Journal of Consumer Policy (2026) 49:25
https://doi.org/10.1007/s10603-026-09628-2

RESEARCH

A Decision Tree for the Legal Classification of Food Supplements in the European Union Based on an Analysis of RASFF Notifications on Food Traded Online

Paula Krejbich[1,2,4] · **Kai P. Purnhagen**[1,3] · **Marc Birringer**[2,4]

Received: 13 October 2025 / Accepted: 6 July 2026 / Published online: 27 July 2026
© The Author(s) 2026

Abstract

The continuous growth of food e-commerce increasingly reveals food safety concerns and public health risks amplified by regulatory and enforcement challenges. Yet, systematic assessment of the associated hazards remains limited. This study characterises food safety hazards in the EU online food market, assesses the extend to which they are addressed by current regulatory frameworks, and identifies gaps that undermine effective risk management. We conducted a secondary analysis of publicly available RASFF notifications related to e-commerce and performed a structured legal classification to determine the regulatory status of hazards associated with food supplements. To enable systematic analysis, we developed a decision tree incorporating international, European and national decision bases. We identified 910 RASFF notifications related to e-commerce submitted between November 2017 and June 2023. These included 786 notifications on food, which were mostly related to the presence of specific substances or ingredients (82.1%) and reported 210 distinct hazards – most commonly 2,4-dinitrophenol, cannabidiol and yohimbine. Food supplements reported in 689 notifications mainly contained "other substances", notably botanicals. Applying the decision tree, two thirds of the 178 distinct hazards identified in food supplement notifications could be classified using food-related decision bases. Together, these results demonstrate the wide range of hazards in food and especially food supplements traded online and highlight substantial gaps in the European regulatory framework. Based on our findings, we recommend strengthening consumer health protection through more coherent and effective risk management measures for food supplements and propose our decision tree as a practical tool for their evaluation and (automated) monitoring in e-commerce.

Highlights

- 689 of 786 RASFF notifications on food traded online concerned food supplements.
- 55 food supplement hazards fell outside EU and German food-related decision bases.
- Decision tree offers a novel tool for (automated) evaluation of food supplements.

Keywords RASFF · Food safety · E-commerce · Food supplements · Risk management · Botanicals

Extended author information available on the last page of the article

Introduction

The utilization of electronic commerce (e-commerce) continues to expand. E-commerce are "all types of commercial transaction and business activities taking place over electronic online systems" (Voldnes et al., 2020, p. 5). Within the European Union (EU), the proportion of consumers shopping online rose from 59.3% in 2014 to 76.6% in 2024. In the year 2024, 11.7% of EU consumers reported purchasing food or beverages online, while 15.6% acquired medicinal products or dietary supplements through e-commerce channels (Eurostat, 2025b). This trend has been influenced by various factors, notably the Coronavirus Disease 2019 (COVID-19) pandemic (Dannenberg et al., 2020; East, 2022). Food e-commerce comprises a range of business models, including multi-channel and pure-play concepts (Dederichs & Dannenberg, 2021), meal kit services (Gee et al., 2019), and online delivery services (Li et al., 2020) (Krejbich et al., 2023). Initially focused on specialty and non-perishable food items, e-commerce now encompasses a broad spectrum of products, including perishable and fresh food (Lachenmeier et al., 2013; Lu & Reardon, 2018). In addition to consumer-oriented motivations and barriers to usage (Blitstein et al., 2020; Harris et al., 2017), the academic literature has also identified both potential benefits and adverse implications of food e-commerce for public health (Bennett et al., 2023; Bezirgani & Lachapelle, 2021; Geurden et al., 2022; Jilcott Pitts et al., 2018; Pettigrew et al., 2024; Pomeranz et al., 2022; Wyse et al., 2021).

A principal challenge associated with e-commerce in the food sector pertains to food safety, with experts and regulatory authorities consistently underscoring the necessity for enhanced measures to safeguard consumer protection (Krewinkel et al., 2011). In the EU, food law is largely subject to maximum harmonisation under the General Food Law (Regulation (Reg.) (EC) No 178/2002) and subsequent specific legislative acts aimed at ensuring a high level of consumer health protection. A fundamental principle is that food shall not be placed on the market if it is unsafe (Art. 14 Reg. (EC) No 178/2002), and responsibility for ensuring and verifying compliance lies with food business operators at all stages of the food chain (Art. 17 Reg. (EC) No 178/2002) (Purnhagen & Molitorisová, 2022; Schebesta & Purnhagen, 2024). Food supplements, as a product category, fall within the scope of this framework (Dir. 2002/46/EC) (Warda et al., 2026). Food e-commerce is likewise governed by the General Food Law and is specifically addressed in the Food Information Regulation (Reg. (EU) No 1169/2011) and the Official Controls Regulation (Reg. (EU) 2017/625). In particular, consumers must have access to relevant food information in online settings, and Member States are obliged to enforce EU food law with respect to food products marketed online, necessitating the development of enforcement strategies tailored to the e-commerce context (Krewinkel et al., 2016). However, the European Commission has identified shortcomings in the official control activities of Member States concerning online food trade (European Commission, 2018b), posing significant threats to public health given the continued expansion of food e-commerce.

Numerous concerns related to food e-commerce have been documented in the academic literature, particularly in relation to specific product categories. For example, prior studies have reported species mislabelling in online food sales (Siozios et al., 2020), fraudulent practices involving products with protected designation of origin (Di Pinto et al., 2019), effects of online distribution on bacterial proliferation in fresh food (Murphy et al., 2022), and the potential for widespread foodborne outbreaks driven by the broad distribution of

contaminated products via e-commerce channels (Nsubuga et al., 2022; Wei et al., 2014). In particular, food supplements sold online have long been associated with various health risks and recognised as a major public health concern (Lachenmeier et al., 2013). Common problems include consumer misuse, improper product composition, unauthorised health claims, and inadequate labelling (Carlsohn & Steinhorst, 2018), which are compounded by inconsistent enforcement practices among EU Member States (Warda et al., 2024). Experts have highlighted regulatory and enforcement deficiencies within the e-commerce sector, attributing these, in part, to the distinctive characteristics of this mode of distribution. Specifically, several authors identify a control deficit in online food trade compared to conventional retail. Contributing factors include unregistered food business operators, which cannot be included in risk-based inspections, as well as organisational challenges such as novel sampling procedures, limited resources, and unclear jurisdictions (Büchter et al., 2011; Comans, 2015; Lachenmeier et al., 2013).

In addition to documented potential hazards identified in the academic literature, hazards associated with e-commerce are regularly reported through the EU's Rapid Alert System for Food and Feed (RASFF). The RASFF serves as an important food safety mechanism within the EU, facilitating the timely exchange of information concerning public health risks arising from food, feed, and food contact materials. Member States of the EU, along with members of the European Free Trade Association (EFTA), submit notifications via an interactive online platform, thereby enabling prompt and coordinated actions to mitigate identified health risks (Art. 50 Reg. (EC) No 178/2002) (Kuchheuser & Birringer, 2022b). Several RASFF Annual Reports document health risks and specific hazards linked to e-commerce. These include general enforcement challenges with non-compliant food supplements containing unauthorised substances (European Commission, 2013, 2015b), as well as specific incidents such as adverse cardiac effects from DMAA-containing supplements (European Commission, 2013) and possible online marketing of a kratom-containing product related to a foodborne outbreak (European Commission, 2019). However, to the best of our knowledge, no comprehensive analysis of RASFF notifications specifically pertaining to e-commerce has yet been conducted.

Accordingly, the objective of this research is twofold: (i) to characterise food safety hazards documented in publicly available RASFF notifications pertaining to e-commerce in the EU; and (ii) to assess the extent to which these hazards are covered by current regulatory frameworks and identify potential regulatory gaps within food law affecting risk management. To achieve these aims, we compile all publicly available RASFF notifications issued since the system's inception in 1979, systematically identify those linked to e-commerce, and perform a quantitative analysis of food-related notifications – focusing on affected product categories and reported hazards. Furthermore, we conduct a structured legal classification to determine the regulatory status of hazards in food supplements against international, European, and national decision bases. This step is supported by a novel decision tree developed specifically for this purpose, which could also find practical application in market surveillance. Food supplements were selected as a focal category because they are frequently associated with safety concerns and regulatory challenges in the context of online food trade. In this paper, the terms "hazard" and "risk" are used in accordance with their legal definitions under Art. 3 of Reg. (EC) No 178/2002; a hazard refers to a specific agent or condition with a potentially adverse health effect, while risk reflects the probability and severity of its occurrence.

This study contributes to the existing body of research on food safety in online trade – which often focuses on selected product categories or specific hazards – by providing a comprehensive and systematic analysis of RASFF notifications related to e-commerce. By analysing data resulting from actual risk management measures implemented by EU Member States' competent authorities, it yields valuable insights into regulatory and enforcement practices across jurisdictions. Combining this empirical perspective with a structured legal classification enables the identification of regulatory gaps and inconsistencies, supplying an evidence base to inform targeted and strategic improvements in consumer health protection at both European and national levels.

Methods

Data Collection and Preparation

We undertake a systematic secondary analysis of notifications issued in the Rapid Alert System for Food and Feed (RASFF). The RASFF is a communications system operated by the European Commission. While access to confidential elements of RASFF notifications is restricted to network members under Art. 52 of Regulation (EC) No 178/2002, the publicly available versions still provide substantial information on the reported incidents. Our dataset thus comprises publicly available, non-confidential notifications obtained from two official sources: the RASFF Window public database (European Commission, n. d.-f) and the EU Data Portal public archive of RASFF notifications (European Commission, 2025a). As RASFF notifications are originally compiled for administrative purposes, they represent process-generated data suitable for secondary analysis in research contexts (Salheiser, 2014). Prior studies have demonstrated the utility of such data for academic and policy-related analyses (Kuchheuser & Birringer, 2022b; Kuchheuser et al., 2018; Pigłowski, 2020).

Although the RASFF was established in the late 1970 s, the RASFF Window database provided notifications only from 2018 onwards at the time of data collection. To ensure comprehensive coverage, historical data (1979–2022) were retrieved via two structured datasets available through the EU Data Portal. The initial data download was conducted on 23 May 2023 in Microsoft Excel format from the RASFF Window and the EU Data Portal. All datasets were consolidated into a single spreadsheet for integrated processing.

To systematically identify RASFF notifications related to e-commerce, a structured keyword search was applied to the consolidated dataset – comprising records from 1979 to 2023. The keywords were selected because they are closely associated with online trade and therefore expected to reliably capture e-commerce notifications. Initial search terms included: "online", "internet", "e-commerce", "electronic commerce", "www", "world wide web", "web", "web shop", "webshop", "website", "webpage", and "digital". Iterative refinement of the search revealed additional relevant keywords – "e-trader", "e-platform", "homepage", and "Amazon" – which were subsequently incorporated. A follow-up collection was carried out on 25 July 2023 to include additional notifications submitted through 30 June 2023, after which the keyword search was repeated.

References to e-commerce were primarily located in the fields "action taken" and "distribution status". As this information was included in datasets retrieved from the EU Data Portal archive but not in those downloaded from RASFF Window, the relevant characteristics

were searched in the RASFF Window online database to identify further relevant notifications. While the "action taken" could be filtered through the RASFF Window interface, the "distribution status" required manual inspection.

All notifications confirmed to involve e-commerce were compiled into a dedicated working dataset. This step covered all data records characterised by the same unique reference number, including duplicate notification records from RASFF Window and the EU Data Portal. A multi-step data cleaning and preparation process followed. This included the evaluation of record completeness and transfer of relevant unstructured content (e.g., from the "subject" field) into standardised fields, as well as the deduplication of records and consolidation of entries. Duplicate records with the same reference number relating to multiple hazards or products were retained as separate entries, whereas those citing multiple countries of origin were merged for consistency. Entries for notifications found in both data sources were consolidated. Further steps were the enrichment of entries with supplemental details manually retrieved from the RASFF Window interface – to account for the variation in field coverage compared to the EU Data Portal dataset –, the harmonisation of hazard terminology, and the creation of new fields to accommodate multiple hazard categories in individual notifications. These steps ensured data consistency and analytical readiness for quantitative assessment.

Quantitative Analysis of RASFF Notifications

A descriptive statistical analysis using Microsoft Excel was conducted to present the outcomes of the methodological approach, quantify the scale and investigate the characteristics of RASFF notifications related to e-commerce. This included the number of notifications obtained from both sources, as well as their identification by individual keyword searches and through filter searches ("action taken") or manual review ("distribution status") in the RASFF Window interface.

The analysis employed frequency distributions and cross-tabulations to describe attributes such as: product type (food, feed, or food contact material), notification type and submission date, basis of notification (e.g., official control, consumer complaint), notifying country and country of origin, product and hazard categories, and specific hazards reported. A focused subset analysis was conducted for notifications associated with food traded online to explore trends in product and hazard categories, specific hazards, and regulatory concerns in more depth.

Legal Classification of Reported Hazards and Decision Tree

Following the extraction of hazards from publicly accessible RASFF notifications (hazard identification), a dedicated legal analysis – referred to as legal classification – was undertaken to determine their regulatory status, as RASFF notifications do not consistently cite their legal basis. This procedure involved comparing each hazard against international, European and national decision bases to identify potential regulatory gaps and inconsistencies. The analysis focused on notifications involving food supplements, a product category commonly linked to safety concerns and regulatory challenges in online trade (Carlsohn & Steinhorst, 2018; Lachenmeier et al., 2013; Warda et al., 2024) – which also became apparent at an early stage of this study.

Hazard-specific information was first collected through a combination of open-source search engines (e.g., Google), legal databases (notably EUR-Lex), academic literature databases (such as Web of Science), and additional scholarly and regulatory literature to enable broad information gathering without a specific focus. Based on these findings, a structured framework was developed to map relevant legislation and regulatory decision bases at international, European, and national levels. Germany was chosen as a representative Member State due to its population size (Eurostat, 2025a), high RASFF reporting activity (European Commission, n. d.-a), substantial online food supplement market (Statista, 2022, 2025b), advanced concepts for online trade monitoring (BVL, 2024), and a comprehensive national food regulatory framework.

The legal classification was conducted as a structured analytical procedure designed to systematically determine the regulatory status of each identified hazard against the relevant decision bases. These decision bases included annexes to EU regulations, national registers and legal provisions, as well as official guidance documents (see Table A.1 (Supplementary Information)). From a risk management perspective, this selection ensured that the classification relied on the most relevant and current decision framework, as scientific literature may lag behind regulatory developments or refer to non-EU jurisdictions. All hazards and their synonyms were manually searched in the positive and negative lists of the relevant instruments. In the context of food law, positive lists specify authorised substances, whereas negative lists identify prohibited or restricted ones. For each hazard, the results of this cross-referencing were systematically recorded in a spreadsheet providing a transparent record of the classification results. The stepwise procedure was guided by a decision tree specifically developed for this purpose, which is presented in the results section. The final classification of hazards was completed between September and November 2024, following compilation of applicable decision bases in August 2024.

Results

A total of 82,396 data records – representing 65,872 RASFF notifications, including duplicates – were retrieved from the public archive available on the EU Data Portal. An additional 15,066 data records, corresponding to 15,066 unique notifications, were obtained from the RASFF Window public database. In total, 97,462 data records were compiled from public sources, representing 72,632 individual RASFF notifications submitted between 1979 and June 2023.

Within this dataset, 910 notifications related to e-commerce were identified using various methods. Of these, 733 notifications were detected through systematic keyword searches. The keyword “online” yielded the highest number of results (669 notifications), followed by “web” (64 notifications), “Amazon” (21 notifications), “www” (14 notifications), and other related terms (7 notifications). An additional 177 notifications were identified through the use of filter functions (e.g., for “action taken”) and manual review of the “distribution status” field within RASFF Window (see Table 1).

Of the 910 e-commerce-related notifications, 274 were found in both the EU Data Portal archive and the RASFF Window database. An additional 299 notifications were identified exclusively in the EU Data Portal archive, while 337 notifications were unique to the RASFF Window database (see Fig. 1).

