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ORIGINAL ARTICLE OPEN ACCESS

Food Allergy and Gastrointestinal Disease

Frequency and Severity of Allergic Reactions to Non-Mandatory Labelled Allergenic Foods—Data From Two Large European Cohorts

Sabine Dölle-Bierke[1] | Alejandro Gonzalo-Fernández[2] | Dominique Sabouraud-Leclerc[3,4] | Laura Barreales-Tolosa[5] | Barbara Ballmer-Weber[6,7] | Simona Belohlavkova[8] | Maria B. Bilò[9,10] | Ruta Dubakiene[11] | Karin Hartmann[12,13,14] | Monika Jedrzejczak-Czechowicz[15] | Thuy-My Le[16] | Lars Lange[17] | Nikolaos G. Papadopoulos[18,19] | Guillaume Pouessel[20,21,22,23] | Isabel Reig[24] | Athanasios Sinaniotis[25] | E. N. Clare Mills[26,27] | Margitta Worm[1] | Montserrat Fernández-Rivas[28]

[1]Division of Allergy and Immunology, Department of Dermatology, Venereology and Allergology, Charité—Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin, Humboldt-Universität zu Berlin and Berlin Institute of Health, Berlin, Germany | [2]Grupo de Investigación en Alergia, IdISSC, Madrid, Spain | [3]Presidency on Behalf of Allergy-Vigilance Network, France | [4]Pediatrics Unit, University Hospital Reims, Reims, France | [5]Clinical Epidemiology Unit, Department of Preventive Medicine, Hospital Clinico San Carlos, IdISSC, Madrid, Spain | [6]Department of Dermatology, University Hospital Zurich, Zurich, Switzerland | [7]Clinic for Dermatology and Allergology, Cantonal Hospital Sankt Gallen, Sankt Gallen, Switzerland | [8]Medical Faculty and Faculty Hospital Pilsen, Pilsen, Czech Republic | [9]Department of Clinical and Molecular Sciences, Università Politecnica Delle Marche, Ancona, Italy | [10]Department of Internal Medicine/Allergy Unit, University Hospital Ospedali Riuniti, Ancona, Italy | [11]Clinics of Chest Diseases, Immunology and Allergology of Medical Faculty, Vilnius University, Vilnius, Lithuania | [12]Division of Allergy, Department of Dermatology, University Hospital Basel and University of Basel, Basel, Switzerland | [13]Department of Clinical Research, Department of Dermatology, University Hospital Basel and University of Basel, Basel, Switzerland | [14]Department of Biomedicine, Department of Dermatology, University Hospital Basel and University of Basel, Basel, Switzerland | [15]Department of Immunology and Allergy, Medical University of Lodz, Lodz, Poland | [16]Department Dermatology/Allergology, University Medical Center Utrecht, Utrecht University, Utrecht, the Netherlands | [17]Department of Pediatrics, GFO-Kliniken Bonn, St. Marien-Hospital, Bonn, Germany | [18]Allergy Department, 2nd Pediatric Clinic, University of Athens, Athens, Greece | [19]University of Manchester, Manchester, UK | [20]CH Roubaix, Department of Paediatrics, Children's Hospital, Roubaix, France | [21]CHU de Lille, Pediatric Pulmonology and Allergy Department, Hôpital Jeanne-de-Flandre, Lille, France | [22]Université de Lille, ULR 2694: Metrics, Lille, France | [23]Allergy-Vigilance Network, Vandoeuvre-lès-Nancy, France | [24]Allergy Department, Hospital Universitario Peset, Valencia, Spain | [25]Allergology Department, Sotiria Thoracic Diseases Hospital of Athens, Athens, Greece | [26]School of Biosciences, Faculty of Health and Medical Sciences, University of Surrey, Guildford, UK | [27]Division of Immunology, Immunity to Infection and Respiratory Medicine, School of Biological Science, Wythenshawe Hospital, University of Manchester, Manchester, UK | [28]Allergy Department, Hospital Clínico San Carlos, IdISSC and Facultad de Medicina, Universidad Complutense, Madrid, Spain

Correspondence: Margitta Worm (margitta.worm@charite.de) | Montserrat Fernández-Rivas (mariamontserrat.fernandez@salud.madrid.org)

Received: 18 June 2025 | **Revised:** 12 January 2026 | **Accepted:** 5 March 2026

Keywords: anaphylaxis | codex | non-mandatory labelling | pea | seeds | severity

ABSTRACT

Background: The consumption of plant-based food has lately largely increased, raising concerns about allergic reactions from ingredients which are currently not subject to mandatory labelling.

Methods: We analysed the frequency and severity of allergic reactions to non-mandatory labelled allergenic foods (pea, lentil, bean, chickpea, fenugreek, pine nut, sunflower-, poppy-, pumpkin seed, buckwheat) from two large European cohorts: The Anaphylaxis Registry (NORA) and EuroPrevall outpatient clinic study. Severity was assessed using the Food Allergy Severity Score (FASS) and compared with reactions to mandatory labelled allergenic foods.

Shared first Sabine Dölle-Bierke and Alejandro Gonzalo-Fernández and last Margitta Worm and Montserrat Fernández-Rivas authorship.

Results: Among 589 reactions from both cohorts, sunflower seed was the most frequent trigger ($n = 126$). In NORA, pine nut (1.0% of food-induced allergic reactions) was most common followed by pea and buckwheat (0.7% each); in EuroPrevall, sunflower seed (1.2%), poppy seed (0.6%) and lentil (0.6%) predominated. After adjusting for age and sex, the severity of reactions to mandatory labelled seeds and legumes (excluding peanut) were not different (nFASS median: 4.39 vs. 4.43 and 4.56 vs. 4.49). Whereas, cereal-induced reactions (6.47) were significantly more severe than buckwheat (4.77). In Nora, the number of reactions to fenugreek and pumpkin seed were 7.4- and 3.7-fold higher in 2015–2022 versus 2007–2014.

Conclusion: Non-mandatory labelled allergenic foods were identified to cause severe allergic reactions in two large European cohorts. The frequent involvement of sunflower seed, pine nut, pea and lentil, but also rising numbers of reactions to fenugreek and pumpkin seed, indicates their potential risk. These allergenic foods warrant close monitoring and consideration in future allergen labelling revisions.

1 | Introduction

Plant-based diets based on legumes, nuts and seeds are gaining increased popularity worldwide. This shift is often motivated by ethical concerns around food production methods and the need to reduce anthropogenic greenhouse gas emissions [1, 2]. Despite their nutritional benefits, legumes and seeds pose a risk to sensitised individuals and potentially trigger severe allergic reactions [3, 4]. Major allergens are storage proteins like vicilins, legumins, 2S-albumins, but also lipid transfer proteins (LTPs), which are common across all these food groups (Table S1). Within legumes, cross-reactivity is well documented with > 60% of legume-allergic patients showing sensitization to at least one additional legume [5, 6], although clinical relevance varies and depends on the index legume [7]. Molecular studies suggest that particularly vicilins and legumins are relevant in cross-sensitization and LTPs may contribute in specific regions [7].

