

Review

Emerging Chemical Hazards in Animal-Derived Foods: From Public Health to Detection and Control Solutions

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ABSTRACT

Food safety systems are generally effective for known contaminants but are less prepared for chemical hazards that are not captured through routine monitoring. This challenge is particularly relevant for animal-derived foods, where hazardous chemicals may enter and change along the production chain, hindering their detection and interpretation. This review discusses the origins of emerging chemical hazards in animal-derived foods, why they can be overlooked by conventional monitoring, and strategies for integrating detection with public health frameworks. Targeted methods remain essential but are less capable of capturing low-concentration, transformed, or unexpected compounds. When combined with suspect screening and confidence-based identification, high-resolution mass spectrometry can extend detection beyond predefined targets and improve the interpretation of unexpected chemical signals. For public health practice, the value of expanded detection lies not only in identifying more chemicals but also in determining which signals require confirmation, evaluation, and consideration for future monitoring and control.

Ensuring a safe food supply remains a core public health task (1). Updated WHO estimates indicate that the burden of unsafe food extends beyond infectious diseases to chemical and allergy-related health outcomes, with chemical hazards contributing disproportionately to foodborne mortality in 2021 (2). In recent years, food safety concerns have extended beyond well-known contaminants to include chemical hazards that may not be routinely monitored or fully recognized by surveillance systems (3). Animal-derived foods, including meat, milk, eggs, and aquatic products, are widely consumed and can contribute substantially to dietary chemical exposure. Their long

production chains and complex biological matrices make them important pathways for the entry, transfer, and transformation of hazardous chemicals before consumption (4–5). Some of these hazards are not new in a chemical sense but are newly recognized within the context of animal-derived foods (6). Hazardous chemicals may originate from production-related inputs, naturally derived toxins, or environmental or industrial contamination (7–8). These hazardous substances are often present at extremely low concentrations in various forms. Furthermore, the lack of adequate toxicological and exposure data complicates interpretation (9).

Current monitoring strategies still rely heavily on the targeted analysis of predefined compounds, which is highly effective for regulated contaminants but is less suited to identify newly recognized, transformed, or previously overlooked hazards in complex food matrices (10). This review examines the origins of these hazards, why they may be overlooked during routine monitoring, and how detection and follow-up can better align with public health needs. Figure 1 summarizes the major source categories, entry pathways, monitoring targets, and potential health effects of the emerging chemical hazards discussed in this review.

SOURCES OF EMERGING CHEMICAL HAZARDS

Emerging chemical hazards in animal-derived foods do not originate from a single source (11). Some contaminants originate from animal production, whereas others enter food through animal feed or the environment. Contaminants may emerge during processing, packaging, or storage (12). In this context, "emerging" does not always refer to a newly identified chemical; it may also refer to a hazard that has not been routinely monitored or that has received limited attention in animal-derived foods.

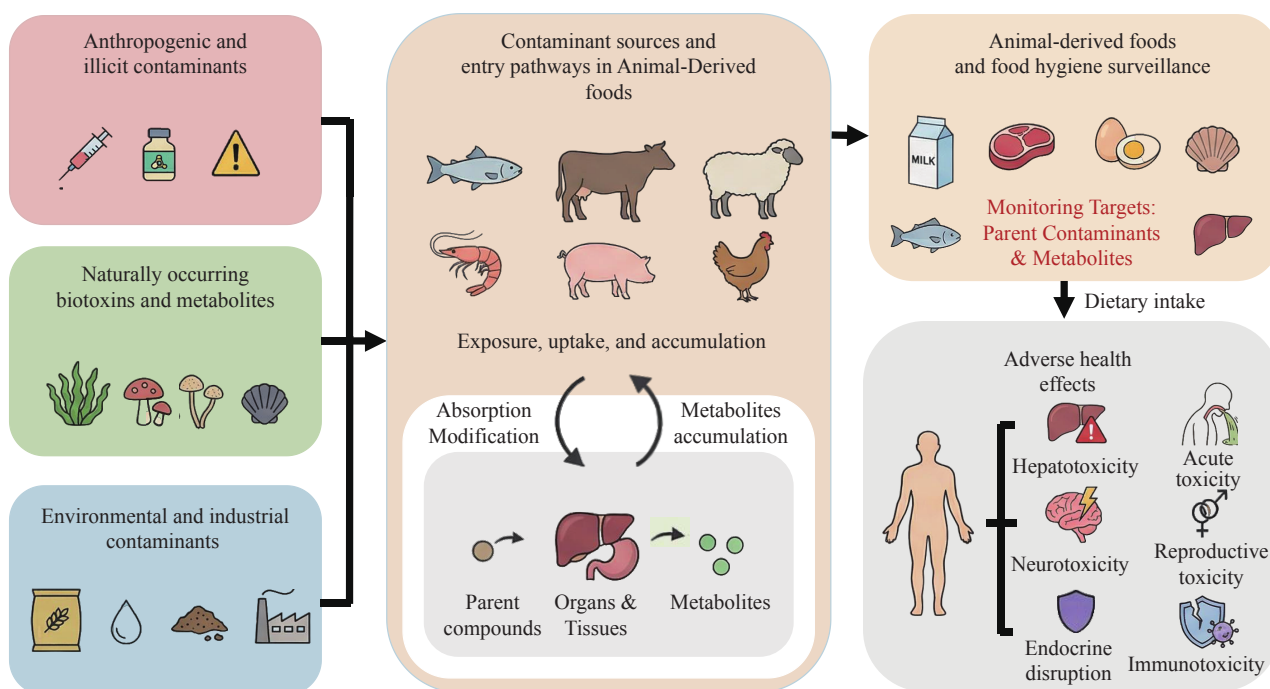


FIGURE 1. Overview of major sources, entry pathways, monitoring targets, and potential health effects of emerging chemical hazards in animal-derived foods.