Table 1 Steps used to identify RASFF notifications related to e-commerce ($n=910$)

Step	Notifications (%)
Systematic searches for specific keywords *keywords: e-commerce, digital, electronic commerce, internet, online, web, webshop, web shop, website, webpage, world wide web, www*	719 (79.0)
Systematic searches for additional keywords *keywords: Amazon, homepage, e-platform, e-trader*	6 (0.7)
Systematic keyword searches for the period 23.05.−30.06.2023	8 (0.9)
Keyword searches (total)	**733 (80.5)**
Filter search in RASFF Window for "action taken" "(requested) removal of online offer" (not covered by systematic keyword searches)	42 (4.6)
Manual search in RASFF Window for "distribution status" "product traded online" (not covered by systematic keyword searches)	135 (14.8)
Additional searches (total)	**177 (19.5)**
Total	**910**

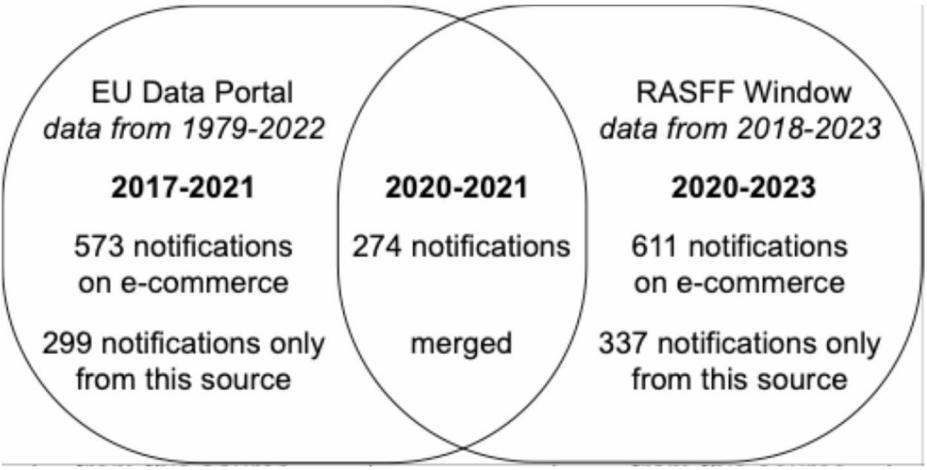


Fig. 1 Data sources of RASFF notifications and number of identified notifications concerning food, feed, and food contact material traded online ($n=910$). The EU Data Portal contains data from 1979 to 2022, including 573 notifications on e-commerce from 2017 to 2021. RASFF Window contains data from 2018 to 2023, including 611 notifications on e-commerce from 2020 to 2023. Duplicates from 2020 to 2021 contained in both data sources were merged

The first RASFF notification identified as related to e-commerce was submitted on 10 November 2017. Since that date, a total of 23,344 notifications have been published in the RASFF system, of which 1,811 notifications pertain to the product category "dietetic foods, food supplements and fortified foods". Notifications associated with e-commerce thus represent 3.9% of all RASFF notifications issued during this period (910 of 23,344 notifications) and account for 39.0% of notifications within the specified product category (707 of 1,811).

RASFF Notifications on Food Traded Online

Of the 910 e-commerce-related notifications, 786 notifications (86.4%) pertained to food, while 24 notifications (2.6%) and 100 notifications (11.0%) concerned feed and food contact materials, respectively (see Table 2). The dataset includes 180 alert notifications (19.8%), 421 information notifications for attention (46.3%), 308 information notifications for follow-up (33.8%), and one news notification (0.1%) (see Table 3).

Given the focus of this study, the analysis is confined to 786 notifications concerning food products traded online, with a further evaluation focusing on the subset of food supplements. Accordingly, the following sections refer to different notification numbers depending on the analytical focus. Figure 2 illustrates how these subsets relate to each other. A concise summary of RASFF notifications concerning feed and food contact materials traded online is provided in the Supplementary Information.

Between November 2017 and June 2023, a total of 786 RASFF notifications concerning food products traded via e-commerce were submitted. The number of such notifications increased from 104 notifications in 2018 to 168 notifications in 2022, reaching the highest annual count of 177 notifications in 2019, which corresponds to 22.5% of the total (see Table 2; Fig. 3).

The majority of notifications were classified as information notifications for attention (360; 45.8%) and information notifications for follow-up (251; 31.9%), followed by alert notifications (174; 22.1%) and one news notification (0.1%). The primary sources of these notifications were media monitoring (499; 63.5%), official controls on the market (169; 21.5%), and consumer complaints (101; 12.8%) (see Table A.2).

Notifications concerning food products traded online were submitted by 24 notifying countries and the European Commission. The highest number of notifications originated from Sweden (171; 21.8%), followed by Belgium (136; 17.3%), the United Kingdom (UK) (120; 15.3%), Denmark (84; 10.7%), and Germany (66; 8.4%). These five countries collectively accounted for 577 notifications (73.4%), while the ten most active notifying countries submitted 718 notifications (91.3%) (see Table 4; Table A.3). An analysis of the notifications submitted by individual Member States revealed notable variations in reporting behaviour and the content of published notifications. For example, Sweden and the UK reported elevated numbers of notifications in 2018–2019 and 2020, respectively, while Belgium, Denmark, and Germany demonstrated a progressive increase in notification activity over the study period (see Table 4).

Table 2 RASFF notifications related to e-commerce by type and year ($n=910$)

Type	2017	2018	2019	2020	2021	2022	2023	Total (%)
Food	3	104	177	107	111	168	116	**786 (86.4)**
Feed	0	1	9	4	4	4	2	**24 (2.6)**
Food contact material	0	1	3	0	89	7	0	**100 (11.0)**
Total	**3**	**106**	**189**	**111**	**204**	**179**	**118**	**910**

Table 3 RASFF notifications related to e-commerce by notification type and year ($n=910$)

Notification type	2017	2018	2019	2020	2021	2022	2023	Total (%)
Alert	0	38	66	12	25	25	14	**180 (19.8)**
Information for attention	1	55	90	55	86	83	51	**421 (46.3)**
Information for follow-up	2	13	33	44	92	71	53	**308 (33.8)**
News	0	0	0	0	1	0	0	**1 (0.1)**

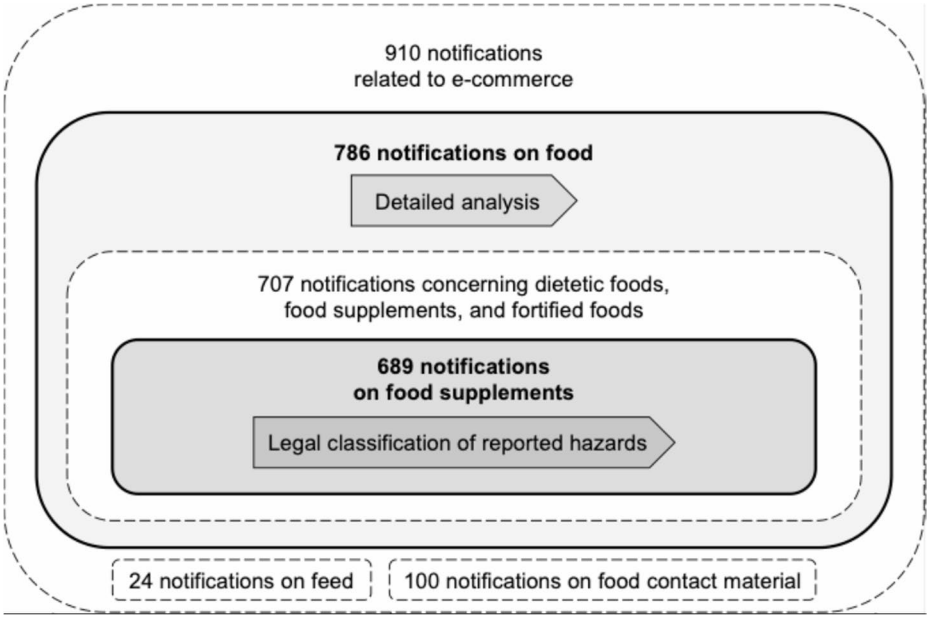


Fig. 2 Overview of RASFF notifications related to e-commerce and the analytical subsets considered in this study

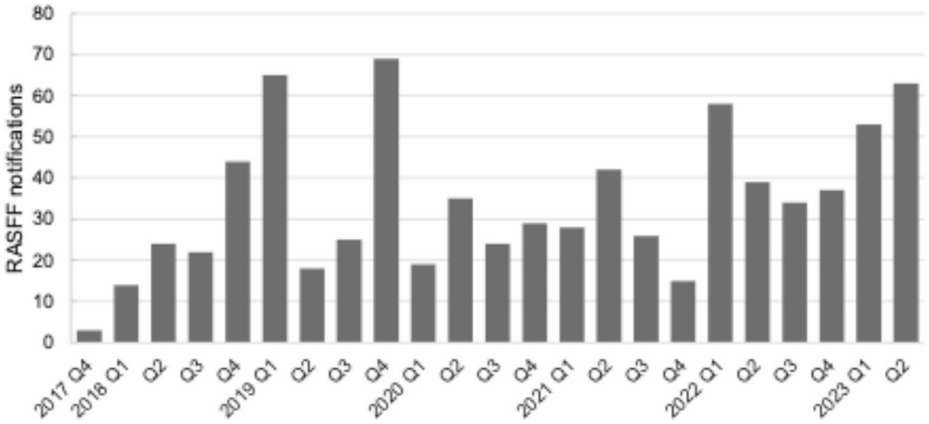


Fig. 3 RASFF notifications on food traded online by time ($n = 786$). Data are shown by quarter (Q1-Q4) to balance temporal resolution and detail, avoiding misleading annual aggregation for the incomplete year 2023. Figures in the 4th quarter (Q4) of 2018 as well as the 1 st (Q1) and 4th (Q4) quarter of 2019 include numerous notifications submitted by Sweden and the United Kingdom (see Table 4)

The notifications identified a wide range of countries of origin; the United States was reported most frequently (194 notifications; 24.7%), followed by the Netherlands (80; 10.2%), the UK (73; 9.3%), China (45; 5.7%), and Germany (40; 5.1%). These five countries accounted for 432 notifications (55.0%), while the ten most frequently cited countries of origin accounted for 528 notifications (67.2%). In 104 notifications (13.2%), no country

Table 4 RASFF notifications on food traded online by notifying country and year ($n=786$)

Notifying country	2017	2018	2019	2020	2021	2022	2023	Total (%)
Sweden	0	40	75	25	14	12	5	**171 (21.8)**
Belgium	0	1	3	8	18	58	48	**136 (17.3)**
United Kingdom	0	40	55	25	0	0	0	**120 (15.3)**
Denmark	0	2	6	18	18	18	22	**84 (10.7)**
Germany	0	9	9	8	15	17	8	**66 (8.4)**
Poland	0	0	7	1	4	36	4	**52 (6.6)**
Czech Republic	0	2	3	3	13	6	3	**30 (3.8)**
Switzerland	0	1	0	9	8	1	4	**23 (2.9)**
Spain	0	1	0	3	4	6	6	**20 (2.5)**
Hungary	0	1	11	1	2	1	0	**16 (2.0)**
Other	3	7	8	6	15	13	16	**68 (8.7)**

of origin was specified (see Table 5; Table A.4). Temporal trends in notifications by country of origin showed varying developments (see Table 5).

Of the 786 food-related notifications, 707 notifications (89.9%) concerned products categorised as dietetic foods, food supplements, and fortified foods. Within this category, 689 notifications (97.5%) specifically related to food supplements. A smaller portion (21 notifications; 2.7%) concerned the category "cocoa and cocoa preparations, coffee and tea" (see Table A.5), primarily involving (herbal) tea, as well as chocolate and coffee (data not shown).

The notifications involving food traded online reported one or more hazards, resulting in a total of 911 individual hazard entries across various categories (i.e., multiple entries per notification). The most frequently cited hazard category was the presence of certain substances or ingredients, reported in 645 notifications (82.1%), followed by high content/intake or (risk of) overdosage (126; 16.0%) and non-compliant labelling and unauthorised health claims (38; 4.8%) (see Table A.6). Within the predominant category "presence of certain substances or ingredients", the majority referred to the presence of unauthorised or prohibited substances/ingredients (449; 57.1%), including Novel Foods (266; 33.8%), or (potentially) unsafe substances/ingredients (84; 10.7%) (see Fig. 4).

Table 5 RASFF notifications on food traded online by country of origin and year ($n=786$). Numerous notifications do not clearly indicate the origin of products concerned, which is categorised as "unknown" (104 notifications, 13.2%)

Country of origin	2017	2018	2019	2020	2021	2022	2023	Total (%)
United States	2	54	38	29	10	37	24	**194 (24.7)**
Netherlands	0	3	8	5	16	26	22	**80 (10.2)**
United Kingdom	0	9	19	12	9	15	9	**73 (9.3)**
China	0	6	33	3	1	0	2	**45 (5.7)**
Germany	0	5	3	3	9	10	10	**40 (5.1)**
Spain	0	2	12	4	3	3	1	**25 (3.2)**
Turkey	0	4	4	5	2	1	1	**17 (2.2)**
Czech Republic	0	0	2	1	7	1	5	**16 (2.0)**
Switzerland	0	0	3	0	6	2	3	**14 (1.8)**
France	0	0	0	3	1	5	3	**12 (1.5)**
Sweden	0	0	1	4	1	2	4	**12 (1.5)**
Unknown	1	9	18	22	25	25	4	**104 (13.2)**
Other	0	12	36	16	21	41	28	**154 (19.6)**

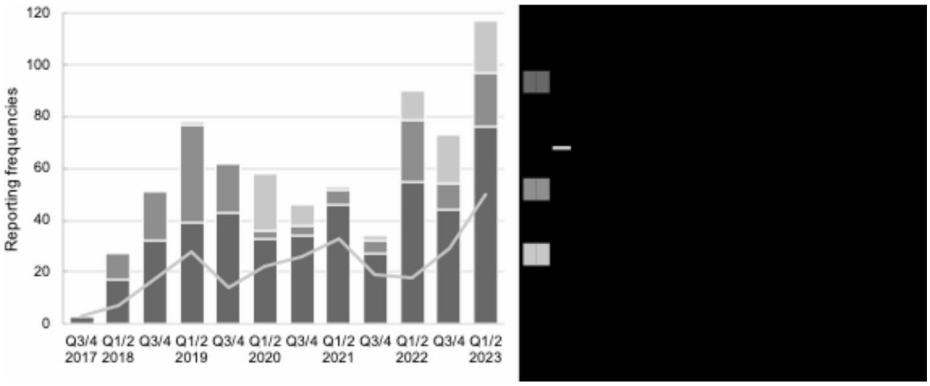


Fig. 4 Reporting frequencies of RASFF notifications on food traded online for the hazard category "presence of certain substances/ingredients" (multiple entries) ($n=645$). The figure on the left shows the reporting frequencies for different subcategories (bar chart) by time, including Novel Foods (line chart). The table on the right shows the total number of notifications reporting hazards in the hazard category "presence of certain substances/ingredients" and subcategories. Notifications reporting different hazards of the same category or subcategory were counted once. Therefore, the total number of notifications reporting hazards in the main category differs from the sum of notifications reporting hazards in the subcategories

A total of 210 distinct hazards were identified in 1,002 entries, reflecting multiple hazard entries per notification. Individual hazards were cited in as many as 108 notifications, representing 13.7% of the 786 notifications concerning food traded online. The most frequently reported hazards, as presented in Table 6, account for 67.4% of all food-related e-commerce notifications. By contrast, the remaining hazards were reported infrequently – fewer than 10 times each – with nearly 160 hazards mentioned in three or fewer notifications (see Table A.7).