Food-induced anaphylaxis (FIA) is predominantly caused by plant-based allergenic foods, accounting for 74% of reported cases [8]. Notably, in children, cashew has recently emerged as the third most frequent allergenic food [9]. With increasing age, plant-derived foods like wheat, tree nuts, legumes, celery and seeds become common triggers, alongside shellfish [4].

Certain legumes (e.g., peanut, soybean, lupin) and seeds (e.g., sesame) require mandatory allergen labelling in many countries including the EU and UK [10]. However, other potentially allergenic plant-based foods, such as pea and lentil, are not on the global priority list for allergen disclosure and may be declared generically as 'vegetable proteins', without highlighting the direct protein source under current EU law [11]. For the food industry, such legumes are an attractive, sustainable dietary protein sources due to their high protein content, diverse technological properties and relative ease of cultivation [7, 12]. As a result, highly concentrated forms of these proteins are increasingly used in ultra-processed products [13, 14]. Indeed, recent studies indicate that allergic reactions can be triggered by foods containing pea protein as a hidden ingredient [15–19].

The prevalence of food allergies is determined by a complex interplay of endogenous factors, such as genetic predisposition and immunoregulatory mechanisms, as well as exogenous factors [20]. The latter include geographical region, allergen and environmental exposure, but also individual dietary habits [21, 22]. Previous data suggest a higher prevalence of legume allergies in countries with increased legume consumption [18, 23]. However, other studies failed to demonstrate a consistent link between the consumption of a given food and the occurrence of a corresponding food allergy [24, 25]. For pea and lentil, very limited data were available and the study by Smits et al. [25] did not allow firm conclusions regarding a relationship between consumption and sensitization.

Given the increasing use of novel and highly concentrated plant-based protein ingredients in the food supply, ongoing monitoring of allergic reactions is essential. To obtain more insights on the frequency and severity of allergic reactions towards non-mandatory labelled allergenic foods, we analysed real-world data from the Anaphylaxis Registry (NORA) [26] and the EuroPrevall outpatient clinic study [27].

2 | Methods

2.1 | Non-Mandatory Labelled Allergenic Foods

This analysis focused on foods that are not subject to mandatory allergen labelling. Individual foods were included if they were reported in at least 10 cases in either of the two data sets. Four food groups were analysed; (1) legumes: pea, lentil, bean, chickpea, fenugreek; (2) seeds: pine nut, sunflower-, poppy-, pumpkin seed; (3) buckwheat; and (4) beehive products (encompasses honey, propolis, royal jelly and pollen pellets, also known as bee pollen).

2.2 | Data Acquisition

2.2.1 | NORA

The European Anaphylaxis Registry conducted by the Network for Online Registration of Anaphylaxis (NORA) is a database that collects data on real-life anaphylaxis from moderate to severe anaphylactic reactions by means of a standardised online questionnaire [26]. NORA was launched in 2007 in German-speaking countries and expanded to other countries in 2011. By the time of this analysis, data on anaphylaxis cases had been contributed by specialised tertiary allergy centres from 10 European countries (Germany, Switzerland, Austria, France, Italy, Spain, Poland, Greece, Bulgaria, Ireland). The study was approved by the ethics committee at Charité—Universitätsmedizin Berlin, Germany (EA1/079/06) and was accredited by the local ethics committees in participating centres. The study centres enter severe anaphylaxis cases after obtaining written informed consent

from patients and/or their caregivers. Deidentified data from patients who had experienced an anaphylaxis episode within the past 12 months before presenting to the participating allergy centres were captured by trained healthcare professionals on-site through the Web interface. Data were submitted after completion of the diagnostic work-up. The diagnostic certainty of the triggering allergenic food was documented at the level of confirmed or highly suspected, based on the local allergy specialist's individual judgement. In total, 17,469 cases were registered until March 2023, including 5239 cases with moderate to severe FIA. Finally, 284 cases with FIA to non-mandatory labelled allergenic foods (Figure 1; Figure S1) were identified.

2.2.2 | EuroPrevall

The EuroPrevall outpatient study was a cross-sectional study conducted between October 2005 and December 2009 in 12 centres across Europe: Greece (Athens), Poland (Lodz), Spain (Madrid), UK (Manchester), Italy (Milano), Czech Republic (Prague), Iceland (Reykjavik), Bulgaria (Sofia), France (Strasbourg), the Netherlands (Utrecht), Lithuania (Vilnius) and Switzerland (Zurich). The study was approved by all the local ethics committees and written informed consent was obtained from all participants or their legal representatives before enrolment. The clinical evaluation was standardised, performed in all centres following the same methodology and information was collected on specific case record forms and then transferred to a central database. A detailed clinical history was collected including demographic data, family and personal history of atopy and thorough information on food allergic reactions [27]. The inclusion required both an immediate reaction history and concordant sensitisation (skin prick test and/or specific IgE), known as 'probable IgE-mediated food allergy'. Patients analysed in the current study are those who reported an adverse reaction within 2 h of ingestion of any of the non-mandatory labelled allergenic foods under study. The involvement of the culprit food in the reported reaction was based on the local investigator allergy work-up and diagnosis. In the final EuroPrevall outpatient clinic database, 8232 immediate food reactions, ranging from mild to severe, were collected in 2112 patients, of which 305 reactions in 249 patients were caused by the non-mandatory allergenic foods and included in this study (Figure 1).

2.3 | Data Analysis

The data set for analysis included the following variables: age, sex, country, concomitant atopic diseases (rhinitis, asthma, atopic dermatitis, other food allergies) and symptoms. The definition of anaphylaxis was verified by applying the National Institute of Allergy and Infectious Diseases/Food Allergy and Anaphylaxis Network (NIAID/FAAN) criteria [28] retrospectively to the reported cases. Symptom severity was assessed by the iFAAM Food Allergy Severity Score (FASS) [29].

A descriptive analysis was conducted for demographic and clinical variables. Categorical variables were expressed as frequencies and percentages. Continuous variables were reported as mean and standard deviation (SD) for those with a normal distribution and as median and quartiles (Q1 and Q3) for non-parametric data. For normally distributed continuous variables, comparisons between two independent groups were made using the *t*-test, while the Mann–Whitney test was applied to non-parametric continuous variables. Associations between categorical variables were analysed using the chi-square test or Fisher's exact test, as appropriate. For comparisons across more than two groups, the Kruskal-Wallis test was applied, followed by a post hoc Bonferroni correction to identify specific group differences. Associations between sIgE levels to mandatory and non-mandatory allergenic foods within the EuroPrevall outpatient cohort were explored by calculating Spearman's rank correlation coefficients (ρ).

