like physical condition, nutritional insufficiency (vitamin D and Omega-3 fatty acids) or drug use that can influence barrier function, food (allergen) digestion, and allergen clearance. Physical exercise, stress, sleep disturbance, alcohol, antibiotics (disruption to the microbiome impairing gut function and immunity), gastric acidity inhibitors (impairment of protein digestion, requiring an acid pH) and non-steroidal anti-inflammatory drugs (NSAIDs), all of which influence the immune response, may increase the likelihood of food-allergic reactions (Shin, 2021).

The route of exposure is the second key consideration. The development of allergic sensitization to proteins can result from oral (dietary), inhalation and/or skin exposure. There is little information regarding the relative effectiveness of different routes of exposure. However, quite some evidence is available on the importance of respiratory sensitization, through aeroallergens, followed by food allergy due to cross-reactive allergen components that can be found in different plant families (so called pollen-food syndrome) (Popescu, 2015). Changes in dietary habits as a result of globalization can also contribute to new exposures. The introduction of traditional foods from one region or country, to another can result in an increase in prevalence or even a new allergen.

Finally, the characteristics of the protein allergen will influence the inherent potency of the allergen itself. The following has been identified as being important: structural features and characteristics of 2D and 3D epitopes (antigenic determinants), enzymatic activity (and possibly other functional attributes of the protein), the influence of post-translational modifications (and perhaps in particular glycosylation), and physico-chemical properties such as stability and resistance to proteolytic digestion. In addition, the matrix in which allergenic proteins are encountered, and other cofactors may also be influential (Verhoeckx et al., 2020). The allergenic activity of a complex food may be decreased, remain unchanged, or even be increased by food processing. As an example, the application of different (novel) nonthermal processing techniques for whey protein (WP) have demonstrated potential in minimizing the allergenicity of WP (Khan et al., 2021) on the contrary, thermal processing resulting in Maillard product formation could enhance the immunogenicity of allergen proteins (Teodorowicz et al., 2017). 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- or non-IgE binding capacity of several allergens have been investigated, less information is available on the effects of processing on clinical reactivity (EFSA NDA Panel, 2014; Verhoeckx et al., 2015). New processing techniques applied to known protein sources could therefore result in new allergenic hazards. This phenomenon is, for instance, demonstrated by the rise of peanut allergy in the pediatric population in Asia, partly due to the exposure to differently processed peanuts (roasted peanut butter versus boiled peanuts) (Liew et al., 2013).

## 4. Newly introduced potential hazards

Plant food allergens belong to a relatively limited number of protein families with seed storage, structural or defense properties. The latter are part of the first defense line of plants, particularly against invading pathogens, but also in case of biotic and abiotic stresses. Studies have demonstrated that alterations in environmental conditions may enhance the expression of allergenic defense proteins, thereby potentially increasing the allergenicity of different plants (Shihali & Dadar, 2018). Alternative proteins are a growing industry, and thus the global food sector should initiate collaborative efforts to ensure the safety of foods in this category.

To assess the allergenicity of new protein sources current guidance relies mainly on a weight-of-evidence allergenicity risk assessment, which mainly focuses on the impact of a single protein (or at most a few proteins) on individuals with pre-existing allergies and the potential for sensitization and cross-reactivity. This approach protects individuals with known existing allergies, but it is not applicable for the prediction of risks of *de novo* (new) sensitization and allergies to novel proteins. For example, Broekman et al. (2017) showed that exposure to mealworm can induce *de novo* sensitization to larval cuticle proteins, leading to food-allergic responses confirmed in a double-blind placebo-controlled food challenge (DBPCFC). The affected individuals were not allergic to any other food, in contrast to participants in the same study with allergies to crustacea, which were well-predicted and confirmed to be food allergic to mealworm proteins in addition to crustacea. The offending proteins were not identified as allergenic using the homology testing strategy proposed by CAC guidelines and adopted by national food safety authorities. Another study identified newly introduced epitopes after deamidation of gluten, which could be responsible for the severe allergic reactions in people normally tolerant to unmodified wheat products (Denery et al., 2013).