Legal Classification of Reported Hazards

Based on the identified diversity of hazards and a comprehensive review of relevant European and national legislation – with Germany serving as a representative Member State –, an overview of the applicable legal framework was developed (see Fig. 5). Given the substantial number of notifications concerning food supplements, the developed legal framework focuses primarily on this product category. Figure 5 provides a simplified overview of the main regulatory domains, encompassing not only core areas of food law but also pharmaceutical legislation and the legal domains governing doping substances, narcotic drugs, and psychotropic substances. The full set of decision bases underlying the legal classification of reported hazards is presented in the supplementary version of the figure (see Fig. A.1). A brief description of each decision basis is provided in Table A.1.

All 178 distinct hazards reported in the 689 RASFF notifications on food supplements traded online were subject to legal classification, a structured analytical procedure designed to systematically determine the regulatory status of each identified hazard against decision bases at international, European and national levels. The classification of the most frequently reported hazards is presented in Table 7, while a comprehensive classification of all identified hazards is included in Table A.8.

Table 6 Most frequently reported hazards in RASFF notifications on food traded online (multiple entries) ($n = 786$). The 786 notifications reported a total of 210 hazards in 1,002 entries. The most frequently reported hazards account for 530 notifications (67.4%). The column "hazard category" refers to the most frequently reported categories

Hazard	Hazard category	Notifications (%)
2,4-Dinitrophenol (DNP)	presence of (unsafe) substance	108 (13.7)
Cannabidiol (CBD)	unauthorised Novel Food	103 (13.1)
Yohimbine	unauthorised substance	73 (9.3)
Pausinystalia johimbe (yohimbe)	unauthorised Novel Food/ingredient	38 (4.8)
Monacolin K (Lovastatin)	high content/intake	28 (3.6)
Withania somnifera (ashwagandha)	presence of (unsafe) ingredient	28 (3.6)
1,3-Dimethylamylamine (DMAA)	unauthorised substance	26 (3.3)
Artemisia annua	unauthorised (unsafe) Novel Food	17 (2.2)
Mitragyna speciosa (kratom)	unauthorised Novel Food	17 (2.2)
Caffeine	high content/intake	16 (2.0)
Eurycoma longifolia (tongkat ali)	unauthorised (unsafe) Novel Food	16 (2.0)
Agmatine sulphate	unauthorised Novel Food	15 (1.9)
Sodium chlorite	unauthorised substance	15 (1.9)
Sildenafil	unauthorised substance	13 (1.7)
Tetrahydrocannabinol (THC)	presence, high content/intake	13 (1.7)
Vitamin B6	high content/intake	13 (1.7)
5-Hydroxytryptophan (5-HTP)	unauthorised substance	12 (1.5)
Ephedra	unauthorised ingredient	11 (1.4)
Epimedium	unauthorised Novel Food	11 (1.4)
Epimedium grandiflorum	unauthorised Novel Food	10 (1.3)
Huperzine A	presence, unauthorised Novel Food	10 (1.3)
Zinc	high content/intake	10 (1.3)

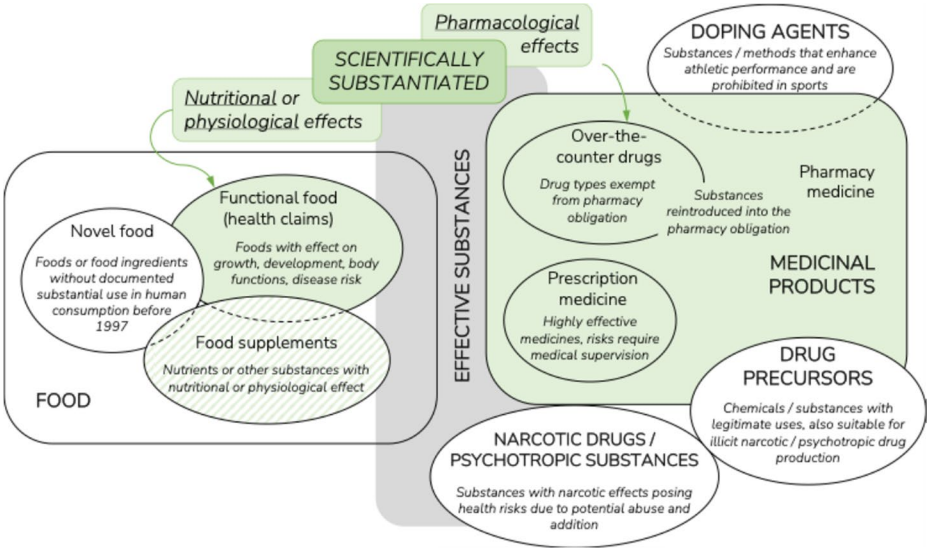


Fig. 5 Legal framework for mapping hazards reported in RASFF notifications on food traded online (based on legislation and Fuhrmann et al. (2020), Holle et al. (2018), Körner et al. (2022))

Table 7 Legal classification of the most frequently reported hazards in RASFF notifications on food supplements traded online. *Epimedium* could not be classified using the described procedure. A classification of all hazards is provided in Table A.8

Hazard	Food										Drugs	Medicinal products				Doping agents
	Information on Novel Food status	Vitamin or mineral	UL/ Maximum level	Prohibited or restricted	National recommendation	Scientific Opinion	EFSA Compendium	HoA Statement	Health claims	Other non-compliance	Narcotic drug/psychotropic substance/ drug precursor	Active substance	Herbal medicinal product	Prescription medicine	Information on pharmacy obligation	Doping agent
2,4-Dinitrophenol (DNP)						x BfR						x DE				x WADA
Cannabidiol (CBD)	x NF					x EFSA						x EU, DE		x		
Yohimbine												x DE		x		
Pausinystalia johimbe (yohimbe)				x prohibited	x Part A	x EFSA, BfR	x					x DE	x		x pharmacy obligation	
Monacolin K (Lovastatin)				x restricted		x EFSA, BfR			x [non-authorised]			x DE		x		
Withania somnifera (ashwagandha)	x -				x Part B	x BfR		x Prio	x [on hold]							

Table 7 (continued)

Hazard	Food										Drugs	Medicinal products				Doping agents
	Information on Novel Food status	Vitamin or mineral	UL/ Maximum level	Prohibited or restricted	National recommendation	Scientific Opinion	EFSA Compendium	HoA Statement	Health claims	Other non-compliance	Narcotic drug/psychotropic substance/ drug precursor	Active substance	Herbal medicinal product	Prescription medicine	Information on pharmacy obligation	Doping agent
1,3-Dimethylamylamine (DMAA)						x BfR										x WADA
Artemisia annua	x NF				x		x		x [on hold]							
Mitragyna speciosa (kratom)					x Part A	x BfR	x									
Caffeine						x EFSA, BfR			x [non-authorised] [on hold]			x DE				
Eurycoma longifolia (tongkat ali)	x NF					x EFSA	x									
Agmatine sulphate	x NF															
Sodium chlorite						x BfR						x EU, DE				
Sildenafil												x EU, DE		x		

Table 7 (continued)

Hazard	Food										Drugs	Medicinal products				Doping agents
	Information on Novel Food status	Vitamin or mineral	UL/ Maximum level	Prohibited or restricted	National recommendation	Scientific Opinion	EFSA Compendium	HoA Statement	Health claims	Other non-compliance	Narcotic drug/psychotropic substance/ drug precursor	Active substance	Herbal medicinal product	Prescription medicine	Information on pharmacy obligation	Doping agent
Tetrahydrocannabinol (THC)	x NF					x EFSA, BfR					x	x EU				x WADA
Vitamin B6		x	x UL, max. level			x EFSA, BfR			x [authorised] [non-authorised]			x EU, DE				
5-Hydroxytryptophan (5-HTP)	x NF								x [non-authorised]							
Ephedra				x prohibited	x Part A	x EFSA, BfR	x		x [on hold]			x DE	x	x	x pharmacy obligation	
Epimedium																
Epimedium grandiflorum	x NF				x		x					x DE				

Table 7 (continued)

Hazard	Food										Drugs	Medicinal products				Doping agents
	Information on Novel Food status	Vitamin or mineral	UL/ Maximum level	Prohibited or restricted	National recommendation	Scientific Opinion	EFSA Compendium	HoA Statement	Health claims	Other non-compliance	Narcotic drug/psychotropic substance/ drug precursor	Active substance	Herbal medicinal product	Prescription medicine	Information on pharmacy obligation	Doping agent
Huperzine A	x -							x								
Zinc		x	x UL, max. level			x EFSA, BfR			x [authorised] [non-authorised]			x EU, DE		x	x	

Abbreviations/explanation: *NF* Novel Food, *EU* European Union, *DE* Germany, information on Novel Food status ("x NF"=information available, Novel Food/"x -"=information available, not novel), prohibited or restricted: prohibition or restriction according to Reg. (EC) No 1925/2006, national recommendation recommendation made in the Stofflisten ("Part A"=recommendation of non-use in food/"Part B"=recommendation of restricted use in food/"Part C"=identification of possible harmful health effects), HoA statement ("x"=substance included in the HoA report/"x Prio"=substance prioritised in the HoA report), active substance registration as active substance at European (EU) or national (DE) levels

Using the developed legal framework and the identified decision bases, 159 of the 178 hazards reported in food supplements traded online – representing 89.3% – were successfully legally classified. More specifically, 123 hazards were referenced in food-related decision bases (of which 54 appeared exclusively within this legal domain), while 105 hazards were identified in other legal frameworks (with 36 cited exclusively in non-food-related legal fields). A total of 69 hazards were identified in both food law and other relevant legal domains, reflecting overlapping regulatory coverage. Nineteen hazards (10.7%) could not be classified using the established methodology; these are indicated in bold in Table 7 and Table A.8.

In the subsequent section, the legal classification of the five most frequently reported hazards is examined as illustrative examples. For 2,4-dinitrophenol (DNP), no applicable provisions were found within food-related legislation; however, a scientific opinion issued by the German Federal Institute for Risk Assessment (BfR) served as the primary reference within the food sector (BfR, 2015). In addition, DNP is listed as an active substance in the context of homeopathic medicinal products in Germany (BfArM, n. d.). Furthermore, DNP is included in the list of prohibited substances, an international standard issued by the World Anti-Doping Agency (WADA) as part of the World Anti-Doping Program (WADA, 2023).

Cannabidiol (CBD) is classified as an unauthorised Novel Food (European Commission, n. d. b). A scientific opinion issued by the European Food Safety Authority (EFSA) identified significant data gaps and uncertainties, concluding that the safety of CBD as a Novel Food cannot be established (EFSA NDA Panel et al., 2022). CBD is listed as an active substance in the EU (European Commission, 2025b) and Germany (BfArM, n. d.), which is only available as a prescription medicine in Germany (AMVV).

Yohimbine is classified as an active substance and prescription-only medicine in Germany (AMVV; BfArM, n. d.). Yohimbine is the main alkaloid of the plant *Pausinystalia johimbe* (yohimbe) (Melzig & Hiller, 2023). Yohimbe is a prohibited food ingredient according to Reg. (EC) No 1925/2006 (Annex III, Part A), as also recommended by German risk assessment and risk management authorities (BVL, 2020). The EFSA (EFSA Ans Panel, 2013b) and the BfR (BfR, 2013) have published scientific opinions on yohimbe, which is further mentioned in EFSA's Compendium of Botanicals (EFSA, 2025a). In Germany, yohimbe is listed as an active substance (BfArM, n. d.) and herbal medicinal product, which is subject to the pharmacy obligation (AMVerkRV).

Monacolin K (lovastatin) is a restricted substance according to Reg. (EC) No 1925/2006 (Annex III, Part B). The Regulation lays down conditions of use (maximum daily intake) and additional labelling requirements for monacolins from red yeast rice. Scientific opinions by the EFSA (EFSA Ans Panel, Younes, Aggett, Aguilar, Crebelli, Dusemund, et al., 2018) and the BfR (BfR, 2020) are available. The EU register of health claims lists a non-authorised health claim for monacolin K (European Commission, n. d.-c). In Germany, lovastatin (monacolin K) is listed as an active substance (BfArM, n. d.) and as a prescription-only medicinal product (AMVV).

Withania somnifera (ashwagandha) is not considered novel in food supplements according to the Novel Food status Catalogue (European Commission, n. d.-b). German risk assessment and risk management authorities recommend to include ashwagandha as a restricted substance in Annex III, Part B to Reg. (EC) No 1925/2006 (BVL, 2020). A scientific opinion by the BfR was identified (BfR, 2013). Further, the Heads of Food Safety Agencies (HoA) working group "Food Supplements" recommends prioritising ashwagandha for an article

8 procedure (assessment for inclusion in Annex III to Reg. (EC) No 1925/2006) due to the assumed risk to consumers, the high intake and "(possible) carcinogenic, mutagenic or reprotoxic properties" (Heads of Food Safety Agencies, 2024, p. 24). Several non-reviewed health claims are included in the list of botanical claims on hold (EFSA, n. d.).

Decision Tree for the Legal Classification of Food Supplements

During the legal classification of hazards reported in RASFF notifications on food supplements traded online, the decision tree illustrated in Fig. 6 was developed to enable systematic analysis. Similar decision trees have been established for other purposes (BLV, 2024, p. 5; BVL, 2025, p. 20; BVL & BfArM, 2020, p. 22). The decision tree shows the general procedure followed in the legal classification and includes the relevant decision bases which were reviewed in consecutive steps.

The decision tree combines a review of food law with reviews of other legal fields. In the area of food law, an assessment at the European level precedes one at the national level, addressing first ingredients (Novel Foods, vitamins or minerals, other substances) and then labelling (general requirements, health claims). Besides legislative decision bases, risk assessments and communications from risk managers were included. Where food law does not permit classification, other legal fields may substantiate relevant RASFF notifications or justify complaints, e.g., through the presence of pharmacologically active, narcotic or psychotropic substances contesting the presentation as food defined in Art. 2 of Reg. (EC) No 178/2002, although the practical implementation may be another matter (Sproll et al., 2025). Construction was guided by two criteria: the capacity of decision bases to substantiate RASFF notifications and their hierarchical weight, examining the most relevant decision bases first to enable rapid initial judgments and prioritising legal decision bases.

Discussion

Characterisation of Food Safety Hazards in E-Commerce from RASFF Notifications

From November 2017 to June 2023, a total of 910 notifications related to e-commerce have been submitted in the RASFF, including 786 notifications on food traded online. The analysis of these RASFF notifications yielded valuable insights into food safety hazards in e-commerce, thereby addressing the first research objective. Accordingly, a majority of RASFF notifications on food traded online concerned the product category of dietetic foods, food supplements, and fortified foods (707 notifications, 89.9% of 786). In total, 689 notifications (87.7% of 786) reported on non-compliant food supplements. This observation is not particularly surprising. Non-compliant food supplements have long been a focus of the competent authorities in the EU, and the problem is regularly highlighted in RASFF reports (e.g., European Commission, 2022, 2023a, 2024). Moreover, several articles have been published on food supplements reported in the RASFF. Petroczi et al. (2011) analysed RASFF notifications on dietetic foods, food supplements, and fortified foods (2003-July 2010) with a focus on product contamination, and also discussed the results with regard to regulation and enforcement issues in e-commerce. Czepielewska et al. (2018) examined RASFF notifications (2003-December 2016) focusing on drug-adulterated food supplements, yet

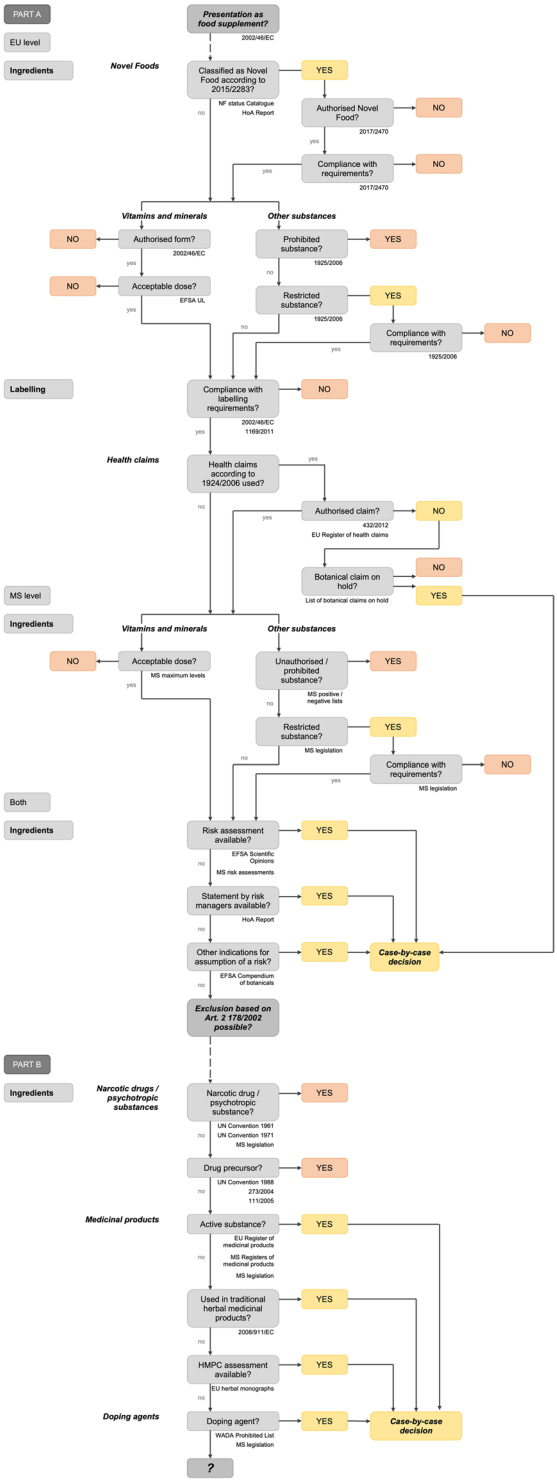


Fig. 6 Decision tree for the legal classification of food supplements, developed based on an analysis of RASFF notifications on food traded online

without significantly mentioning e-commerce. Most recently, Koncz et al. (2020) systematically reviewed RASFF notifications (1988–2019) with a focus on weight loss supplements, reporting a total of 2,559 records on food supplements, however, without any reference to e-commerce.