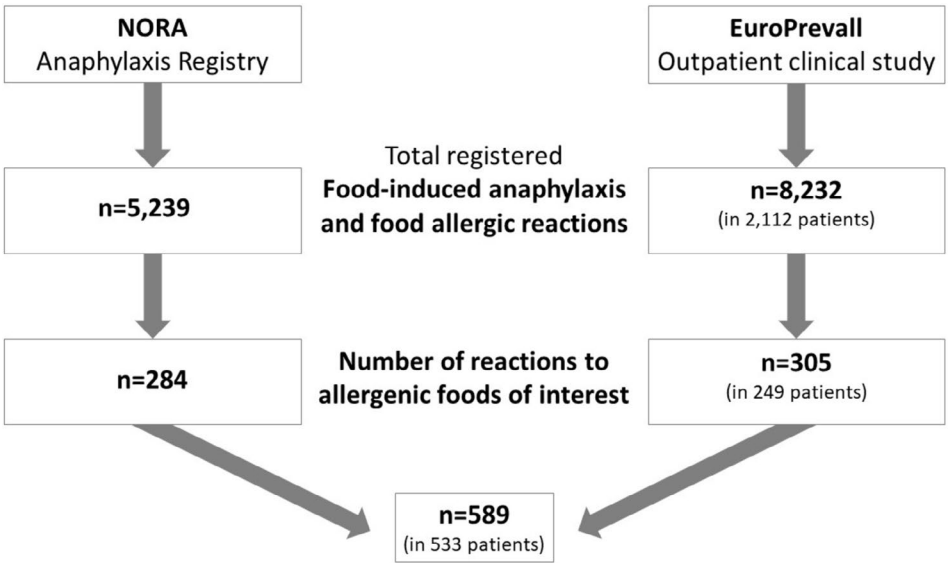

FIGURE 1 | Data flow chart of the Anaphylaxis Registry (NORA) and the EuroPrevall outpatient clinic study. Shown are numbers of reactions to allergenic foods. In the EuroPrevall outpatient clinic study, subjects could report on more than one reaction to an allergenic food. A detailed description of data set adjustments for the NORA data is provided in Figure S1. An overview of the countries contributing cases related to non-mandatory labelled allergenic foods is presented in Table S2.

To control for potential confounding factors and differences in sample size, propensity score matching was used for the comparison of mandatory and non-mandatory labelled allergenic foods. A 1:1 matching ratio was applied for seeds and cereals and a 1:4 matching ratio for legumes, adjusting for age and sex. The nearest neighbour (k-NN matching) method was employed to ensure comparability between groups. For the matching of mandatory labelled legumes excluding peanut vs. non-mandatory labelled legumes we applied a calliper of 0.15, according to the criterion of Rosenbaum & Rubin [30]. All statistical analyses were performed using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA) and Python version 3.12, specifically using the PsmPy [31] and SciPy packages [32].

3 | Results

3.1 | Study Cohorts

In the combined data set, 589 reactions to non-mandatory labelled allergenic foods were reported, corresponding to 4.4% of food-induced allergic reactions (Figure 1). The demographics differed in the cohorts. The NORA data set included a higher proportion of children (53.5%) and male subjects (55.3%) compared with the EuroPrevall cohort (children 30.9%; male 42.2%) (Table 1). Countries contributing to the cases are detailed in Table S2 and reactions to allergenic food of interest by country are provided in Table S3.

3.2 | Frequency of Non-Mandatory Labelled Allergenic Foods

Seeds were the most frequently reported non-mandatory labelled allergenic foods with sunflower seed ($n=126$), pine nut ($n=66$), poppy ($n=61$) and pumpkin seed ($n=26$), followed by legumes including lentil ($n=77$), pea ($n=56$), bean ($n=25$), chickpea ($n=24$) and fenugreek ($n=10$) (Table S4). Other allergenic foods of interest in this analysis were buckwheat ($n=53$) and beehive products ($n=65$) (Table S4).

The relative frequency of allergic reactions to mandatory labelled legumes was eight times more frequent than to non-mandatory ones (11.8% vs. 1.4%) mainly due to the high numbers of peanut-induced reactions in both data sets. A comparable ratio was observed between mandatory labelled cereals and buckwheat (3.3% vs. 0.4%). In contrast, non-mandatory labelled seeds showed a similar frequency to mandatory ones (2.1% vs. 2.0%) (Figure 2).

3.3 | Severity of Allergic Reactions

3.3.1 | Overall Severity Assessment

The severity of reactions was assessed using FASS, a validated instrument specifically developed to measure the severity of food allergic reactions [29]. FASS is available in two formats: an ordinal version (oFASS) which we applied here using the 5-grade severity scale and a numerical version (nFASS) (see Table 2 for non-mandatory, Tables S5–S7 for mandatory).

All the NORA cases corresponded to oFASS grades 3, 4 and 5 (anaphylaxis), as well as 140 out of the 305 food-induced reactions (45.9%) to non-mandatory labelled allergenic foods recorded in the EuroPrevall data set. Thus, the majority of the reactions were anaphylaxis (oFASS grades 3, 4 and 5): 68.5% of reactions to seeds, 73.4% of those to legumes, 86.7% of those to buckwheat and 70.7% of those to beehive products, corresponding to a median nFASS between 4.26 (seeds) to 4.77 (buckwheat) (Table 2).

TABLE 1 | Baseline characteristics of the subjects.

	All ($n=533$)		NORA ($n=284$)		EuroPrevall ($n=249$)		
	N (children/adults)	%	*N* (children/adults)	%	*N* (children/adults)	%	*p*
Sex							< 0.01
Female	271 (74/197)	51.0	127 (45/82)	44.7	144 (29/115)	57.8	
Male	262 (155/107)	49.0	157 (107/50)	55.3	105 (48/57)	42.2	
Age group							< 0.01
Children/ adolescents	229	42.8	152	53.5	77	30.9	
Adults	304	57.2	132	46.5	172	69.1	
Atopic co-morbidities							
Rhinitis	347 (106/241)	65	112 (39/73)	39	235 (67/168)	94	< 0.01
Asthma	316 (114/202)	59	87 (47/40)	31	229 (67/162)	92	< 0.01
Atopic dermatitis	146 (92/54)	27	55 (42/13)	19	91 (50/41)	37	< 0.01
Other food allergy	262 (100/162)	49	69 (43/26)	24	193 (57/136)	78	< 0.01

Note: Statistical differences between the cohorts were calculated by chi square.

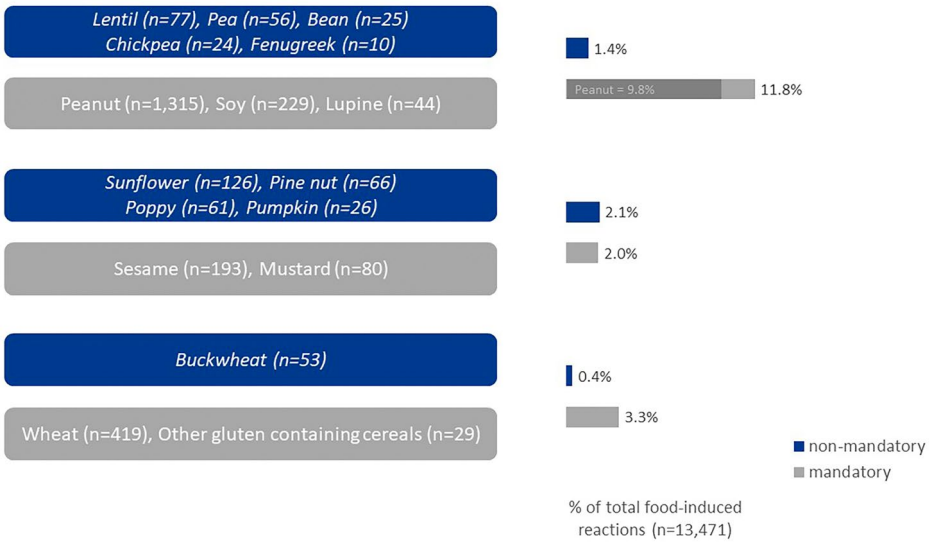

FIGURE 2 | Overview of the mandatory and non-mandatory labelled allergenic foods of interest and frequency in regards to total food-induced reactions. [Correction added on April 1, 2026, after first online publication: Figure 2 has been replaced with a new version.]