These examples highlight the importance of considering the *de novo* sensitization potential of novel and processed proteins and addressing it in the risk assessment of new foods. Such an evaluation would complement the assessment of potential allergenic cross-reactivity and permit a complete prediction of allergenicity. Methods for this are largely lacking; however, several activities are ongoing to address these gaps. For instance, within the Improving Allergy Risk Assessment Strategy for novel food proteins (ImpARAS) project (ImpARAS, 2015), the Adverse Outcome Pathway (AOP) for the *de novo* sensitization has been established identifying molecular initiating events and all key events eventually leading to the AOP of sensitization. Existing *in vitro* and *in vivo* tools are discussed to address these events as part of the pathway. However, a better understanding of AOPs could guide the development of better *in vitro* and *in vivo* testing methods to assess protein allergenicity (Verhoeckx et al., 2020). In addition, the derivation of a threshold of allergic concern (TAC) has been discussed, excluding the proteins for assessment that remain below this threshold. Another strategy has been applied by Westerhout et al. (2019), developing an *in silico* model, applying machine learning, making use of the Radom Forest model to predict allergenicity, based on all the known physicochemical and biochemical protein characteristics.

In addition to the continuous effort to control and inform consumers about known allergens, it is pivotal to screen for emerging food allergen risks and develop appropriate approaches to assess and manage those. Currently there are no national or global initiatives to screen for allergen prevalence and/or incidence. There are several initiatives on an *ad hoc* basis to get insights into regional allergen prevalence and incidence (e.g., EC, 2021) to aid the establishment of allergen priority lists and get further insight into allergen risk factors, but it is not a continuum at the moment.

## 5. Identifying new risks and new reporting

To provide consumers with unambiguous information on actual allergen risk, efforts have been made over the last decade to develop and harmonize the application of a threshold-based quantitative risk assessment in case of unintended allergen presence. Such approaches rely on some of the internationally established thresholds, so-called reference doses, established from clinical reactivity thresholds or 'eliciting doses' in allergic consumers for well-established major allergens (FAO & WHO, 2021b; 2022b; ILSI, 2021; Taylor et al., 2014). To apply this approach successfully, robust analytical methods need to be available to detect and verify allergen levels in the finished food product. In particular cases, there are also opportunities to have verifications performed upstream in the value chain through the testing of the ingredient raw material and factoring in the actual ingredient dilution in the finished product (Remington et al., 2022). Further efforts are needed in the area of known allergens, let alone for truly new protein sources (Holzhauser et al., 2020). Furthermore, the development and use of a statistically relevant food intake datasets representative of single meal (acute) ingestion for food categories based on the adequate food consumption surveys of the involved countries is recommended to facilitate risk management efforts and harmonization of known allergens (Blom et al., 2019; Meima et al., 2021).

Noteworthy, although being at an advanced stage of wider recognition internationally, the use of science-based reference doses based on clinical data is not yet harmonized and therefore is not ready to be applied in global allergen risk management approaches. It is still subject to discussion between scientists (e.g., Turner et al., 2022; Zuberbier et al., 2022), (food) allergologists, patient associations and different food safety authorities. Some of the diverging viewpoints have different starting points such as differences in risk acceptance level (e.g., AFSCA, 2017; NVWA, 2016), versus accepting only zero tolerance approaches defaulting to the analytical detection limit; or the existence of a unified default thresholds for precautionary allergen labelling being already embedded in some regulations (e.g., Japan, Switzerland).

The development of a reliable, harmonized, evidence-based and validated allergenicity risk assessment requires the commitment and collaboration of multiple stakeholders across the scientific community, food industry, government agencies and consumer and patient associations. The identification and use of food allergen thresholds as tools for manufacturers have a key role to play to ensure consumer protection for unintended allergen presence through the application of relevant precautionary allergen labelling (Yeung & Robert, 2018).