Although food supplements were among the first product categories in e-commerce (Lachenmeier et al., 2013), the online market for food supplements has continued to grow in recent years, likely also driven by social media and influencer marketing (Engel et al., 2024; Ricke & Seifert, 2024; Wang, 2025). The share of vitamins and minerals purchased online increased from 16.6% in 2017 to 24.1% in 2023 in the EU (Statista, 2025a) and from 15.9% (2017) to 28.6% (2023) in Germany (Statista, 2025b). According to Nielsen, online sales of food supplements in Germany amounted to 380.8 Mio. EUR in 2022, accounting for 25% of the total market (1,522 Mio. EUR) (Statista, 2022). In the context of fact-finding missions on Member States' official controls of food supplements in 2013 and 2014, the European Commission already predicted challenges due to the increasing online distribution of this product category (European Commission, 2015a). In fact, several articles report about non-compliant and potentially hazardous food supplements in relation to e-commerce (Bashyal & Roberts, 2024; Benedito da Silva Cardoso et al., 2024; Decke & Seifert, 2025; Gaudiano et al., 2016; Nsubuga et al., 2022; Palasamudram Shekar et al., 2019; Petróczi et al., 2015; Tessele et al., 2024; Vanhee et al., 2024; Viana et al., 2016; Vida et al., 2023; West & Deng, 2024; Willers et al., 2021). In this analysis, a comparison showed that RASFF notifications on dietetic foods, food supplements, and fortified foods traded online account for almost 40% of all notifications concerning this product category in the relevant period. For all food categories, however, this share is around 4%, which means that for food supplements and related products a considerably higher share of notifications relates to e-commerce. This finding once again highlights that e-commerce is a distribution channel for non-compliant and potentially dangerous food supplements.

The analysis showed that most products were reported due to the presence of certain substances or ingredients (645 notifications), high contents or intakes (126), or non-compliances in labelling (38). These are common infringements of food supplements, as noted in RASFF reports (e.g., European Commission, 2013) and in the academic literature (e.g., Koncz et al., 2020). Thus, a frequent problem was the product composition and labelling itself, which can usually be determined by visual label inspection. In contrast, adulteration with (unsafe) substances not listed as ingredients or other contamination (e.g., with pathogens) can only be revealed by physical inspection. Given the greater effort required for physical inspection – particularly in e-commerce, where a specific sampling procedure under Art. 36 of Regulation (EU) 2017/625 applies –, it may be assumed that such hazards are underrepresented in the analysed dataset. However, this analysis demonstrates that comprehensive monitoring of e-commerce may already identify numerous non-compliant and potentially dangerous products through visual inspection alone, which could be automated in the future (Krewinkel et al., 2016).

The notifications concerned products both from third countries and European Member States. With regard to third countries, most notifications reported about non-compliant products from the United States (194 notifications; 24.7%) and China (45; 5.7%). Similar observations have previously been made in RASFF analyses focusing on food supplements and related products (Czepielewska et al., 2018; Petroczi et al., 2011). Moreover, the EU coordinated control plan on Novel Food ingredients in e-commerce has identified

the United States and China as important third countries of origin (European Commission, 2018a). This may, at least in part, be explained by divergent legislations and markets for food supplements (Low et al., 2017; Zovi et al., 2025), as already assumed by others (Czepielewska et al., 2018). Besides, several (previous) network members have been reported as the origin of concerned products, most frequently the Netherlands (80 notifications; 10.2%), the UK (73; 9.3%), and Germany (40; 5.1%). While in the EU coordinated control programme the Member States reportedly focused on traders within their own territory (European Commission, 2018a), this observation cannot be confirmed for the three most frequently reported European countries of origin in this analysis. Notifications concerning products from the Netherlands were mostly submitted by Belgium (50 notifications) and nine other network members. Notifications reporting on products from the UK were often issued by Sweden (21) and 14 other network members, including the UK (4). However, products from Germany were frequently notified by Germany (9) and Denmark (9), with notifications by eight other network members. Importantly, this finding might be influenced by the fact that non-compliances at the national level not necessarily trigger RASFF notifications. This observation further suggests that network members notified products from other Member States, possibly due to differing legislation on food supplements and particularly on other substances than vitamins and minerals – which becomes particularly evident in the cross-border online trade of these products. Interestingly, 104 notifications (13.2%) report an unknown origin, probably complicating enforcement measures.

Interestingly, the first identified notification on products traded online was submitted in November 2017. This observation could be linked to the revised Official Controls Regulation (Reg. (EU) 2017/625) introducing specific provisions for e-commerce, although most of the provisions only started to apply from December 2019. The revised Official Controls Regulation explicitly addresses official controls in e-commerce by specifying the registration obligation for operators in e-commerce (Art. 15(5)), establishing a sampling procedure for products traded online (Art. 36), and enabling the competent authorities to take measures in case of established non-compliance (Art. 138(2)(i)) (Reg. (EU) 2017/625). Another contributing factor could be the increasing focus of competent authorities at European and national levels on health risks in e-commerce. For instance, in 2017 the European Commission carried out a series of fact-finding missions on official controls in e-commerce conducted by Member States (European Commission, 2018b) and initiated the first EU coordinated control plan on food products traded online (European Commission, 2018a). This increased oversight may also help to explain the overall trend of growing notification numbers reporting on products traded online (see Fig. 3).

Notification activity varied considerably among network members. Taken together, the ten most frequently notifying countries reported more than 90% of notifications, with Sweden, Belgium, the UK, Denmark, and Germany being the main contributors. This observation can possibly be explained by differences in risk management at the national level. The Commissions' fact-finding missions revealed different approaches and priorities assigned to official controls in e-commerce, with generally limited activities but specialised teams established in some Member States (European Commission, 2018b). For instance, the Swedish Food Agency (Livsmedelsverket) has developed a strategy for official controls in e-commerce and established a centralised monitoring unit focusing on food supplements (Livsmedelsverket, 2016). In Germany, the Common Central Unit G@ZIELT has been

established in 2013 in the Federal Office of Consumer Protection and Food Safety (BVL). The central unit supports the federal states by conducting systematic online searches for hazardous foods and other product categories (BVL, 2024). The number and content of notifications submitted by network members may further be influenced by national circumstances or incidents. For instance, the UK issued a total of 102 notifications on the substance DNP between 2018 and 2020 following numerous poisonings and deaths linked to (online traded) DNP (BBC, 2019, 2020; Blasius, 2019; Mackintosh, 2020; Thomas, 2018). In addition, differences between notifications by network members may be explained by national risk assessment. For example, Denmark published 25 of 28 notifications on food supplements containing the botanical *Withania somnifera* (ashwagandha), which is currently not regulated at the European level (Heads of Food Safety Agencies, 2024). However, the Danish DTU National Food Institute published a risk assessment on ashwagandha root in 2020 (DTU Fødevareinstituttet, 2020), and the subsequent national ban in 2023 provides the legal basis for these official objections in Denmark (McKeown, 2023).

Coverage of Hazards by Current Food Law Frameworks and Implications for Risk Management

Overall, the 689 notifications on food supplements reported 178 distinct hazards, which were rarely associated with vitamins and minerals but predominantly linked to so-called "other substances", notably botanicals. The numerous hazards were subjected to legal classification to assess their coverage by current regulatory frameworks and to identify potential regulatory gaps within food law affecting risk management (second research objective). The structured analytical approach to determining the regulatory status of reported hazards could only partially align individual hazards in food supplements with the EU's regulatory frameworks outlined in Fig. 5, based on the decision bases detailed in Fig. A.1 and Table A.1. Accordingly, the legal classification suggests that a significant number of substances reported as hazardous are not explicitly covered by current EU food law, a shortcoming discussed in the following section.

Within the EU, the regulation of food supplements is minimally harmonised under Directive 2002/46/EC, which aims to align assorted aspects of national legislation concerning food supplements (Warda et al., 2024). The Directive provides a list of authorised forms of vitamins and minerals permitted in food supplements and envisions the establishment of minimum and maximum permissible levels for these nutrients – though such thresholds have yet to be formally adopted. The Standing Committee on Plants, Animals, Food and Feed has initiated a regulatory process expected to culminate in the adoption of a new Regulation in 2024 (European Commission, n. d.-d). As part of this initiative, the European Commission requested the EFSA to revise the Tolerable Upper Intake Levels for several nutrients. In response, EFSA adopted revised Tolerable Upper Intake Levels in 2023 and 2024 (EFSA, 2024), paving the way for the establishment of maximum levels for vitamins and minerals in the EU.

In addition to vitamins and minerals the regulatory framework also encompasses "other substances with a nutritional or physiological effect" (Art. 2(a) Directive 2002/46/EC), which qualify as potential ingredients in food supplements. EFSA categorises these substances to include "amino acids, essential fatty acids, fibre and various plants and herbal extracts" (EFSA, 2025b). Although the inclusion of a positive list of other substances is

mentioned as a risk management strategy (Art. 4(8) Directive 2002/46/EC), the current Directive lacks specific provisions to harmonise the regulation of these substances at the European level.

However, Reg. (EC) No 1925/2006 on the addition of vitamins and minerals and of certain other substances to foods sets out a list of prohibited and restricted substances that also applies to food supplements. As of July 2024, the relevant Annex III comprised six entries for prohibited substances (Part A) and three entries for restricted substances (Part B). This Regulation possibly explains numerous notifications reporting the presence of the prohibited ingredient yohimbe (*Pausinystalia yohimbe*) (38 notifications) and its main alkaloid yohimbine (73) or high levels of the restricted substance monacolin K (28), as well as several notifications reporting on *Ephedra* (11), hydroxyanthracene derivatives (3), aloin (3), emodin (1), and epigallocatechin gallate (EGCG) (1).

Furthermore, other substances in food supplements may be subject to the Novel Food Regulation (EU) 2015/2283. In the EU, Novel Food – which is defined as "food that was not used for human consumption to a significant degree within the Union before 15 May 1997" (Art. 3(2)(a) Reg. (EU) 2015/2283) – must be authorised following food safety assessment. The Regulation provides for a Union list of authorised Novel Foods, which is set out in Commission Implementing Regulation (EU) 2017/2470. Furthermore, the European Commission maintains the Novel Food status Catalogue as an online database with non-binding information on the Novel Food status of food products, ingredients, and substances "based on information provided by the EU Member States" (European Commission, n. d.-e). In fact, several notifications reported ingredients as Novel Foods, and the legal classification identified numerous substances in the Novel Food status Catalogue (see Table A.8). However, not all substances described as unauthorised Novel Foods were also listed in the online database. For instance, no entries were found for *Mitragyna speciosa* (kratom), Huperzine A, and *Epimedium*. As the catalogue lists "*Epimedium brevicornum*", "*Epimedium grandiflorum*", and "*Epimedium sagitattum*" as Novel Foods (European Commission, 2023b, 2023c, 2023d), the notifications concerning *Epimedium* probably referred to one of these species. Yet, this specific information was not provided in the public notification version.

Without harmonised regulation at the EU level, Member States may adopt and apply national legislation. In the area of food supplements, some Member States have established maximum levels for vitamins and minerals as well as use restrictions, positive or negative lists for other substances. Especially for other substances, this results in a fragmented regulatory landscape primarily governed by national provisions (Warda et al., 2024), which may be applied in compliance with the principle of mutual recognition ensuring the free movement of goods in the EU (European Commission, 2010, 2020, 2021; Heads of Food Safety Agencies, 2024; Warda et al., 2024). As not all reported hazards could be linked to international and European decision bases, it can be assumed that several RASFF notifications were based on national decision bases (manuscript in preparation). However, this analysis demonstrates that a wide range of hazards in food supplements traded online was reported in the RASFF within a relatively short timeframe. Dissemination of this information via the RASFF implies either transboundary relevance (i.e., the hazards potentially impacted multiple Member States) or that the notifying authorities deemed it important to alert the broader network for other reasons. These findings underscore that non-compliant food supplements, particularly those distributed via e-commerce, pose a cross-border concern rather than iso-

lated national issues. This highlights the urgent need for enhanced, harmonised European risk management tools to strengthen consumer health protection across the EU.

The regulation of other substances in food supplements is subject to debate. In a 2008 report to the Council and the European Parliament, the European Commission concluded that "laying down specific rules applicable to substances other than vitamins and minerals for use in food supplements is not justified" (European Commission, 2008, p. 11). Instead, the Commission considered available tools (i.e., Reg. (EC) No 1925/2006 and Novel Food Reg. (EU) 2015/2283) sufficient for risk management at the European level (European Commission, 2008). This report draws in part on findings from a 2007 investigation of the European food supplements market (European Advisory Services, 2007). However, the food supplement market has undergone substantial transformation over the past two decades, driven in particular by the rapid expansion of e-commerce. As a vast and highly dynamic cross-border marketplace (Krejbich et al., 2023), e-commerce presents unique regulatory challenges that may warrant, or even necessitate, a reassessment of available risk management strategies.

In the absence of specific provisions for other substances in food supplements, there is a clear need to strengthen the use of existing instruments through various approaches. One potential measure would be the establishment of a legally binding list of non-authorised substances that have been confirmed to possess Novel Food status. As previously noted, not all substances identified as novel could be found in the Novel Food Catalogue, which provides non-binding information (European Commission, n. d.-e). While a list of authorised Novel Foods is set out with Reg. (EU) 2017/2470, no official list of non-authorised novel substances exists. However, this list could increase the legal certainty both for competent authorities and business operators and provide reliable information to consumers. Second, further substances could be prohibited or restricted in foods by inclusion in Part A or Part B of Annex III to Reg. (EC) No 1925/2006. As of July 2024, Annex III only comprised six prohibited and three restricted substances, but some of these provisions were overturned in December 2024 (Kelly, 2024). Additional substances may be included in Annex III based on a risk assessment, following the regulatory procedure described in Art. 8 of Reg. (EC) No 1925/2006.