TABLE 2 | Severity among the allergenic foods of interest.

		oFASS-5, *N* (%)						
	***N* (%)**	**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**	**nFASS median [Q1, Q3]**	**Intragroup differences *p* value**
Seeds	279 (47.4)	46 (16.5)	42 (15.1)	22 (7.9)	116 (41.6)	53 (19)	4.26 [2.12, 4.89]	
Pine nut	66 (11.2)	4 (6.1)	1 (1.5)	9 (13.6)	34 (51.5)	18 (27.3)	4.69 [4.41, 6.24]	Pumpkin seed > Sunflower seed, $p < 0.01$ Pine nut > Poppy, $p < 0.01$ Pumpkin seed > Poppy, $p = 0.03$
Poppy	61 (10.4)	13 (21.3)	15 (24.6)	3 (4.9)	17 (27.9)	13 (21.3)	3.44 [2.11, 4.83]	
Pumpkin seed	26 (4.4)	1 (3.8)	1 (3.8)	2 (7.7)	16 (61.5)	6 (23.1)	4.77 [4.41, 5.54]	
Sunflower seed	126 (21.4)	28 (22.2)	25 (19.8)	8 (6.3)	49 (38.9)	16 (12.7)	4.10 [2.07, 4.89]	
Legumes	192 (32.2)	21 (10.9)	30 (15.6)	26 (13.5)	69 (35.9)	46 (24)	4.49 [2.75, 5.58]	
Lentil	77 (13.1)	11 (14.3)	18 (23.4)	11 (14.3)	27 (35.1)	10 (13)	3.53 [2.29, 4.92]	Pea > Lentil, $p = 0.02$ Fenugreek > Lentil, $p < 0.01$
Pea	56 (9.5)	3 (5.4)	4 (7.1)	9 (16.1)	21 (37.5)	19 (33.9)	4.61 [3.68, 6.47]	
Bean	25 (4.2)	4 (16)	2 (8)	3 (12)	10 (40)	6 (24)	4.67 [3.07, 5.55]	
Chickpea	24 (4.1)	3 (12.5)	6 (25)	1 (4.2)	9 (37.5)	5 (20.8)	4.51 [2.36, 5.38]	
Fenugreek	10 (1.7)	0	0	2 (20)	2 (20)	6 (60)	6.53 [5.32, 7.38]	
Buckwheat	53 (8.9)	3 (5.7)	4 (7.5)	5 (9.4)	20 (37.7)	21 (39.6)	4.77 [4.39, 6.47]	
Beehive products	65 (11)	4 (6.2)	15 (23.1)	6 (9.2)	29 (44.6)	11 (16.9)	4.41 [2.68, 4.9]	

Note: The percentage is given in relation to the total number of reactions, $n = 589$.
Abbreviations: Grade 1, isolated oropharyngeal symptoms; Grade 2, systemic reactions involving one organ system (skin, nose/eye, digestive, uterus); Grade 3, systemic multi-organ reactions without lower respiratory or cardiovascular involvement; Grade 4, moderate-to-severe reaction with lower respiratory involvement (larynx/bronchial); Grade 5, severe life-threatening reaction with cardiovascular or neurological involvement; nFASS, numerical Food Allergy Severity Score; oFASS-5, ordinal Food Allergy Severity Score with 5 grades; Q1, first quartile; Q3, third quartile.

When examining the severity of reactions to the allergenic foods of interest within seeds, differences were observed (Table 2). The frequency of anaphylaxis (oFASS grade 3, 4 and 5 reactions) was higher for pumpkin seed (92.3% of reactions) and pine nut (92.4%) than for poppy (54.1%) and sunflower seed (57.9%). The nFASS of pumpkin seed reactions (median 4.77) was higher in comparison

to sunflower (median 4.10, $p < 0.01$) and poppy seed (median 3.44, $p = 0.03$). Additionally, pine nut was associated with higher nFASS (median 4.69) compared with poppy seed ($p < 0.01$) (Table 2).

In the group of non-mandatory legumes, 87.5% of pea-induced reactions and 100% of fenugreek-induced reactions were anaphylaxis and they both exhibited significantly higher nFASS severity scores compared with lentil ($p = 0.02$ and $p < 0.01$) (Table 2).

3.3.2 | Comparison of Reaction Severity to Non-Mandatory Versus Mandatory Labelled Allergenic Foods

To compare the clinical severity of reactions induced by non-mandatory versus mandatory labelled allergenic foods, we applied an age- and sex-matched approach. Reactions triggered by mandatory labelled legumes (nFASS median: 4.73 [3.84; 6.39]) and cereals (6.47 [4.67; 7.17]) were more severe than those caused by non-mandatory labelled ones (4.49 [2.75; 5.57], $p < 0.01$ and 4.77 [4.39; 6.47], $p = 0.02$). By contrast, the severity of reactions was comparable within the group of seeds, regardless their labelling requirement (mandatory: 4.39 [2.36; 5.61] and non-mandatory: 4.43 [2.62; 5.212], $p = 0.47$) (Figure 3, Table S8A). Both data sets were also analysed separately (Table S8B—NORA, S8C—EuroPrevall) and did not reveal substantial differences due to the limited sample size. When excluding peanut from the group of mandatory labelled legumes the reaction severity was not different between the groups (4.56 [3.10; 5.59] vs. 4.49 [2.67; 5.62]; $p = 0.16$) (Table S8D).

3.3.3 | Age-Dependent Severity of Reactions

Given the broad age range of the patients analysed, severity scores were subsequently assessed by age group (Table S9). Differences were observed between children/adolescents and adults (oFASS, $p < 0.01$). This difference was primarily driven by a higher proportion of grade 1 (isolated oropharyngeal symptoms) and a lower proportion of grade 3 (systemic multi-organ reactions without lower respiratory or cardiovascular involvement) reactions among adults.