Furthermore, the accurate determination of food allergy prevalence confirmed by the golden standard of double-blind, placebo-controlled oral food challenge (DBPCFC) is resource intensive and not without health risk, limiting the availability of good quality data collected on a population-basis. Outside Europe, the United States of America and Australia, there is variability in the scientific robustness in reported prevalence of food allergy that is proven through challenge testing (challenge proven). Information is gathered not necessarily through oral challenge (e.g., through skin prick testing) or the application of a double-blind placebo-controlled protocol (Loh & Tang, 2018). At the same time, the use of challenge proven diagnosis in Asia and Africa is also increasing which shows evidence of growing allergy prevalence in these regions. In terms of tracking and reporting incidents of emerging allergies, these represent a particular challenge for public health systems. This is because there usually is a poor correlation between self-reported and challenge-confirmed food allergy. This can be improved, for instance, by combining self-reporting with experienced symptoms to be assessed by health care providers with regards to IgE relatedness (Gupta et al., 2019) and clinical history such as hospital admission (Loh & Tang, 2018).

## 6. Concluding comments and way forward

Allergens in food have been considered by the CAC on a number of occasions since 1993. The list of foods and ingredients known to cause hypersensitivity was included into the General Standard for the Labelling of Packaged Foods (GSLPF) in 1999 (FAO & WHO, 2018), but there have been many scientific developments in the understanding of food allergens, their identification, detection and management since then. Recently, a series of ad hoc joint FAO/WHO expert consultations were convened to address the new challenges for food allergy. Recent scientific advice (FAO & WHO, 2022a, b; 2021a, b, c) is available to further inform allergen risk analysis and eventually support international harmonization of allergen threshold levels in risk management.

The introduction of new proteins into the diet and selective transfer of traditional protein foods from one region to another requires a careful consideration of the exposure risk for consumers and existing allergy sufferers. Many of the plant-based protein alternatives are known sources of food allergens such as legumes, nuts, seeds, cereals and tubers. Therefore, ensuring consumer protection requires the ability of the food control system to identify, assess, control and accurately label allergens in the food supply. The existence of scientific evaluation processes for new foods is key in ensuring that the overall safety, as well as allergenicity of new sources of protein are assessed. The push for alternative proteins from genetic engineering and novel food source may further challenge the capabilities to assess allergenicity and necessitate new approaches to risk assessment (Fernandez et al., 2021). Furthermore, it is important to note that equivalent, science-based approaches to assessing new food sources including novel proteins are not in place worldwide (FSA, 2021). This represents a significant weakness in the food control system through which new exposure risks may go unidentified until they present as food safety incidents and hospitalisations with anaphylaxis. In addition to allergen risks, it is important to assess, like for any other foods, how new protein sources may also introduce chemical, microbiological, and physical food safety hazards for plant-based meat alternatives, cultured meat, insect protein, fungal protein and algae (Hadi & Brightwell, 2021).

Furthermore, the capacity of the food control system to foster advances in the identification, assessment and management of emerging allergens must not ignore the pre-existing challenges for securing the fundamentals. Food allergen management practices must be embedded in good manufacturing (GMP) and good hygiene practices (GHP), including HACCP systems, and allergens must be managed throughout the supply chain and manufacturing process (FAO & WHO, 2020). There are stark differences in the regulatory and socio-economic landscape which impact allergen management around the world. There remains many countries which still do not have any mandatory allergen labelling requirements and therefore no effective protection for food allergy sufferers today (Diao, 2017). In addition, the unequal distribution of food allergy reporting systems and data collection worldwide as well as the persistent problem of under-recognition and under-reporting in developing nations (Hossny et al., 2019; Warren et al., 2020). Even in those countries where allergen labelling is required, the level of suffering can be associated with income status. In the United States of America, children with food allergies from families with the lowest incomes faced 2.5 times the amount of emergency department and hospitalization costs than children from families with higher incomes due to the lack of resources needed for preventive care (access basic health care and allergen-free foods) (Bilaver et al., 2016).

As we work towards sustainable agrifood systems, it is essential that food is safe and nutritious for everyone, including those that suffer from food allergy or are predisposed to food allergy. Food safety should not be an afterthought, but rather a prerequisite when transforming agrifood systems to benefit all people, the environment, and the economy and societies at large. Sustainability (or innovation) should not compromise public health.

Everyone has a role to play when it comes to managing food allergens. Regulators need to develop flexible policies that can accommodate changing consumption and advancements in science. FBO must be diligent in applying good manufacturing practices, clinicians with the monitoring and diagnosis of food allergy and susceptible consumers with the reading of food labels.

## Data availability

No data was used for the research described in the article.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