However, the vast array of other substances that may be added to food supplements necessitates a structured prioritisation process both for risk assessment and risk management. A potential prioritisation framework was recently suggested by a European working group comprising representatives of competent authorities. As an initiative of several Member States, the HoA working group "Food Supplements" aims to harmonise the regulation of other substances. In 2024, the working group published a report in which 13 of 117 reviewed substances were prioritised for the regulatory procedure described in Art. 8 of Reg. (EC) No 1925/2006. The prioritisation was based on a review of scientific information focusing on "(possible) health risk[s] to consumers, especially […] [with] an enhanced intake via food supplements" (Heads of Food Safety Agencies, 2024, p. 3) and also considered the online availability of substances in food supplements on the European market. In fact, several of the prioritised substances were also identified in this analysis of RASFF notifications: *Actaea racemosa* (synonym *Cimicifuga racemosa*, 1 notification), Curcumin in *Curcuma* spp.-preparations (1), *Hypericum perforatum* (3), *Lepidium meyenii* (7), melatonin (8), *Ocimum tenuiflorum* (1), piperine (4), p-Synephrine in *Citrus* spp.-preparations (synephrine, 7), *Tribulus terrestri* (*Tribulus terrestris*, 7), tryptophan, and *Withania som-*

nifera (28). Besides health risks and market availability, a prioritisation could also consider further aspects such as interest by consumers indicated by search machine data (manuscript in preparation) or reports of adverse effects. A European reporting system could serve as a centralised platform to systematically collect medical reports and consumer complaints, while also integrating RASFF notifications related to adverse effects of food supplements, several of which were identified in this analysis. Furthermore, the system could be expanded to include surveillance of academic literature for relevant case reports also originating from other regions (e.g., Palasamudram Shekar et al., 2019).

Several findings of the present study indicate that the insufficient risk assessment and regulation of other substances in food supplements represents a considerable public health concern. First, the results reflect the long-standing issue of blurred boundaries between food supplements and products from other legal fields, such as doping agents and especially medicinal products (see Fig. 5; Table A.8). Despite their similar appearance, important differences exist between food supplements and medicinal products. Most notably, medicinal products are defined as "substance[s] […] presented as having properties for treating or preventing disease […] or modifying physiological functions by […] pharmacological, immunological or metabolic action" (Art. 1(2) Directive 2001/83/EC), whereas food supplements are intended to "supplement the normal diet […] [as] concentrated sources of nutrients or other substances with a nutritional or physiological effect" (Art. 2(a) Directive 2002/46/EC). This legal distinction is inherently complex and remains challenging even for regulatory experts (ALS, 2015; BMG & BMELV, 2012; BVL, 2025; Stephan, 2020). Distinguishing between these product categories may therefore be even more difficult for consumers, who tend to perceive food supplements labelled as 'natural' as safe and healthy (Ang et al., 2023) and may even use food supplements with the intention of preventing or overcoming disease (Ang et al., 2023; BfR, 2021). Such misunderstanding – potentially exacerbated by health claims relating to disease risk reduction – may pose health risks to consumers, for instance when food supplements are used in addition to, or in place of, authorised medicinal products (Koziolek et al., 2019; Krejbich & Birringer, 2022; Leal et al., 2025).

Moreover, risk assessments by EFSA and/or BfR were identified for numerous botanical substances reported in RASFF notifications. While insufficient data hindered a conclusive assessment in many cases, some EFSA risk assessments identified health risks that resulted in a corresponding ban or restriction under Reg. (EC) No 1925/2006 – like for Yohimbe (EFSA Ans Panel, 2013b), monacolins in red yeast rice (EFSA Ans Panel, Younes, Aggett, Aguilar, Crebelli, Dusemund, et al., 2018), *Ephedra* species (EFSA Ans Panel, 2013a), and hydroxyanthracene derivatives (EFSA ANS Panel, Younes, Aggett, Aguilar, Crebelli, Filipič, et al., 2018). As research continues, evidence of serious health risks associated with botanicals is increasing. For instance, the EFSA recently published an update to the risk assessment of monacolins from red yeast rice, which could ultimately turn the restriction under Reg. (EC) No 1925/2006 into ban (EFSA NDA Panel et al., 2025). Entries in the EFSA Compendium of Botanicals, a comprehensive "database of botanicals that are reported to contain naturally occurring substances of possible concern for human health when present in food" (EFSA, 2021), further suggest that several of the notified substances may be associated with adverse health effects. Additionally, many of the herbal ingredients identified in RASFF notifications receive particular attention under medicines legislation. In Germany, several plant ingredients – which are generally excluded from pharmacy obligation (§ 44 Abs. 2 Nr. 3 AMG; § 1 AMVerkRV) – have been reintroduced to the pharmacy obligation (§ 7 Abs. 1

Nr. 2, Annex 1b AMVerkRV) or are regulated as prescription-only medicinal products (§ 1, Annex 1 AMVV) for reasons of health protection (von Czettritz, 2020). At the European level, the European Medicines Agency's (EMA) Committee on Herbal Medicinal Products (HMPC) has published several so-called EU herbal monographs addressing the safety, efficacy, and benefit-risk relation of herbal substances used in medicinal products (e.g., EMA Hmpc, 2015a, 2015b) to support national competent authorities in application procedures (EMA, n. d.). Notably, while side effects may be acceptable for medicinal products with a positive benefit-risk relation, food supplements must be safe and free of side-effects (BfR, 2025). This further highlights the particular relevance of appropriate risk management and targeted risk communication, especially for botanical food supplements (Bilia, 2015; Sun et al., 2024).

Practical Utility of the Decision Tree for Risk Mangers and Automated E-Commerce Monitoring

The structured legal classification was guided by a novel decision tree developed specifically to support the analytical procedure. It focuses on substances deliberately added to food supplements for their supposed nutritional or physiological effects. Although primarily intended for this purpose, the decision tree may also assist risk managers in the evaluation of food supplements. This is particularly relevant in e-commerce, where numerous food supplements with a wide variety of ingredients are available. In this setting, the decision tree could serve as a practical decision-making tool, providing risk managers with a starting point for the legal assessment of products. Accordingly, it incorporates additional decision bases beyond those directly applied in this investigation – for instance, the evaluation of compliance with labelling requirements under Directive 2002/46/EC (food supplements) and Reg. (EU) No 1169/2011 (food), as well as provisions for health claims under Reg. (EC) No 1924/2006. The relevance of such consideration is underscored by the fact that the analysed RASFF notifications frequently identified inadequate labelling. However, these aspects could not be examined in our legal classification, as relevant product-specific information (e.g., label, product picture) was unavailable. Aspects such as the classification as a food additive, flavouring, or special-purpose food as well as food safety under Art. 14 Reg. (EC) No 178/2002 fall outside the scope of the proposed decision tree but may warrant consideration.

Accordingly, the decision tree could support consumer protection by different means. As already mentioned, it may be used as a decision-making tool by risk managers in the evaluation of food supplements. For this purpose, the decision bases could be combined into a register that enables simultaneous searches for substances. One step further, it may serve as a template for the development of a (semi-)automated tool to monitor e-commerce for non-compliant or suspicious food supplements. By comparing online offers with relevant decision bases, a preliminary assessment and corresponding recommendations for action can be made – such as official complaints in case of unauthorised substances or case-by-case assessments in ambiguous situations. In order to increase the practical use of the decision tree, it may be adapted to include the relevant decision bases at European and national levels. Furthermore, the decision tree may also support the training of future risk managers.

Limitations

This study characterises hazards in online food trade as documented in publicly available RASFF notifications. However, the findings represent only a fraction of a broader phenomenon of hazardous products in e-commerce. First, the applied method likely did not capture all notifications related to e-commerce. For instance, whilst an EU coordinated control plan on food products traded online conducted in autumn 2017 resulted in 139 RASFF notifications (European Commission, 2018a), our analysis identified only three likely related notifications – suggesting that not all public versions of these notifications mentioned the specific keywords used for searching. Second, only a subset of non-compliances identified by competent authorities is reported in the RASFF, as Member States primarily submit notifications on incidents considered relevant for other network members – meaning non-compliances without cross-border relevance may not result in a notification. For instance, whilst Germany published 17 food notifications in 2022, the Common Central Unit G@ZIELT reported 534 online offers of potentially dangerous food products in the same period (BVL, 2023). Third, competent authorities likely identify only a portion of non-compliant products, given the numerous infringements reported in the literature (e.g., Nsubuga et al., 2022; Palasamudram Shekar et al., 2019; Vanhee et al., 2024) as well as the well-documented enforcement challenges specific to e-commerce (Krewinkel et al., 2016; Lachenmeier et al., 2013; Plana Casado, 2021). Accordingly, the RASFF notifications serving as the data basis for this analysis were likely influenced by methodological limitations as well as by reporting and enforcement gaps. Our analysis therefore provides a specific perspective on non-compliant products traded online and may not capture the full scope of infringements, suggesting that certain hazards in food supplements could remain underreported and inadequately addressed.

Furthermore, this work is limited by the data quality provided by the public versions of RASFF notifications, which required comprehensive data preparation. On the one hand, the data collection involved two sources, and numerous notifications were included in both the RASFF Window database and the EU Data Portal archive. Thus, the working dataset contained duplicates with partly differing information that required merging into a single data record. On the other hand, the information in the original data records was often incomplete or not sufficiently structured for data analysis. While some modifications were made as described in the methods, no subsequent improvement in data quality was possible in other cases. For instance, several notifications reported rather unspecific hazards such as substance groups instead of individual substances (e.g., hydroxyanthracene derivatives vs. aloin, emodin) or botanical genera instead of species (e.g., *Epimedium* vs. *Epimedium grandiflorum*) with no mention of concerned plant parts. However, unspecific hazards caused difficulties in the legal classification, as the hazards were sometimes not sufficiently described for a precise categorisation. Moreover, the natural, process-generated character of the data limited options in the quantitative analysis.

In addition, the public notification data only allowed limited insights into the respective circumstances. With public access to more detailed notification versions, further information could have been included in the analysis and thus contributed to the knowledge gained. In general, RASFF notifications contain valuable information that can not only provide relevant insights for the scientific community, but also support the activities of the competent authorities for food safety and consumer protection (Kuchheuser & Birringer, 2022a, 2022b; Kuchheuser et al., 2018). In our research, access to more detailed notifications could

have supported the categorisation of reported hazards which could not be classified with the described approach – either due to unspecific hazard definitions or lack of justification for the notifications.

With regard to the legal classification and decision tree, it should be noted that the classification was performed at the level of individual hazards reported in RASFF notifications. An overall assessment of concerned products was not possible due to limited access to original notification data. As the legal classification was carried out for 178 individual hazards, the analysis remained rather general and did not consider additional background information that could be particularly relevant for individual case decisions by experts. Moreover, relevant decision bases for the legal classification were downloaded in August 2024 and do not necessarily reflect available decision bases at the time of notification.

Furthermore, the results in Table 7 and Table A.8 are presented as a simplified summary of a more complex table. Accordingly, these tables may not be able to fully describe the significance of an entry for a particular hazard in a specific decision basis, which may have different meanings. More specifically, legislation may describe a non-conformity, while other decision bases may inform individual case decisions. The entries may also specify certain conditions, such as dosages or dosage forms defined in the AMVerkRV or AMVV. Besides, the identification as an active substance alone does not allow any conclusion regarding the authorisation status (e.g., sibutramine is listed as an active substance despite the authorisation being suspended). Therefore, the legal classification presented in our research only provides a first indication that requires further consideration in the specific context. This work does not constitute a legal assessment of hazards reported in RASFF notifications.

The decision tree was developed to include relevant decision bases identified through literature searches. However, it may be adjusted to include additional decision bases or fit more specific purposes. We developed the decision tree with a focus on the European level but also considering the Member State level using Germany as an example. This might also explain notifications that could not be substantiated (by food law) in our legal classification, as the reported hazards may be covered by provisions in other Member States. In addition, the decision tree is mainly based on the visual inspection of food supplements, for instance considering the product design, labelling, and declared ingredients. Specifically, the decision tree focuses on deliberately added substances which are labelled on the product. Other infringements related to microbiological safety, contaminants, or undeclared ingredients to be detected by physical inspections are not covered by the decision tree.

Conclusions

From November 2017 to June 2023, a total of 910 notifications related to e-commerce were submitted in the EU Rapid Alert System for Food and Feed (RASFF). These notifications were collected from the EU Data Portal public archive of RASFF notifications and the RASFF Window public database and identified using a systematic and documented procedure. Overall, 786 notifications on food traded online were issued by 24 network members, with high notification numbers by individual Member States – possibly related to specific strategies for the surveillance of e-commerce, such as the Common Central Unit G@ZIELT in Germany. Over time, an increasing number of notifications were observed, probably due to an increasing focus on e-commerce. However, we consider our findings the tip of an even

more serious problem. Almost all of the included RASFF notifications (689 notifications; 88%) concerned food supplements traded online, accounting for approximately 40% of all notifications published on this product category in the same period. The detailed analysis of food notifications identified a wide range of 210 hazards. A legal classification of the 178 hazards reported in food supplements highlighted gaps in the regulation of food supplements in the EU, as several so-called "other substances" could not be substantiated by European (legal) decision bases in the legal field of food law. Furthermore, the classification again demonstrated the proximity of food supplements to other legal fields such as pharmaceutical law, with several ingredients mentioned both in food law and in other legal fields. In combination with the enforcement challenges associated with food e-commerce, this regulatory gap in the food supplement sector poses a considerable risk to public health, particularly in relation to food supplements traded online. Considering the characteristics and challenges of e-commerce – especially the cross-border online trade of food supplements – there is an urgent need for harmonised European risk management measures. A better utilisation of existing risk management tools can increase consumer health protection, for instance by assessing further substances for an inclusion in Annex III to Reg. (EC) No 1925/2006 and providing a legally binding list of non-authorised Novel Foods in accordance with the Novel Food Regulation (EU) 2015/2283. Our decision tree may support risk managers in the (visual) evaluation of food supplements, possibly also as an automated decision-making tool. To fit individual purposes, the decision tree may be adapted to include other relevant decision bases both at the European and national levels.

Abbreviations

AMG	Medicinal Products Act [Gesetz über den Verkehr mit Arzneimitteln (Arzneimittelgesetz)]
AMVerkRV	Ordinance on Pharmacy-Only Medicinal Products and Medicinal Products Sold outside Pharmacies [Verordnung über apothekenpflichtige und freiverkäufliche Arzneimittel]
AMVV	Ordinance on Prescription-Only Medicinal Products [Verordnung über die Verschreibungspflicht von Arzneimitteln (Arzneimittelverschreibungsverordnung)]
BfR	German Federal Institute for Risk Assessment [Bundesinstitut für Risikobewertung]
BVL	Federal Office of Consumer Protection and Food Safety [Bundesamt für Verbraucherschutz und Lebensmittelsicherheit]
CBD	cannabidiol
DNP	2,4-dinitrophenol
DTU	Technical University of Denmark [Danmarks Tekniske Universitet]
EFSA	European Food Safety Authority
EFTA	European Free Trade Association
EMA	European Medicines Agency
EUR-Lex	online database of European Union law
G@ZIELT	Common Central Unit for Control of internet trade in products covered by the Food and Feed Code and tobacco products [Gemeinsame Zentralstelle "Kontrolle der im Internet gehandelten Erzeugnisse des LFGB und Tabakerzeugnisse"]

HMPC	Committee on Herbal Medicinal Products
HoA	Heads of Food Safety Agencies
RASFF	Rapid Alert System for Food and Feed
Reg.	Regulation
UL	Tolerable Upper Intake Level
WADA	World Anti-Doping Agency

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10603-026-09628-2.

Author Contributions P.K.: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review and editing. K.P.P.: Supervision, Writing – review and editing. M.B.: Supervision, Conceptualization, Investigation, Writing – original draft, Writing – review and editing.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data Availability The raw data used for our research originate from the RASFF Window public database and the EU Data Portal public archive of RASFF notifications and were published under a Creative Commons Attribution 4.0 International License (CC BY 4.0). Raw data will be made available on request.

Declarations

Clinical Trial Number Not applicable.