To further elucidate age-dependent differences, we stratified the patients below 18 years into three age groups (0–5, 6–11 and 12–17 years). The data indicate that adolescents (12–17 years) had a similar severity pattern to adults. The age-stratified

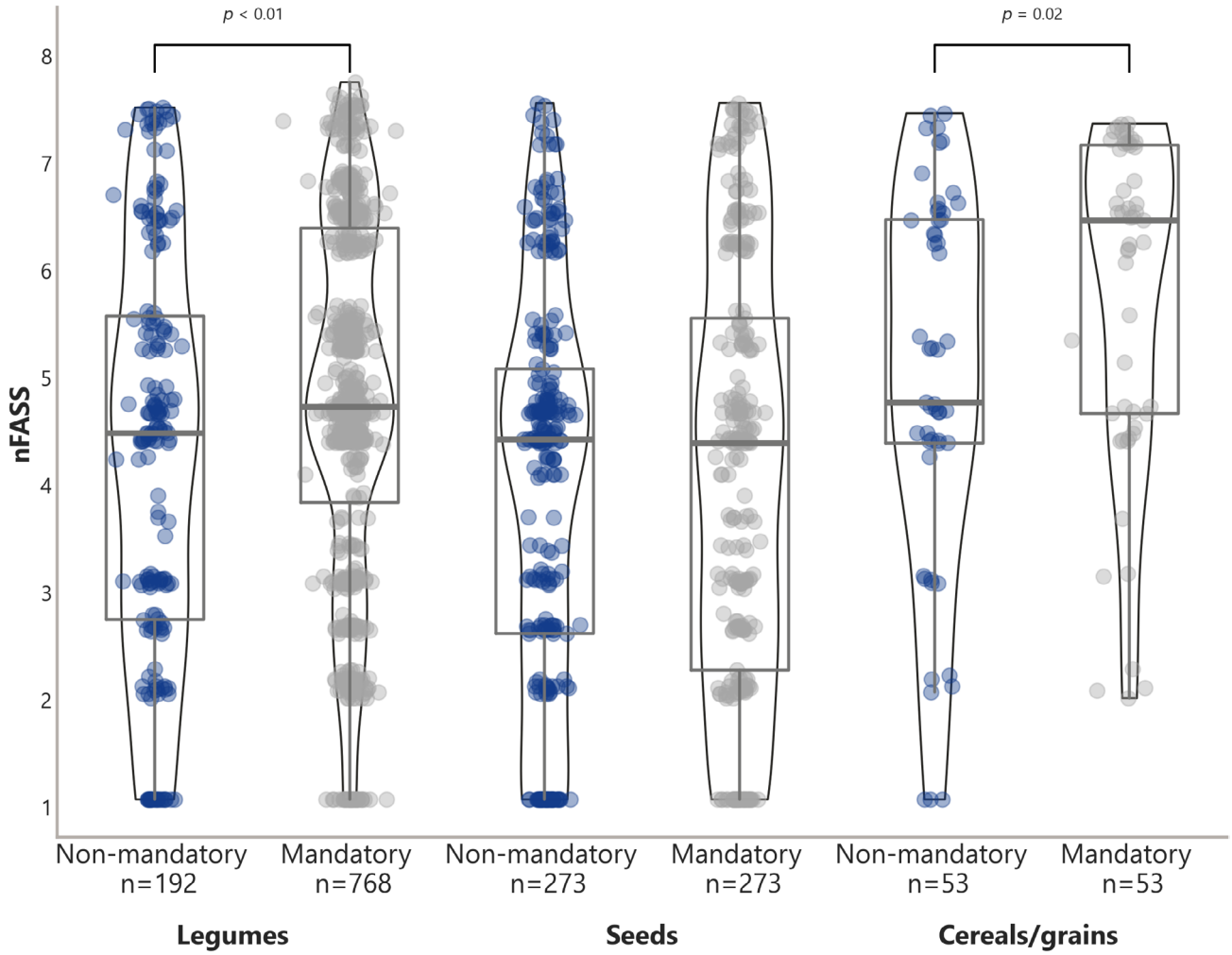

FIGURE 3 | Severity scores of mandatory and non-mandatory labelled allergenic foods of interest, nFASS—numerical Food Allergy Severity Score. Significance was calculated after post hoc correction (using the Bonferroni method). Detailed calculations of severity differences and the matching strategy are provided in Table S8.

comparison revealed no differences in the median nFASS across all reactions for any of the age groups.

3.4 | Allergic Reactions Over Time

To elucidate the frequency of the non-mandatory labelled allergenic foods causing allergic reactions over time, we analysed NORA data from 2007 to 2022 (Figure 4). We identified increased rates of reactions to fenugreek (7.4-fold) and pumpkin seed (3.7-fold) in 2015–2022 compared with 2007–2014. The majority of reactions to fenugreek (90%, 9 out of 10) and pumpkin seed (82%, 18 out of 22) occurred after 2015.

4 | Discussion

Avoidance is still the major therapeutic approach in the management of food allergy [33]. Mandatory labelling of food ingredients from allergenic sources of public health importance has been introduced to support patients and their relatives to better manage their food allergy in daily life. The Codex Alimentarius Commission (CXs 1-1985) recommends the labelling of ingredients from eight food groups (priority allergen list), which has been enacted in legislation around the world. These foods are: cereals containing gluten, crustaceans, egg, fish, peanut and soy, mammalian milk, tree nuts and sulphites. Geographical differences in the prevalence of food allergies have led some countries to include additional allergenic foods in their mandatory declaration. Thus, the EU and UK requires labelling of celery, mustard, sesame, lupin and molluscan shellfish [11]. Japan and Republic of Korea include buckwheat and sesame was recently added to the regional priority allergen list in the US [34]. Regional variations in allergen labelling and evolving environmental and dietary patterns, have encouraged a re-evaluation of food allergen prioritisation in the light of new data [35]. The FAO-WHO expert consultation revised the global priority allergen list based on measures of public health importance, namely (1) prevalence; (2) potency (threshold dose); and (3) severity. It acknowledged regional variations (e.g., buckwheat, pine nut and Brazil nut) and a call for a 'watch list' for potentially new emerging allergenic foods [35]. These non-priority allergenic foods may escape correct identification, behaving as 'hidden allergenic foods' and potentially increasing the risk of allergic reactions among sensitised individuals [36]. This watch list is a signal-detection tool rather than a labelling mandate. If convergent evidence indicates public-health relevance, the next steps would include setting reference doses, developing analytical methods and targeted risk communication.

In this study, we analysed legumes, seeds, buckwheat and beehive products as emerging allergenic foods that may warrant inclusion in a watch list. Lentil and pea were the most common allergenic foods among legumes (0.6% and 0.4% of all food-induced reactions), while sunflower seed (0.9%) was the leading food allergen among seeds. By contrast, reactions to lupin,