Competing Interests Kai P. Purnhagen is a member of the editorial board of the Journal of Consumer Policy. The authors declare that no other competing interests exist.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

ALS. (2015). *Stellungnahme Nr. 2015/31: Nahrungsergänzungsmittel mit sonstigen Stoffen im Regelungsbereich von NemV, HCV und LMIV [Opinion No. 2015/31: Food supplements with other substances in the regulatory area of NemV, HCV and LMIV]*. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit. Retrieved from https://www.bvl.bund.de/SharedDocs/Downloads/01_Lebensmittel/ALS_ALTS/Stellungnahmen_Nr_2015_31.html

Ang, J. Y., Ooi, G. S., Abd.Aziz, F., & Tong, S. F. (2023). Risk-taking in consumers' online purchases of health supplements and natural products: A grounded theory approach. *Journal of Pharmaceutical Policy and Practice, 16*(1), Article 134. https://doi.org/10.1186/s40545-023-00645-x

Bashyal, R., & Roberts, D. L. (2024). A systematic survey of online trade in the caterpillar fungus *Ophiocordyceps sinensis*. *Oryx, 58*(1), 29–37. https://doi.org/10.1017/s003060532300131x

BBC. (2019, 28.01.2019). *Bethany Shipsey: Drugs arrest in Ukraine after probe*. British Broadcasting Corporation. Retrieved 06.04.2025 from https://www.bbc.com/news/uk-england-hereford-worcester-47030624

BBC. (2020, 11.02.2020). *Eloise Parry: 'Vulnerable' woman died after taking diet pills*. British Broadcasting Corporation. Retrieved 06.04.2025 from https://www.bbc.com/news/uk-england-shropshire-51466461

Benedito da Silva Cardoso, F., Alves Dantas, C. E., Batista de Azevedo, M. d. G., & Pereira de Souza, J. B. (2024). Qualidade dos suplementos de creatina: um estudo baseado na análise do teor e da rotulagem [Quality of creatine supplements: a study based on content and labeling analysis]. *Vigil Sanit Debate*, *12*, 1–8, Article e02269. https://doi.org/10.22239/2317-269x.02269

Bennett, R., Keeble, M., Zorbas, C., Sacks, G., Driessen, C., Grigsby-Duffy, L., Adams, J., Burgoine, T., & Backholer, K. (2023). The potential influence of the digital food retail environment on health: A systematic scoping review of the literature. *Obesity Reviews, 25*(3), Article e13671. https://doi.org/10.1111/obr.13671

Bezirgani, A., & Lachapelle, U. (2021). Online grocery shopping for the elderly in Quebec, Canada: The role of mobility impediments and past online shopping experience. *Travel Behaviour and Society, 25*, 133–143. https://doi.org/10.1016/j.tbs.2021.07.001

BfArM. (n. d.). *Arzneimittelinformationssystem AMIce [Medicinal Products Information System AMIce]*. Bundesinstitut für Arzneimittel und Medizinprodukte. Retrieved 06.04.2025 from https://www.bfarm.de/DE/Arzneimittel/Arzneimittelinformationen/Arzneimittel-recherchieren/AMIce/_node.html

BfR. (2025). *Health assessment of food supplements*. Bundesinstitut für Risikobewertung. Retrieved 06.04.2025 from https://www.bfr.bund.de/en/health_assessment_of_food_supplements-736.html

BfR. (2013). *Risikobewertung von Pflanzen und pflanzlichen Zubereitungen. 2., ergänzte Auflage [Risk assessment of plants and herbal preparations. 2nd, amended edition]*. Bundesinstitut für Risikobewertung. Retrieved from https://www.bfr.bund.de/cm/350/risikobewertung-von-pflanzen-und-pflanzlichen-zubereitungen-ergaenzte-auflage.pdf

BfR. (2015). *Nahrungsergänzungsmittel, die Dinitrophenol (DNP) enthalten, können zu schweren Vergiftungen bis hin zu Todesfällen führen. Aktualisierte Mitteilung Nr. 046/2015 des BfR vom 26. November 2015 [Food supplements containing dinitrophenol (DNP) can lead to severe poisoning and even death. Updated Communication No. 046/2015 of the BfR from 26 November 2015]*. Bundesinstitut für Risikobewertung. Retrieved from https://www.bfr.bund.de/cm/343/nahrungsergaenzungsmittel-die-dinitrophenol-dnp-enthalten-koennen-zu-schweren-vergiftungen-bis-hin-zu-todesfaellen-fuehren.pdf

BfR. (2020). *Cholesterinsenkung mit Folgen: Nahrungsergänzungsmittel mit Rotschimmelreis nur nach ärztlicher Rücksprache einnehmen. Stellungnahme Nr. 003/2020 des BfR vom 15. Januar 2020 [Cholesterol reduction with consequences: Only take food supplements containing red mould rice after consulting a doctor. Opinion No. 003/2020 of the BfR of 15 January 2020]*. Bundesinstitut für Risikobewertung. Retrieved from https://mobil.bfr.bund.de/cm/343/cholesterinsenkung-mit-folgen-nahrungsergaenzungsmittel-mit-rotschimmelreis-nur-nach-aerztlicher-ruecksprache-einnehmen.pdf

BfR. (2021). *BfR-Verbrauchermonitor 2021. Spezial Vitamine als Nahrungsergänzungsmittel [BfR Consumer Monitor 2021: Special Vitamins as food supplements]*. Bundesinstitut für Risikobewertung. https://www.bfr.bund.de/cm/350/bfr-verbrauchermonitor-2021-spezial-vitamine-als-nahrungsergaenzungsmittel.pdf

Bilia, A. R. (2015). Herbal Medicinal Products versus Botanical-Food Supplements in the European market: State of Art and Perspectives. *Nat Prod Commun*, *10*(1), 125–131.

Blasius, H. (2019, 25.06.2019). *Gefährliche Diätpillen. Briten warnen vor DNP zum Abnehmen [Dangerous diet pills. British warn against DNP for weight loss]*. Deutsche Apotheker Zeitung. Retrieved 06.04.2025 from https://www.deutsche-apotheker-zeitung.de/news/artikel/2019/06/25/briten-warnen-vor-dnp-zum-abnehmen

Blitstein, J. L., Frentz, F., & Jilcott Pitts, S. B. (2020). A mixed-method examination of reported benefits of online grocery shopping in the United States and Germany: Is health a factor? *Journal of Food Products Marketing, 26*(3), 212–224. https://doi.org/10.1080/10454446.2020.1754313

BLV. (2024). *Information letter 2021/7.1: Self-supervision of non-regulated other substances in food supplements*. Bern: Bundesamt für Lebensmittelsicherheit und Veterinärwesen. Retrieved from https://www.blv.admin.ch/blv/de/home/lebensmittel-und-ernaehrung/lebensmittelsicherheit/einzelne-lebensmittel/nahrungsergaenzungsmittel.html#235_1718108019775__content_blv_de_home_lebensmittel-und-ernaehrung_lebensmittelsicherheit_einzelne-lebensmittel_nahrungsergaenzungsmittel_jcr_content_par_tabs

BMG, & BMELV. (2012). *Gemeinsamer Erlass des Bundesministeriums für Gesundheit und des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz über die Einrichtung einer Gemeinsamen Expertenkommission - Kommission zur Einstufung von Borderline-Stoffen, die als Lebensmittel oder Lebensmittelzutat in den Verkehr gebracht werden [Joint decree of the Federal Ministry of Health and the Federal Ministry of Food, Agriculture and Consumer Protection on the establishment of a Joint Commission of Experts on the Classification of Borderline Substances Placed on the Market as Food or Food Ingredients]*. Berlin, Bonn: Bundesministerium für Gesundheit, Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz. Retrieved from https://www.bvl.bund.de/SharedDocs/Downloads/01_Lebensmittel/expertenkommission/errichtungserlass.pdf?__blob=publicationFile&v=4

Büchter, B., Kuhr, C., & Schreiber, G. A. (2011). Pilotprojekt zur amtlichen Kontrolle des Handels mit Lebensmitteln im Internet. *J Verbr Lebensm*, *6*(3), 375–380. https://doi.org/10.1007/s00003-011-0700-9

BVL. (2020). *Stofflisten des Bundes und der Bundesländer. Pflanzenliste - Einträge L-Z, 2. Auflage, Oktober 2020 [Lists of Substances of the Federal Government and the Federal State Authorities. List of Plants - entries L-Z, 2nd edition, October 2020]*. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit. https://www.bvl.bund.de/SharedDocs/Berichte/08_Stoffliste_Bund_Bundeslaender/Pflanzenliste_Eintraege_L-Z_%202_Aufl_10_2020.html;jsessionid=6CDCD9B9BD9D547AE89FA8C104BBC009.internet951?nn=11035366

BVL. (2023). *Common Central Unit "Control of Food, Feed, Cosmetics, Consumer Products and Tobacco Products traded on the Internet". Annual Report 2022*. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit. https://www.bvl.bund.de/SharedDocs/Downloads/01_Lebensmittel/Internethandel/Annual-Report_2022_G@zielt.pdf;jsessionid=0A59D1E48B2A912D2690F76C7827BB15.internet971?__blob=publicationFile&v=2

BVL. (2024). *'Common Central Unit for Control of internet trade in products covered by the Food and Feed Code and tobacco products' Annual Report 2023*. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit. https://www.bvl.bund.de/SharedDocs/Downloads/01_Lebensmittel/Internethandel/Annual-Report_2023_G@zielt.pdf;jsessionid=D0370971494D50028905DA1FA4DE7B40.internet952?__blob=publicationFile&v=2

BVL. (2025). *Preface to the Lists of Substances of the Federal Government and the Federal State Authorities. In co-operation with experts from Germany, Austria and Switzerland. 3rd edition*. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit. https://www.bvl.bund.de/SharedDocs/Berichte/08_Stoffliste_Bund_Bundeslaender/Preface_ListsOfSubstances_3rd_edition_Febr2025.pdf?__blob=publicationFile&v=4

BVL, & BfArM. (2020). *Gemeinsame Expertenkommission zur Einstufung von Stoffen. Stellungnahme zur Einstufung von Produkten der ayurvedischen Tradition (01/2020) [Joint Commission of Experts on the Classification of Substances. Statement on the classification of products of the Ayurvedic tradition (01/2020)]*. Berlin, Bonn: Bundesamt für Verbraucherschutz und Lebensmittelsicherheit, Bundesinstitut für Arzneimittel und Medizinprodukte. Retrieved from https://www.bvl.bund.de/SharedDocs/Downloads/01_Lebensmittel/expertenkommission/Stellungnahme_Ayurveda.pdf;jsessionid=E032E2E7F940181F91A998B9967972F3.internet001?__blob=publicationFile&v=3

Carlsohn, A., & Steinhorst, L. (2018). Fragen Sie Ihren Arzt oder Apotheker? Gesundheitliche und juristische Aspekte des Konsums von Nahrungsergänzungsmitteln aus dem Internet [Consult Your Physician or Health Care Provider? Health and Legal Aspects Regarding the Use of Dietary Supplements Offered in the World Wide Web]. *Sportverletzung-Sportschaden*, *32*(4), 264–271. https://doi.org/10.1055/a-0753-7694

Comans, C. (2015). Onlinehandel mit Lebensmitteln – Mit den Projekten „ELKE" und „G@zielt" auf dem Weg zu einer funktionierenden Überwachung des Onlinehandels. *J Verbr Lebensm*, *10*(2), 109–116. https://doi.org/10.1007/s00003-014-0926-4

Czepielewska, E., Makarewicz-Wujec, M., Różewski, F., Wojtasik, E., & Kozlowska-Wojciechowska, M. (2018). Drug adulteration of food supplements: A threat to public health in the European Union? *Regul Toxicol Pharmacol*, *97*, 98–102. https://doi.org/10.1016/j.yrtph.2018.06.014

Dannenberg, P., Fuchs, M., Riedler, T., & Wiedemann, C. (2020). Digital transition by COVID-19 pandemic? The German food online retail. *Tijdschrift voor Economische en Sociale Geografie, 111*(3), 543–560. https://doi.org/10.1111/tesg.12453

Decke, J., & Seifert, R. (2025). Market analysis of vitamin C-containing dietary supplements in Germany and the USA: Consumer information and risks and benefits. *Naunyn Schmiedebergs Arch Pharmacol*, *398*, 15807–15823. https://doi.org/10.1007/s00210-025-04248-y

Dederichs, S., & Dannenberg, P. (2021). Spatial change in German online food retailing: Examples from brick-and-mortar, pure-play and combined e-commerce. *Raumforsch Raumordn*, *79*(6), 590–605. https://doi.org/10.14512/rur.102

Di Pinto, A., Mottola, A., Marchetti, P., Savarino, A., & Tantillo, G. (2019). Fraudulent species substitution in e-commerce of protected denomination origin (PDO) products. *Journal of Food Composition and Analysis, 79*, 143–147. https://doi.org/10.1016/j.jfca.2019.03.018

DTU Fødevareinstituttet. (2020). *Risikovurdering af roden fra Withania somnifera [Risk assessment of Withania somnifera root]*. Retrieved from https://foedevarestyrelsen.dk/Media/637171962718095885/Withania%20somnifera%20risikovurdering%2015%20maj%202020-a.pdf

East, R. (2022). Online Grocery Sales after the Pandemic. *Int J Mark Res*, *64*(1), 13–18. https://doi.org/10.1177/14707853211055047

EFSA ANS Panel, Younes, M., Aggett, P., Aguilar, F., Crebelli, R., Dusemund, B., Filipič, M., Frutos, M. J., Galtier, P., Gott, D., Gundert-Remy, U., Kuhnle, G. G., Lambré, C., Leblanc, J. C., Lillegaard, I. T., Moldeus, P., Mortensen, A., Oskarsson, A., Stankovic, I.,. . Wright, M. (2018). Scientific opinion on the safety of monacolins in red yeast rice. *EFSA J*, *16*(8), Article e05368. https://doi.org/10.2903/j.efsa.2018.5368

EFSA NDA Panel, Turck, D., Bohn, T., Castenmiller, J., De Henauw, S., Hirsch-Ernst, K. I., Maciuk, A., Mangelsdorf, I., McArdle, H. J., Naska, A., Pelaez, C., Pentieva, K., Siani, A., Thies, F., Tsabouri, S., Vinceti, M., Cubadda, F., Frenzel, T., Heinonen, M.,. . Knutsen, H. K. (2022). Statement on safety of cannabidiol as a novel food: data gaps and uncertainties. *EFSA J*, *20*(6), Article e07322. https://doi.org/10.2903/j.efsa.2022.7322

EFSA NDA Panel, Turck, D., Bohn, T., Cámara, M., Castenmiller, J., De Henauw, S., Hirsch-Ernst, K. I., Jos, Á., Mangelsdorf, I., McNulty, B., Naska, A., Pentieva, K., Siani, A., Thies, F., Matijević, L., Martinez, S. V., & Maciuk, A. (2025). Scientific Opinion on additional scientific data related to the safety of monacolins from red yeast rice submitted pursuant to Article 8(4) of Regulation (EC) No 1925/2006. *EFSA J*, *23*(2), Article e9276. https://doi.org/10.2903/j.efsa.2025.9276

EFSA ANS Panel, Younes, M., Aggett, P., Aguilar, F., Crebelli, R., Filipič, M., Frutos, M. J., Galtier, P., Gott, D., Gundert-Remy, U., Kuhnle, G. G., Lambré, C., Leblanc, J. C., Lillegaard, I. T., Moldeus, P., Mortensen, A., Oskarsson, A., Stankovic, I., Waalkens-Berendsen, I.,. . Wright, M. (2018). Safety of hydroxyanthracene derivatives for use in food. EFSA J, 16(1), Article e05090. https://doi.org/10.2903/j.efsa.2018.5090

EFSA ANS Panel. (2013b). Scientific Opinion on the evaluation of the safety in use of Yohimbe (Pausinystalia yohimbe (K. Schum.) Pierre ex Beille). *EFSA J*, *11*(7), Article 3302. https://doi.org/10.2903/j.efsa.2013.3302

EFSA. (2025a, 31.03.2025). *Compendium of botanicals. Botanical Summary Report*. European Food Safety Authority. Retrieved 06.04.2025 from https://www.efsa.europa.eu/en/microstrategy/botanical-summary-report

EFSA. (n. d.). *Questions on hold Botanical claims.* European Food Safety Authority. https://www.efsa.europa.eu/sites/default/files/2021-06/questions-on-hold-botanical-claims.xlsx

EFSA. (2025b, 04.03.2025). *Food supplements*. European Food Safety Authority. Retrieved 06.04.2025 from https://www.efsa.europa.eu/en/topics/topic/food-supplements

EFSA ANS Panel. (2013a). Scientific Opinion on safety evaluation of Ephedra species for use in food. *EFSA J*, *11*(11), Article 3467. https://doi.org/10.2903/j.efsa.2013.3467

EFSA. (2024, 05.08.2024). *Dietary reference values*. European Food Safety Authority. Retrieved 06.04.2025 from https://www.efsa.europa.eu/en/topics/topic/dietary-reference-values

EFSA. (2021, 03.03.2021). *Compendium of botanicals*. European Food Safety Authority. Retrieved 06.04.2025 from https://www.efsa.europa.eu/en/data-report/compendium-botanicals

EMA. (n. d.). *Committee on Herbal Medicinal Products (HMPC)*. European Medicines Agency. Retrieved 06.04.2025 from https://www.ema.europa.eu/en/committees/committee-herbal-medicinal-products-hmpc

EMA HMPC. (2015a). *Assessment report on Serenoa repens (W. Bartram) Small, fructus*. European Medicines Agency - Committee on Herbal Medicinal Products. https://www.ema.europa.eu/en/documents/herbal-report/final-assessment-report-serenoa-repens-w-bartram-small-fructus_en.pdf

EMA HMPC. (2015b). *European Union herbal monograph on Serenoa repens (W. Bartram) Small, fructus*. European Medicines Agency - Committee on Herbal Medicinal Products. https://www.ema.europa.eu/en/documents/herbal-monograph/final-european-union-herbal-monograph-serenoa-repens-w-bartram-small-fructus_en.pdf

Engel, E., Gell, S., Heiss, R., & Karsay, K. (2024). Social media influencers and adolescents' health: A scoping review of the research field. *Social Science & Medicine, 340*, Article Article 116387. https://doi.org/10.1016/j.socscimed.2023.116387

European Commission. (2023c, 18.10.2023). *Food and Feed Information Portal Database. EU Novel Food status Catalogue. Epimedium grandiflorum*. Retrieved 06.04.2025 from https://ec.europa.eu/food/food-feed-portal/screen/novel-food-catalogue/search

European Commission. (2023d, 21.05.2023). *Food and Feed Information Portal Database. EU Novel Food status Catalogue. Epimedium sagitattum*. Retrieved 06.04.2025 from https://ec.europa.eu/food/food-feed-portal/screen/novel-food-catalogue/search

European Commission. (2024). *2023 Annual Report. Alert and Cooperation Network*. https://food.ec.europa.eu/document/download/911d49f2-b3ef-4752-8ea3-5f20dbbe9945_en?filename=acn_annual-report_2023.pdf

European Commission. (2025a). *Food and Feed Alert Notifications [dataset]*. https://data.europa.eu/data/datasets/restored_rasff?locale=en

European Commission. (n. d.-c). *Food and Feed Information Portal Database. Health Claims*. Retrieved 07.04.2025 from https://ec.europa.eu/food/food-feed-portal/screen/health-claims/eu-register

European Commission. (n. d.-a). *The EU Agri-Food Fraud Network. Reports and publications*. Retrieved 16.03.2026 from https://food.ec.europa.eu/food-safety/eu-agri-food-fraud-network/reports-and-publications_en

European Commission. (n. d.-b). *Food and Feed Information Portal Database. EU Novel Food status Catalogue*. European Commission. Retrieved 07.04.2025 from https://ec.europa.eu/food/food-feed-portal/screen/novel-food-catalogue/search

European Commission. (2023b, 21.05.2023). *Food and Feed Information Portal Database. EU Novel Food status Catalogue. Epimedium brevicornum Maxim*. Retrieved 06.04.2025 from https://ec.europa.eu/food/food-feed-portal/screen/novel-food-catalogue/search

European Commission. (n. d.-d). *Food safety - vitamins and minerals added to food (minimum and maximum levels)*. Retrieved 07.04.2025 from https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12750-Food-safety-vitamins-and-minerals-added-to-food-minimum-and-maximum-levels-_en

European Commission. (2025b, 07.04.2025). *Public Health - Union Register of medicinal products. General index of products by active substance*. Retrieved 07.04.2025 from https://ec.europa.eu/health/documents/community-register/html/reg_index_inn.htm

European Commission. (2023a). *2022 Annual Report. Alert and Cooperation Network*. Publications Office of the European Union. https://food.ec.europa.eu/document/download/499ffcf1-6c99-43ec-8905-5ff3e812eeb2_en?filename=acn_annual-report_2022.pdf

European Commission. (2020). *The application of the mutual recognition regulation to food supplements. Training material for authorities*. European Commission. Retrieved from https://ec.europa.eu/docsroom/documents/45185

European Commission. (2021). *Commission Opinion of 30.9.2021 on the application of the principle of mutual recognition and the requirements of Regulation (EU) 2019/515 regarding food supplements based on Article 8 of Regulation (EU) 2019/515 on the mutual recognition of goods*. (C(2021) 6950 final). Brussels: European Commission. Retrieved from https://ec.europa.eu/docsroom/documents/47254

European Commission. (2019). *The Rapid Alert System for Food and Feed. 2018 Annual Report*. Publications Office of the European Union. https://data.europa.eu/doi/10.2875/914558

European Commission. (2018b). *Overview report. Official controls on internet sales of food in EU Member States* (Ref. Ares(2019)133219). Publications Office of the European Union. https://data.europa.eu/doi/10.2772/57153

European Commission. (2018a). *The first EU coordinated control plan on online offered food products. Analysis of the main outcome of the implementation of the Commission Recommendation on a coordinated control plan on the official control of certain foods marketed through the Internet* (Ref. Ares(2018)893577). https://food.ec.europa.eu/system/files/2018-02/oc_oof_analysis_main_outcome_en.pdf

European Commission. (2015b). *The Rapid Alert System for Food and Feed. 2014 annual report*. Publications Office of the European Union. https://data.europa.eu/doi/10.2875/945461

European Commission. (2015a). *Overview report. Controls on food supplements in Member States*. Publications Office of the European Union. https://data.europa.eu/doi/10.2772/5906

European Commission. (2013). *The Rapid Alert System for Food and Feed. 2012 annual report*. Publications Office of the European Union. https://data.europa.eu/doi/10.2772/48887

European Commission. (2010). *Guidance document. The application of the Mutual Recognition Regulation to food supplements*. Brussels: European Commission. Retrieved from https://ec.europa.eu/docsroom/documents/13481

European Commission. (2008). *Report from the Commission to the Council and the European Parliament on the use of substances other than vitamins and minerals in food supplements*. (COM(2008) 824 final). Brussels: European Commission. Retrieved from https://food.ec.europa.eu/document/download/0f0ac6ad-585d-45a7-b41a-abd0a62711bf_en?filename=labelling_nutrition-supplements-comm_2008_0824_en.pdf

European Advisory Services. (2007). *The use of substances with nutritional or physiological effect other than vitamins and minerals in food supplements. Study undertaken for DG SANCO, European Commission*. https://food.ec.europa.eu/document/download/bc1927f5-9eba-4ed1-ba79-d70c38f9cffc_en?filename=labelling_nutrition-supplements-2007_a540169_study_other_substances_en.pdf

European Commission. (n. d.-f). *RASFF Window*. Retrieved 07.04.2025 from https://webgate.ec.europa.eu/rasff-window/screen/search

European Commission. (2022). *2021 Annual Report. Alert and Cooperation Network*. Publications Office of the European Union. https://food.ec.europa.eu/document/download/e8b14245-1f30-4f2b-bf5c-5e70e525e753_en?filename=acn_annual-report_2021-final.pdf

European Commission. (n. d.-e). *Novel Food status Catalogue (New)*. Retrieved 07.04.2025 from https://food.ec.europa.eu/food-safety/novel-food/novel-food-status-catalogue_en

Eurostat. (2025b, 20.02.2025). *Online shopping in the EU keeps growing*. Retrieved 09.04.2025 from https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20250220-3

Eurostat. (2025a). *Demography of Europe – 2025 edition*. Retrieved 16.03.2026 from https://ec.europa.eu/eurostat/web/interactive-publications/demography-2025

Fuhrmann, S., Klein, B., & Fleischfresser, A. (Eds.). (2020). *Arzneimittelrecht: Handbuch für die Rechtspraxis [Pharmaceutical law: Manual for legal practice]* (3rd ed.). Nomos Verlag.

Gaudiano, M. C., Manna, L., Bartolomei, M., Rodomonte, A. L., Bertocchi, P., Antoniella, E., Romanini, L., Alimonti, S., Rufini, L., & Valvo, L. (2016). Health risks related to illegal and on-line sale of drugs and food supplements: results of a survey on marketed products in Italy from 2011 to 2013. *Ann Ist Super Sanità*, *52*(1), 128–132. https://doi.org/10.4415/ANN_16_01_21

Gee, I. M., Davidson, F. T., Speetles, B. L., & Webber, M. E. (2019). Deliver Me from food waste: Model framework for comparing the energy use of meal-kit delivery and groceries. *Journal of Cleaner Production*, *236*, Article 117587. https://doi.org/10.1016/j.jclepro.2019.07.062

Geurden, B., Cant, J., & Beckers, J. (2022). Food Accessibility in the Suburbs of the Metropolitan City of Antwerp (Belgium): A Factor of Concern in Local Public Health and Active and Healthy Aging. *Int J Environ Res Public Health*, *19*(23), Article 15754. https://doi.org/10.3390/ijerph192315754

Harris, P., Dall'Olmo Riley, F., Riley, D., & Hand, C. (2017). Online and store patronage: A typology of grocery shoppers. *International Journal of Retail & Distribution Management, 45*(4), 419–445. https://doi.org/10.1108/ijrdm-06-2016-0103

Heads of Food Safety Agencies. (2024). *First report of the HoA working group "Food Supplements"*. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit. https://www.bvl.bund.de/SharedDocs/Downloads/01_Lebensmittel/Internationales/report_HoA_WG_FS-en.pdf;jsessionid=2822F69A74FAF659B93BE4CB64BAD0F9.internet941?__blob=publicationFile&v=6

Holle, M., Hüttebräuker, A., Konnertz-Häußler, C., Conte-Salinas, N., & Guttau, T. (2018). *HCVO: Verordnung (EG) Nr. 1924/2006 über nährwert- und gesundheitsbezogene Angaben über Lebensmittel: Kommentar [HCVO: Regulation (EC) No 1924/2006 on nutrition and health claims made on foods: Legal commentary]*. C. H. Beck.

Jilcott Pitts, S. B., Ng, S. W., Blitstein, J. L., Gustafson, A., & Niculescu, M. (2018). Online grocery shopping: promise and pitfalls for healthier food and beverage purchases. *Public Health Nutr*, *21*(18), 3360–3376. https://doi.org/10.1017/s1368980018002409

Kelly, B. E., K.; Van Vooren, B.; Bogaert, P. (2024, 22.11.2024). *EU Court Overturns EU-wide Botanical Food Ban*. Covington. Retrieved 07.04.2024 from https://www.globalpolicywatch.com/2024/11/eu-court-overturns-eu-wide-botanical-food-ban/

Koncz, D., Tóth, B., Roza, O., & Csupor, D. (2020). A Systematic Review of the European Rapid Alert System for Food and Feed: Tendencies in Illegal Food Supplements for Weight Loss. *Front Pharmacol*, *11*, Article 611361. https://doi.org/10.3389/fphar.2020.611361

Körner, H. H., Patzak, J., Volkmer, M., & Fabricius, J. (2022). *Betäubungsmittelgesetz: Betäubungsmittel-Verschreibungsverordnung, Arzneimittelgesetz, Neue-psychoaktive-Stoffe-Gesetz, Anti-Doping-Gesetz, Grundstoffüberwachungsgesetz [Narcotics Act: Narcotic Drugs Prescription Ordinance, Medicinal Products Act, New Psychoactive Substances Act, Anti-Doping Act, Drug Precursor Monitoring Act]* (10 ed). C. H. Beck.

Koziolek, M., Alcaro, S., Augustijns, P., Basit, A. W., Grimm, M., Hens, B., Hoad, C. L., Jedamzik, P., Madla, C. M., Maliepaard, M., Marciani, L., Maruca, A., Parrott, N., Pávek, P., Porter, C. J. H., Reppas, C., van Riet-Nales, D., Rubbens, J., Statelova, M.,. . Corsetti, M. (2019). The mechanisms of pharmacokinetic food-drug interactions - A perspective from the UNGAP group. *Eur J Pharm Sci*, *134*, 31–59. https://doi.org/10.1016/j.ejps.2019.04.003

Krejbich, P., Ruppenthal, T., & Birringer, M. (2023). Digitaler Lebensmitteleinkauf. Entwicklungen und Perspektiven des Onlinehandels [Online grocery shopping. Developments and prospects for online retail]. *Ernahr Umsch*, *70*(6), M362-M375.

Krejbich, P., & Birringer, M. (2022). The self-administered use of complementary and alternative medicine (CAM) supplements and antioxidants in cancer therapy and the critical role of Nrf-2-A systematic review. *Antioxidants, 11*(11), Article Article 2149. https://doi.org/10.3390/antiox11112149

Krewinkel, A., Sünkler, S., Lewandowski, D., Finck, N., Tolg, B., Kroh, L. W., Schreiber, G. A., & Fritsche, J. (2016). Concept for automated computer-aided identification and evaluation of potentially non-compliant food products traded via electronic commerce. *Food Control, 61*, 204–212. https://doi.org/10.1016/j.foodcont.2015.09.039

Krewinkel, A., Tolg, B., & Fritsche, J. (2011). Online grocery trade and strategies to control the virtual food market. *J Verbr Lebensm*, *6*(3), 395–400. https://doi.org/10.1007/s00003-011-0701-8

Kuchheuser, P., & Birringer, M. (2022a). Evaluation of specific import provisions for food products from third countries based on an analysis of RASFF notifications on pesticide residues. *Food Control, 133*, Article Article 108581. https://doi.org/10.1016/j.foodcont.2021.108581

Kuchheuser, P., & Birringer, M. (2022b). Pesticide residues in food in the European Union: Analysis of notifications in the European Rapid Alert System for Food and Feed from 2002 to 2020. *Food Control*, *133*, Article 108575. https://doi.org/10.1016/j.foodcont.2021.108575

Kuchheuser, P., Dünnebier, K., Hoffbauer, J., Butschke, A., & Birringer, M. (2018). Warnmeldungen zu Lebensmittelkontaktmaterialien im Europäischen Schnellwarnsystem RASFF von 2012 bis 2017 [Alerts notifications on food contact materials in the European Rapid Alert System RASFF from 2012 to 2017]. *J Consum Prot Food Saf*, *13*(4), 347–357. https://doi.org/10.1007/s00003-018-1182-9

Lachenmeier, D. W., Löbell-Behrends, S., Böse, W., & Marx, G. (2013). Does European Union food policy privilege the internet market? Suggestions for a specialized regulatory framework. *Food Control*, *30*(2), 705–713. https://doi.org/10.1016/j.foodcont.2012.07.034

Leal, S., Sousa, A. C., Valdiviesso, R., Padua, I., Goncalves, V. M. F., & Ribeiro, C. (2025). Exploring Factors Associated with Health Status and Dietary Supplement Use Among Portuguese Adults: A Cross-Sectional Online Survey. *Healthcare*, *13*(7), Article 769. https://doi.org/10.3390/healthcare13070769

Li, C., Mirosa, M., & Bremer, P. (2020). Review of Online Food Delivery Platforms and their Impacts on Sustainability. *Sustainability*, *12*(14), Article 5528. https://doi.org/10.3390/su12145528