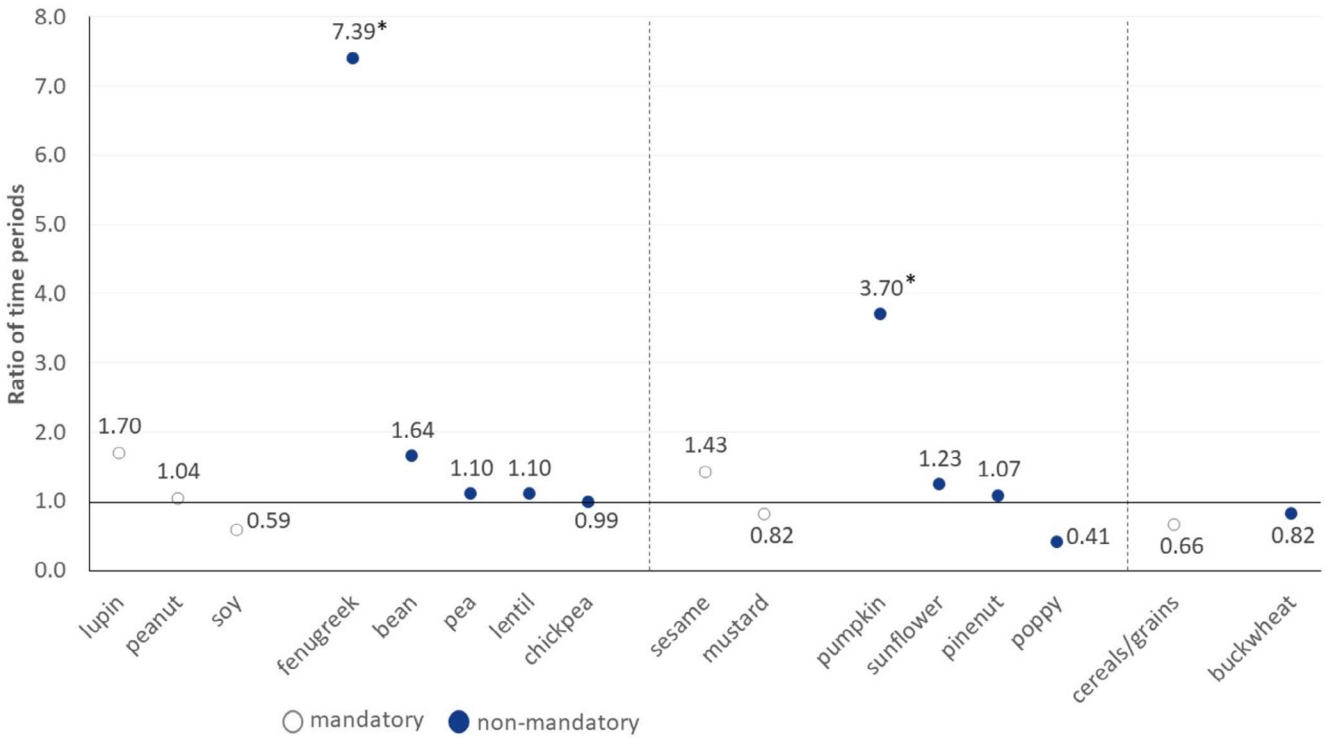

FIGURE 4 | Frequency ratios of allergic reactions to mandatory and non-mandatory labelled allergenic foods of interest over time. The ratio was calculated by dividing the frequency of reactions reported between 2015 and 2022 by those reported between 2007 and 2014 for each allergenic food. Frequencies were calculated based on all food-induced anaphylaxis reactions. A marked increase in reaction frequency was observed for fenugreek (7.4-fold) and pumpkin seed (3.7-fold). The majority of reactions to fenugreek (90%) and pumpkin seed (82%) occurred after 2015. Dashed lines separate food group categories. *Statistical significance was assessed using the chi-square test or Fisher's exact test, as appropriate, revealing significant differences for fenugreek ($p = 0.05$) and pumpkin seed ($p = 0.02$).

a legume currently included in the EU allergen labelling regulations, were much less frequently reported as a cause of severe allergic reactions in our study (0.3%), with only one case reported in EuroPrevall. This might reflect regional and dietary differences. A separate French analysis, for example, reported a higher frequency of lupin-induced anaphylaxis at 2.3% between 2002 and 2022, although, dropping to 1.4% in 2017–2022 [37]. Notably, 95% of these reactions were triggered by prepacked food products, highlighting the potential of lupin as a hidden allergenic food.

Besides frequency, we also tried to get an insight into the severity of the reactions. The majority of reactions analysed in the combined data set (NORA and EuroPrevall) were severe indicated by the overall nFASS median > 4.07. In our cohort, reactions induced by pea and fenugreek, but also pine nut and pumpkin seed were more severe than others (e.g., lentil, sunflower or poppy seed). Consistently, severe allergic reactions to these foods have also been documented in the literature [15, 16, 38–42].

Peanut stands out as the predominant trigger of legume-induced anaphylaxis, occurring about six times more frequently than soy [4]. This observation may indicate that peanut differs in its reactivity profile from other legumes. Notably, when excluding peanut from the analysis, the severity of reactions to priority and non-priority legumes was not different (Table S8D).

This finding indicates that, if the dietary shift envisaged by the EAT LANCET commission is realised and an increased vegetarian-based diet is adopted more widely by the general population, such legumes and seeds may emerge as significant allergenic foods of public health importance in future.

Age-stratified analyses demonstrated that anaphylaxis occurred across all age groups. While nFASS medians were comparable (Table S9), oFASS was more sensitive to distributional shifts. Adolescents and adults experienced a higher proportion of mild (local oral allergic symptoms) reactions compared with children < 12 years with a higher proportion of systemic reactions (≥ grade 3). This pattern is not at odds with the established evidence that adolescence/young adults carry the highest risk of severe food allergic reactions [43, 44]; rather, it reflects data set differences (NORA: anaphylaxis-only with a higher paediatric representation; EuroPrevall: broader severity spectrum with more adults) and allergen-specific biology. We hypothesise that storage protein sensitisation (notably in legumes and seeds; Table S1) is more prevalent in younger children and predisposes to systemic reactions, whereas older patients more often exhibit pollen-associated sensitisation to heat labile allergens [45–47].

Our exploratory time trend analysis revealed fenugreek and pumpkin seed as emerging allergenic foods associated with increased reported allergic reactions in recent years (2015–2022). Given the small number of cases, mainly from France and Germany, these findings are not representative of the general population but rather a signal consistent with the current literature. For example, while the first documented case of fenugreek allergy dates back to 1997 [48], an increase in reported allergic reactions has been observed in recent years [6].

A rise in seed-induced allergies has been reported as well, with sesame being the most common reported seed [49–51]. Such increase of seed-related reactions coincides with the growing use of seeds in food products such as bread or pasta, a trend expected to continue [52, 53]. A retrospective study from the US observed a rising incidence of sunflower seed allergy from 2007 onward [54]. Sunflower seed allergy has been reported across all age groups and is also frequently described as having adult onset [55]. Data on prevalence of probable sunflower seed allergy in Europe are rare [55]. In the EuroPrevall prevalence studies, estimates for sunflower seed were highest for children from Madrid with 0.53% (95% CI 0.02–1.85) [56, 57]. Concerns have been raised regarding potential cross-reactivity to peanut, tree nuts and fruits. In the present study, we were able to examine correlations between sIgE values in the EuroPrevall data set for legumes and seeds from both mandatory and non-mandatory labelled allergenic foods (Table S10). The observation that > 50% of patients with peanut allergy are sensitised to sunflower seed, as well as to lentil and buckwheat, underscores the importance of monitoring trends related to the increasing use of non-priority plant-based allergenic food. In our analysis, sunflower seed-induced reactions showed a slight increase over time. The observed upward trend may partially be due to increased clinician awareness and advances in diagnostic testing.

While buckwheat allergy is more prevalent in Asian countries such as Japan, Korea and China, where it is widely consumed [58–60], severe and even fatal reactions have also been reported in non-Asian countries (e.g., Italy, Australia), primarily in adults [61]. In our data set, buckwheat accounted for 0.4% of all reported food-induced reactions. Notably, half of these reactions were reported in France, likely reflecting regional dietary habits, particularly in western areas where 'galettes de Bretagne' are commonly consumed.

Other emerging allergenic sources were beehive products like honey, propolis and pollen pellets, with a total of $n = 65$ reported cases. These products are a heterogeneous mixture of pollen protein, flower nectar, bee enzymes, sugars and moulds. Despite their popularity as natural health products (neutraceuticals), these substances can cause allergic reactions [62]. Given their increasing use, these substances warrant closer clinical attention and improved allergen risk communication.

Although the patient populations overlap, the two data sets differ in methodology and scope, providing additional perspectives for analysis. NORA, covering severe, multi-system allergic reactions from tertiary allergy centres [26] and EuroPrevall, a multi-centre outpatient study conducted in allergy clinics across Europe [27], capturing a large patient group and covering the full clinical spectrum of food allergy severity. The combination of these data sets allows for a broader understanding of reaction severity and frequency across different levels of clinical presentation. Other strengths of the two data sets include the vast experience of the participating centres in food allergy that ensures high-quality data entry and the detailed collection of specific symptoms during reactions that enables grading and comparison of reactions using various severity scores. However, the study has several limitations. Because grading relied on retrospectively reported/documented symptoms, residual recall and information bias

may persist despite mitigation steps (standardised clinician-collected records). This study comprises reactions captured at voluntarily participating centres and is not an exhaustive enumeration. Mild events, primary-care-managed cases, or reactions outside participating regions are likely underrepresented. The heterogeneity of data collection methods limits the direct comparability between the two data sets. Neither NORA nor EuroPrevall do provide population-based data. Moreover, all NORA cases are FIA, introducing a potential bias towards more severe cases, potentially underrepresenting milder reactions which were only collected in the EuroPrevall study. Despite these limitations, the analysis of the reaction patterns to non-mandatory labelled compared with those of established allergenic foods within the same cohorts offers valuable insights into the clinical frequencies and severity of emerging allergenic foods. In addition, the long runtime of the registry allows for detection of variations over time. Finally, while efforts were made to group comparable food categories, differences in exposure and allergenicity limit direct equivalence.

5 | Conclusion and Outlook

We identified several foods frequently associated with severe allergic reactions which are not currently considered to be priority allergenic foods in terms of labelling. The frequency and severity in real-life allergic reactions reported to these foods suggest the need for further evaluation. Indeed, pea and fenugreek but also pine nut and pumpkin seed frequently triggered anaphylaxis. These findings highlight the need for further evaluation and suggest placing such foods on a Europe-wide watch list to enable structured monitoring of prevalence, severity and potency as proposed by the recent FAO-WHO expert consultation. This would pave the way for evidence-based inclusion in mandatory allergen labelling.

Author Contributions

Sabine Dölle-Bierke, Margitta Worm and Montserrat Fernández-Rivas contributed to the conceptualization and methodology of the study. Formal analysis and data curation were performed by Sabine Dölle-Bierke and Alejandro Gonzalo-Fernández. Dominique Sabouraud-Leclerc, Laura Barreales-Tolosa, Barbara Ballmer-Weber, Simona Belohlavkova, Maria B. Bilò, Ruta Dubakiene, Karin Hartmann, Monika Jedrzejczak-Czechowicz, Thuy-My Le, Lars Lange, Nikolaos G. Papadopoulos, Guillaume Pouessel, Isabel Reig, Athanasios Sinaniotis, E. N. Clare Mills, Margitta Worm, Montserrat Fernández-Rivas were involved in the investigation and contributed to the review and editing of the manuscript. Sabine Dölle-Bierke prepared the original draft. Margitta Worm and Montserrat Fernández-Rivas supervised the project. Project administration was carried out by Sabine Dölle-Bierke, Margitta Worm and Montserrat Fernández-Rivas. Sabine Dölle-Bierke and Alejandro Gonzalo-Fernández contributed equally to this work and share first authorship. Margitta Worm and Montserrat Fernández-Rivas contributed equally and share last authorship. All authors have read and approved the final version of the manuscript.

Acknowledgements

The authors thank all patients and parents for their support in providing data on the occurrence of anaphylaxis to the European Anaphylaxis Registry. We thank the study personnel for patient counselling and data entry: J. Grünhagen, P. Globig, V. Höfer, L. Faust (Berlin, Germany), F. Ruëff, T. Biedermann, K. Brockow (Munich, Germany), M. Müller, E. Hammer, L. Bonifacio (Basel, Switzerland), S Gernert (Bonn, Germany), C. Pföhler (Homburg, Germany), R. Treudler (now Berlin, formerly Leipzig, Germany), F. Prenzel (Leipzig, Germany), N. Wagner (Erlangen, Germany), A. Köhli (Baden, Switzerland), J. Trück, P. Schmid-Grendelmeier, M. Hoernes (Zurich, Switzerland), T. Hawranek, R. Lang (Salzburg, Austria), A. Bauer, C. Vogelberg, A. Nordwig, K. Nemat (Dresden, Germany), S. Tscheiller and all members of the Allergy Vigilance Networks (France), M. Kritikou, P. Xepapadaki, M. Passioti, M. Makris (Athen, Greece), A. Kleinheinz and A. Brückner (Buxtehude, Germany), B. Wedi (Hannover, Germany), H. Dickel (Bochum, Germany), E. Rietschel (Köln, Germany), N. Reider (Innsbruck, Austria), M. Sulk (Münster, Germany), T. Kinaciyan, Z. Szepfalusi (Vienna, Austria), U. Rabe (Treuenbritzen, Germany), M. Polz (Rüsselsheim, Germany), S. Thies (Schwedt, Germany), A. Henschel, K. Parasher, U. Staden, K. Beyer (Berlin, Germany), K. Schäkel, S. Hämmerling (Heidelberg, Germany), M. Kurowski (Lodz, Poland), M. Fernandez-Rivas, T. M. de Vicente Jiménez (Madrid, Spain), T. Mustakov, G. Christoff (Sofia, Bulgarien), J. Seidenberg and H. Köster (Oldenburg, Germany), V. Cardona, O. Dominguez, R. Munoz Cano, R.L. Bellfill (Barcelona, Spain), B. Garcia (Pamplona, Spain), I. Poziomkowska-Gęsicka (Stettin, Poland), S. Büsing (Osnabrück, Germany), U. Jappe (Borstel, Germany), S. Müller (Freiburg, Germany), H. Straube (Darmstadt, Germany), A. Muraro (Padua, Italy), S. Altrichter (Linz, Austria), A. Fiocchi and S. Arasi (Rome, Italy), C. Feder (Jena, Germany), H. Ott (now Munich, formerly Hannover, Germany), E. Cichocka-Jarosz (Krakau, Poland), L. Ensina (Sao Paulo, Brazil), J. Meister (Aue, Germany), P. Stock and S. Hompes (Hamburg, Germany), E. Hamelmann (Bielefeld, Germany), I. Neustädter (Nürnberg, Germany), I. Maris (Cork, Irland), P. Turner (London, UK), G. Heine (Kiel, Germany), D. Deleanu (Cluj-Napoca, Romania), T. Jakob and A. Jung (Gießen, Germany), J. N. G. Oude Elberink (Groningen, The Netherlands), V. Vukicevic (Zagreb, Croatia). We thank the study personnel for patient selection and data entry to the EuroPrevall outpatient clinic study: R. Asero (Milan, Italy), F. de Blay and A. Purohit (Strasbourg, France), M. Clausen (Reykjavik, Iceland), C. Fernández-Pérez and S. Vázquez-Cortés (Madrid, Spain), T. Kralimarkova (deceased) and T. A. Popov (Sofia, Bulgaria), M. L. Kowalski (deceased, Lodz, Poland), A. C. Knulst (Utrecht, The Netherlands), N. G. Papadopoulos (Athens, Greece), R. van Ree (Amsterdam, The Netherlands), S. L. Seneviratne (Manchester, UK), Odilija Rudzeviciene (Vilnius, Lithuania), Laura Stoskute (Malinauskiene) (Vilnius, Lithuania). Open Access funding enabled and organized by Projekt DEAL.