Livsmedelsverket. (2016). *Samordning och förbättring av kontrollen av e-handel. Regeringsuppdrag [Coordination and improvement of the control of e-commerce. Government assignment]*. Retrieved from https://www.livsmedelsverket.se/globalassets/publikationsdatabas/rapporter/2016/rapport-regeringsuppdrag-e-handel.pdf

Low, T. Y., Wong, K. O., Yap, A. L. L., De Haan, L. H. J., & Rietjens, I. (2017). The Regulatory Framework Across International Jurisdictions for Risks Associated with Consumption of Botanical Food Supplements. *Compr Rev Food Sci Food Saf*, *16*(5), 821–834. https://doi.org/10.1111/1541-4337.12289

Lu, L., & Reardon, T. (2018). An Economic Model of the Evolution of Food Retail and Supply Chains from Traditional Shops to Supermarkets to E-Commerce. *Am J Agric Econ*, *100*(5), 1320–1335. https://doi.org/10.1093/ajae/aay056

Mackintosh, T. (2020, 08.09.2020). *Man died after taking 'toxic' DNP slimming pills*. British Broadcasting Corporation. Retrieved 07.04.2025 from https://www.bbc.com/news/uk-england-london-54050785

McKeown, M. (2023, 02.06.2023). *Why did Denmark ban Ashwagandha?* McGill University, Office for Science and Society. Retrieved 07.04.2025 from https://www.mcgill.ca/oss/article/critical-thinking-health-and-nutrition/why-did-denmark-ban-ashwagandha

Melzig, M. F., & Hiller, K. (2023). *Lexikon der Arzneipflanzen und Drogen [Encyclopaedia of medicinal plants and drugs]* (3rd ed.). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-64800-1

Murphy, S. I., Chen, R., Belias, A. M., Chen, W., Zhang, L. Q., Sunil, S., Bulut, E., Li, Y., Wiedmann, M., & Ivanek, R. (2022). Growth and survival of aerobic and Gram-negative bacteria on fresh spinach in a Chinese supply chain from harvest through distribution and refrigerated storage. *Int J Food Microbiol*, *370*, Article 109639. https://doi.org/10.1016/j.ijfoodmicro.2022.109639

Nsubuga, J., Baugher, J., Dahl, E., Schwensohn, C., Blessington, T., Aguillon, R., Whitney, B., Goldman, S., Brewster, M., Humbert, J., Crosby, A., Gieraltowski, L., Singleton, L. S., & Hilgendorf, J. (2022). Multistate Outbreak Investigation of Salmonella Infections Linked to Kratom: A Focus on Traceback, Laboratory, and Regulatory Activities. *J Food Prot*, *85*(5), 747–754. https://doi.org/10.4315/JFP-21-319

Palasamudram Shekar, S., Rojas, E. E., D'Angelo, C. C., Gillenwater, S. R., & Martinez Galvis, N. P. (2019). Legally Lethal Kratom: A Herbal Supplement with Overdose Potential. *J Psychoact Drugs*, *51*(1), 28–30. https://doi.org/10.1080/02791072.2018.1562591

Petroczi, A., Taylor, G., & Naughton, D. P. (2011). Mission impossible? Regulatory and enforcement issues to ensure safety of dietary supplements. *Food Chem Toxicol*, *49*(2), 393–402. https://doi.org/10.1016/j.fct.2010.11.014

Petróczi, A., Ocampo, J. A. V., Shah, I., Jenkinson, C., New, R., James, R. A., Taylor, G., & Naughton, D. P. (2015). Russian roulette with unlicensed fat-burner drug 2,4-dinitrophenol (DNP): Evidence from a multidisciplinary study of the internet, bodybuilding supplements and DNP users. *Substance Abuse Treatment, Prevention, and Policy, 10*, 39.

Pettigrew, S., Davies, T., O'Brien, P., Sträuli, B., Petticrew, M., & Bowden, J. (2024). The absence of mandatory pregnancy warning labels in online alcohol purchasing contexts. *Drug Alcohol Rev*, *43*(5), 1178–1182. https://doi.org/10.1111/dar.13836

Pigłowski, M. (2020). Food hazards on the European Union market: The data analysis of the Rapid Alert System for Food and Feed. *Food Sci Nutr*, *8*(3), 1603–1627. https://doi.org/10.1002/fsn3.1448

Plana Casado, M. J. (2021). *E-FOOD: Closing the Online Enforcement Gap in the EU Platform Economy*. Springer. https://doi.org/10.1007/978-3-030-79504-7

Pomeranz, J. L., Cash, S. B., Springer, M., Del Giudice, I. M., & Mozaffarian, D. (2022). Opportunities to address the failure of online food retailers to ensure access to required food labelling information in the USA. *Public Health Nutr*, *25*(5), 1–9, Article Pii s1368980021004638. https://doi.org/10.1017/S1368980021004638

Purnhagen, K. P., & Molitorisová, A. (2022). Public and private enforcement in European Union food law. *European Journal of Risk Regulation, 13*(3), 464–476. https://doi.org/10.1017/err.2021.59

Ricke, J. N., & Seifert, R. (2024). Disinformation on dietary supplements by German influencers on Instagram. *Naunyn Schmiedebergs Arch Pharmacol*, *398*, 5629–5647. https://doi.org/10.1007/s00210-024-03616-4

Salheiser, A. (2014). Natürliche Daten: Dokumente [Natural data: Documents]. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung [Handbook of empirical social research methods]* (pp. 813–827). Springer VS. https://doi.org/10.1007/978-3-531-18939-0_62

Schebesta, H., & Purnhagen, K. (2024). *EU Food Law*. Oxford University Press.

Siozios, S., Massa, A., Parr, C. L., Verspoor, R. L., & Hurst, G. D. D. (2020). DNA barcoding reveals incorrect labelling of insects sold as food in the UK. *PeerJ*, *8*, Article e8496. https://doi.org/10.7717/peerj.8496

Sproll, C., Walch, S. G., & Lachenmeier, D. W. (2025). Psychotrope Stoffe und Botanicals: Nicht regulierte Substanzen als Herausforderung für den Konsumierendenschutz. *Dtsch Lebensm-Rundsch*, *121*(3), 94–102. https://doi.org/10.5281/zenodo.15491826

Statista. (2022, 13.05.2022). *Umsatz mit Nahrungsergänzungsmitteln in Deutschland nach Vertriebslinien im Jahr 2022 (in Millionen Euro) [Sales of food supplements in Germany by distribution channel in 2022 (in million euros)]*. Data collected by Nielsen IQ, published in Lebensmittel Zeitung No. 19, 13.05.2022, p. 29. https://de.statista.com/statistik/daten/studie/1308546/umfrage/umsatz-mit-nahrungsergaenzungsmitteln-nach-vertriebslinien/

Statista. (2025a). *Market Insights. Vitamins & Minerals - EU-27*. Retrieved 07.04.2025 from https://www.statista.com/outlook/cmo/otc-pharmaceuticals/vitamins-minerals/eu-27?currency=EUR&locale=en

Statista. (2025b). *Market Insights. Vitamins & Minerals - Germany*. Retrieved 07.04.2025 from https://www.statista.com/outlook/cmo/otc-pharmaceuticals/vitamins-minerals/germany?currency=EUR&locale=en

Stephan, K. (2020). § 2 Zentralbegriffe des Arzneimittelrechts. I. Abgrenzung Arzneimittel/Lebensmittel [§ 2 Central concepts of pharmaceutical law. I. Differentiation between medicinal products and food]. In S. Fuhrmann, B. Klein, & A. Fleischfresser (Eds.), *Arzneimittelrecht: Handbuch für die Rechtspraxis [Pharmaceutical law: Manual for legal practice]* (3rd ed., pp. 28–108). Nomos Verlag.

Sun, Y. T., Zhang, J. T., & Li, Y. X. (2024). Realisation that online advertisements are misleading: Involvement of middle-aged and older adults with botanical dietary supplements. *Journal of Retailing and Consumer Services*, *79*, Article 103832. https://doi.org/10.1016/j.jretconser.2024.103832

Tessele, I., Dal Molin, T. R., Dognini, J., Noremberg, S., & de Carvalho, L. M. (2024). Investigation of thallium as a contaminant in dietary supplements marketed for weight loss and physical fitness. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess*, *41*(7), 800–810. https://doi.org/10.1080/19440049.2024.2354494

Thomas, S. (2018, 13.08.2018). *Deadly DNP*. UK Health Security Agency. Retrieved 07.04.2025 from https://ukhsa.blog.gov.uk/2018/08/13/deadly-dnp/

Vanhee, C., Jacobs, B., Canfyn, M., Malysheva, S. V., Willocx, M., Masquelier, J., & Van Hoorde, K. (2024). Quality Control and Safety Assessment of Online-Purchased Food Supplements Containing Red Yeast Rice (RYR). *Foods*, *13*(12), Article 1919. https://doi.org/10.3390/foods13121919

Viana, C., Zemolin, G. M., Müller, L. S., Dal Molin, T. R., Seiffert, H., & de Carvalho, L. M. (2016). Liquid chromatographic determination of caffeine and adrenergic stimulants in food supplements sold in Brazilian e-commerce for weight loss and physical fitness. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess*, *33*(1), 1–9. https://doi.org/10.1080/19440049.2015.1112040

Vida, R. G., Strauss, L. V., Bajtel, Á., Kiss, T., Csupor, D., & Fittler, A. (2023). Safety and risks of CBD oils purchased online: unveiling uncertain quality and vague health claims. *Front Pharmacol*, *14*, Article 1273540. https://doi.org/10.3389/fphar.2023.1273540

Voldnes, G., Pleym, I. E., Ageeva, T., Alm, S., Nyrud, T., & Rosnes, J. T. (2020). E-commerce of Seafood – A Review of Existing Research. *J Int Food Agribus Mark*, *33*(1), 3–35. https://doi.org/10.1080/08974438.2020.1835779

von Czettritz, P. (2020). § 24 Apothekenpflicht. B. Grundzüge der gesetzlichen Regelung der §§ 43 bis 46 AMG [§ 24 Pharmacy obligation. B. Main features of the legal regulation of §§ 43 to 46 AMG]. In S. Fuhrmann, B. Klein, & A. Fleischfresser (Eds.), *Arzneimittelrecht: Handbuch für die Rechtspraxis [Pharmaceutical law: Manual for legal practice]* (3rd ed., pp. 5–30). Nomos Verlag.

WADA. (2023). *World Anti-Doping Code. International Standard. Prohibited List 2024*. Montreal: World Anti-Doping Agency. Retrieved from https://www.wada-ama.org/sites/default/files/2023-09/2024list_en_final_22_september_2023.pdf

Wang, E. S. T. (2025). Effects of social media influencer credibility on their followers' dietary supplement evaluations and purchase intentions. *J Mark Commun*, 1–24. https://doi.org/10.1080/13527266.2025.2462991

Warda, R., Purnhagen, K., & Molitorisová, M. (2024). Has Mutual Recognition in the EU Failed?—A Legal-Empirical Analysis on the Example of Food Supplements Containing Botanicals and Other Bioactive Substances. *J Consum Policy*, *47*(3), 425–443. https://doi.org/10.1007/s10603-024-09571-0

Warda, R., Fazekaš, T., Molitorisová, M., & Purnhagen, K. (2026). The role of the public and private sectors in the EU hybrid safety governance of food supplements : A study on the example of quality issues notified in the RASFF. *J Consum Policy*, *49(2)*, 12. https://doi.org/10.1007/s10603-026-09616-6

Wei, S. H., Huang, A. S., Liao, Y. S., Liu, Y. L., & Chiou, C. S. (2014). A large outbreak of salmonellosis associated with sandwiches contaminated with multiple bacterial pathogens purchased via an online shopping service. *Foodborne Pathog Dis*, *11*(3), 230–233. https://doi.org/10.1089/fpd.2013.1669

West, B. J., & Deng, S. (2024). Authentication and Differentiation of Morinda citrifolia and Morinda coreia Fruits and Their Commercial Products. *Food Anal Methods*, *18*, 577–583. https://doi.org/10.1007/s12161-024-02748-w

Willers, G., Sangaletti, I. P., & Stefani, G. P. (2021). Analysis of characteristics and compliance with current legislation of BCAA food supplements in the brazilian market e-commerce. *Rev Bras De Nutr Esportiva*, *15*(90), 1–8.

Wyse, R., Jackson, J. K., Delaney, T., Grady, A., Stacey, F., Wolfenden, L., Barnes, C., McLaughlin, M., & Yoong, S. L. (2021). The Effectiveness of Interventions Delivered Using Digital Food Environments to Encourage Healthy Food Choices: A Systematic Review and Meta-Analysis. *Nutrients*, *13*(7), Article 2255. https://doi.org/10.3390/nu13072255

Zovi, A., Vitiello, A., Sabbatucci, M., Musazzi, U. M., Sagratini, G., Cifani, C., & Vittori, S. (2025). Food Supplements Marketed Worldwide: A Comparative Analysis Between the European and the U.S. Regulatory Frameworks. *J Diet Suppl*, *22*(1), 25–40. https://doi.org/10.1080/19390211.2024.2389397

Legislation: Germany

Arzneimittelgesetz in der Fassung der Bekanntmachung vom 12. Dezember 2005 (BGBl. I S. 3394), das zuletzt durch Artikel 2 des Gesetzes vom 23. Oktober 2024 (BGBl. 2024 I Nr. 324) geändert worden ist (AMG)

Arzneimittelverschreibungsverordnung vom 21. Dezember 2005 (BGBl. I S. 3632), die zuletzt durch Artikel 1 der Verordnung vom 3. Mai 2024 (BGBl. 2024 I Nr. 146) geändert worden ist (AMVV)

Verordnung über apothekenpflichtige und freiverkäufliche Arzneimittel in der Fassung der Bekanntmachung vom 24. September 1988 (BGBl. I S. 2150; 1989 I S. 254), die zuletzt durch Artikel 3 der Verordnung vom 21. Oktober 2020 (BGBl. I S. 2260) geändert worden ist (AMVerkRV)

European Union

Directive 2001/83/EC on the Community code relating to medicinal products for human use (2001) OJ L 311/67

Directive 2002/46/EC on the approximation of the laws of the Member States relating to food supplements (2002) OJ L 183/51

Regulation (EC) No 178/2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (2002) OJ L 31/1

Regulation (EC) No 1925/2006 on the addition of vitamins and minerals and of certain other substances to foods (2006) OJ L 404/26

Regulation (EU) 2015/2283 on novel foods, amending Regulation (EU) No 1169/2011 of the European Parliament and of the Council and repealing Regulation (EC) No 258/97 of the European Parliament and of the Council and Commission Regulation (EC) No 1852/2001 (2015) OJ L 327/1

Regulation (EU) 2017/625 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/EC and Council Decision 92/438/EEC (Official Controls Regulation) (2017) OJ L 95/1

Regulation (EU) No 1169/2011 on the provision of food information to consumers, amending Regulations (EC) No 1924/2006 and (EC) No 1925/2006 of the European Parliament and of the Council, and repealing Commission Directive 87/250/EEC, Council Directive 90/496/EEC, Commission Directive 1999/10/EC, Directive 2000/13/EC of the European Parliament and of the Council, Commission Directives 2002/67/EC and 2008/5/EC and Commission Regulation (EC) No 608/2004 (2011) OJ L 304/18

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Paula Krejbich[1,2,4] · Kai P. Purnhagen[1,3] · Marc Birringer[2,4]

✉ Paula Krejbich
Paula.Krejbich@uni-bayreuth.de

Kai P. Purnhagen
Kai.Purnhagen@uni-bayreuth.de

Marc Birringer
Marc.Birringer@oe.hs-fulda.de

1 Faculty of Life Sciences: Food, Nutrition and Health, University of Bayreuth, Kulmbach, Germany

2 Department of Nutritional, Food and Consumer Sciences, Fulda University of Applied Sciences, Fulda, Germany

3 Faculty of Law, Business & Economics, University of Bayreuth, Bayreuth, Germany

4 Wissenschaftliches Zentrum für Ernährung, Lebensmittel und nachhaltige Versorgungssysteme (ELVe), Fulda, Germany