Funding

The Anaphylaxis Registry is supported by the Network for Online Registration of Anaphylaxis NORA e.V. EuroPrevall (GA no 514000) and iFAAM (GA no 312147) were integrated projects funded by the European Commission under the 6th Framework Programme (FOOD-CT-2005-514000) and 7th Framework Programmes, respectively.

Conflicts of Interest

Sabine Dölle-Bierke received funding by the German Federal Ministry of Education and Research (01EA2107B) and by the German Research Association (Deutsche Forschungsgemeinschaft (DFG)) as part of the clinical research unit CRU339: Food Allergy and Tolerance FOOD@ (409525714). Alejandro Gonzalo-Fernández was funded by the BIOGRIAL-SEVERAL (PI19/01095) project and the REI (RD24/0007/0027) cofounded by the Instituto de Salud Carlos III, Ministry of Science of the Spanish Government and FEDER (European Regional Development Fund). Barbara Ballmer-Weber reports honoraria for talks and consulting from ThermoFisher, ALK, Allergopharma, Stallergenes, Takeda, MSD, Blueprint Medicines, Leo Pharma, Sanofi and Novartis, outside the submitted work. Karin Hartmann received

research funding from the Swiss National Science Foundation (SNSF; grant 310030_207705), the Swiss Cancer Research Foundation (grant KFS-5979-08-2023) and the EU-H2020-MSCA-COFUND EURIdoc programme (No. 101034170). Karin Hartmann participates in advisory board and received consultant honoraria: ALK-Abello, Allergopharma, Almirall, BioCryst, Blueprint, Cogent, Galderma, KalVista, Leo, Menarini, Novartis, Pfizer, Sanofi, Takeda and Thermo Fisher. Thuy-My Le received funding for executing the Utrecht part of EuroPrevall project. Lars Lange received lecturer fees from DBV, Thermofisher Scientific, Nestle Nutritional Institute, Nutricia, Sanofi, LETI, HAL Allergy. Nikolaos G. Papadopoulos has received research funding by Numil, VIANEX, Becro, Nutricia, Amgen, Sanofi, Vibrand, SYNEOS Health and honoraria for talks, advisories by Nestle, Abbott, Nutricia, GSK, HAL, Menarini, OM Pharma, Sanofi-Regeneron, Berlin—Chemie, DBV, Hyproca, Med Maps. Guillaume Pouessel has provided consultation and speaker services for AI Therapeutics, Bausch+Lomb, Stallergenes, Novartis, DVB technology, ALK-Abello; serves as a medical consultant/advisor for Bausch+Lomb, Theravia and AI Therapeutics. E. N. Clare Mills declares the receipt of grants through the University of Surrey from the UK Horizon Guarantee Fund associated with the Giant Leaps EU project (GA 101059632), European Food Safety Authority, UKRI Medical Research Council and Innovate with Waters Corporation, UKRI Biological and Biotechnological Sciences Research Council with FERA Science Ltd., NOW and Nestle. Shares in Reacta Healthcare Ltd. Margitta Worm declares the receipt of honoraria or consultation fees by the following companies: Abbvie, Aimmune, ALKAbelló, Allergopharma, Almirall, Amgen, AstraZeneca, Bayer, Bencard, Bioprojet Pharma, Bristol-Myers Squibb, Boehringer Ingelheim, Galderma, Glaxosmithkline, Infectopharm, Leo Pharma, Eli Lilly, Mylan/Viatris, Novartis, Octapharma, Pfizer and Sanofi. Montserrat Fernández-Rivas declares receipt of grants from Instituto de Salud Carlos III, Diater, Aimmune Therapeutics and Novartis (all grants to institution). M. F. R. also received honoraria for lectures or educational events from Aimmune Therapeutics, EPG Health, Ga2LEN, HAL Allergy and GSK. Furthermore, M. F. R. participates in advisory boards for Aimmune Therapeutics, Novartis, Reacta Healthcare, SPRIM, Viatris, Stallergenes Greer and serves on the Data Safety Monitoring Board for DBV. Dominique Sabouraud-Leclerc, Laura Barreales-Tolosa, Simona Belohlavkova, Maria B. Bilò, Ruta Dubakiene, Monika Jedrzejczak-Czechowicz, Isabel Reig and Athanasios Sinaniotis: None in relation to this paper.

Data Availability Statement

The data that support the findings of this study are available from the corresponding authors upon request. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Detailed data flow chart of the Anaphylaxis Registry (NORA) based on data set March 1, 2023. Between July 2007 and March 2023; 17,469 cases were registered of which 15,748 cases met the modified criteria of the National Institute of Allergy and Infectious Diseases/Food Allergy and Anaphylaxis Network [56]. **Table S1:** Food allergens in non-mandatory labelled legumes and seeds as well as buckwheat. **Table S2:** Countries contributing to the patients of non-mandatory allergenic foods. Countries who are involved in both data sets are highlighted in grey. **Table S3:** Reactions to allergenic foods of interest by country. Given as absolute numbers with percentages (*n* (%)) calculated based on the total number of reactions per country. **Table S4:** Overview of the non-mandatory labelled allergenic foods of interest and frequency in regards on total registered cases. **Table S5:** Severity of mandatory labelled allergenic foods NORA & EuroPrevall. **Table S6:** Severity of mandatory labelled allergenic foods in NORA. **Table S7:** Severity of mandatory labelled allergenic foods in EuroPrevall. **Table S8:** Comparison of severity of non-mandatory with mandatory labelled allergenic foods of interest (A) in both data sets combined, (B) in the NORA cohort, (C) in the EuroPrevall study, (D) in both data sets for legumes excluding peanut-induced cases. **Table S9:** Severity scoring among children and adults using Food Allergy Severity Score (FASS). **Table S10:** Correlations (Spearman rho, ρ) between sIgE of mandatory and non-mandatory studied foods, as well as fish in the EuroPrevall outpatient study. The correlation with fish, which has no cross-reactive allergens with the studied plant foods, was additionally included as we cannot establish whether the correlations (ranging from 0.63 to 0.90) are due to allergen cross-reactivity or co-sensitization.