Anthropogenic inputs, which include chemicals associated with animal production and other related practices, are an important category. Representative examples include anabolic steroids and other growth-promoting agents (13). Naturally derived hazards also play an important role. Some mycotoxins enter the bodies of livestock and poultry through contaminated feed (14), whereas marine biotoxins in aquatic foods may arise through trophic transfer and species-specific accumulation rather than intentional introduction (15). A third source includes environmental and industrial contaminants, such as extractables and leachables or packaging-related migrants that may enter foods during processing, storage, or material contact (16). Beyond these differences in origin and entry pathways, emerging chemical hazards may differ in their public health implications. In addition to their direct toxic effects, some environmental contaminants have been identified as potential modifiers of immune responses relevant to food allergies, particularly through their effects on epithelial barrier function, immune regulation, and the gut microbiota (17–18). Table 1 summarizes the representative categories of emerging chemical hazards in animal-derived foods, together with their main food matrices, occurrence findings, and major health concerns.

Although these hazards differ in origin, routine

monitoring does not always accurately capture them, which hinders the early detection and consistent identification of emerging chemical hazards in animal-derived foods.

LIMITATIONS OF CURRENT MONITORING APPROACHES

Current monitoring methods are effective for known contaminants but are less effective for hazards that are not routinely included in target lists or do not appear as parent compounds in food (19). This problem is especially relevant in animal-derived foods, where residues may be present as metabolites or transformation products rather than as the original chemicals. In such cases, the monitoring results may not fully reflect the actual residue profile in the food (20).

A typical challenge is monitoring modified or transformed contaminants. Modified mycotoxins are representative examples. In animal-derived foods, public health concerns are not limited to the parent toxin itself but also include metabolites or related forms generated through feed carry-over, animal metabolism, or food processing (21). These modified or conjugated forms are not always detected by routine

TABLE 1. Representative categories of emerging chemical hazards in animal-derived foods.

Category	Representative substances	Region/market	Main food matrices	Compounds/detection frequency	Major health hazards
Anthropogenic and illicit contaminants	Anabolic agents, unapproved veterinary drugs, illegal additives	Turkey (Istanbul)	Red meat samples ($n=20$) (32)	Testosterone (30%), Diethylstilbestrol (20%)	Endocrine disruption, reproductive toxicity, developmental toxicity, acute poisoning, carcinogenicity
		Global markets (nine countries)	Beef samples ($n=29$) (13)	15 anabolic steroids (20%–100%)	
		Armenia	Fish and honey samples (33)	Nitrofurans metabolites (33.3%, 44.4%)	
		Saudi Arabia	Honey samples ($n=902$) (34)	Chloramphenicol (6%)	
		South Korea	Seafood samples ($n=271$) (35)	Okadaic acid (2.3%), DTX1 (4.1%), DTX3 (9.2%)	
Naturally occurring biotoxins and metabolites	Marine biotoxins, tetrodotoxin-like compounds, plant-/fungal-derived toxins, degradation products	Spain (Galicia)	Marine invertebrate samples ($n=533$) (36)	Paralytic shellfish toxins (50%)	Acute poisoning, neurotoxicity, respiratory paralysis, hepatotoxicity, immunotoxicity, endocrine disruption
		Brazil (São Paulo)	Milk samples ($n=68$) (37)	α -zearalenol (α -ZEL) (57.4%), β -zearalenol (β -ZEL) (41.2%)	
		United States	Beef samples (38)	PFOS (25%)	
Environmental and industrial contaminants	Per- and polyfluoroalkyl substances (PFAS), endocrine-disrupting chemicals (EDCs), pharmaceuticals and personal care products (PPCPs), microplastics (MPs), etc.	China	Raw milk samples ($n=107$) (39)	PFASs (96.3%)	Immunotoxicity, developmental toxicity, endocrine disruption, reproductive toxicity, gut dysbiosis, neurotoxicity
		Pakistan	Packaged milk samples ($n=23$) (40)	BPA (52.2%)	
		Germany	Seafood samples ($n=130$) (41)	Microplastics (94%)	
		Italy	Dairy product samples ($n=28$) (42)	Microplastics (92.9%)	

monitoring and may be overlooked. Limiting surveillance to a predefined set of parent compounds may underestimate the total exposure (22–23).

Confirmation is challenging because many emerging hazards still lack reference standards and validated methods for routine screening (24), making it more difficult to move from signal detection to confident identification. This problem becomes more obvious in animal-derived foods, because proteins, lipids, and endogenous compounds can interfere with the analysis and compromise the detection of low-concentration or unexpected chemicals (25). Some hazards may remain under-recognized, not because they are absent, but because they are not effectively captured by conventional monitoring workflows.

FROM DETECTION TO PUBLIC HEALTH ACTION

Closing the gap between public health burden and

regulatory control requires more than simply adding new compounds to routine target lists (26). Improving both the detection and follow-up of emerging chemical hazards in animal-derived foods is a practical task. The primary objective is to ensure that a signal can be detected and that its significance warrants further investigation.

At the analytical level, broader screening can help identify hazards not included in routine targeted methods. High-resolution mass spectrometry, together with suspect and non-targeted screening, is becoming increasingly useful for this purpose (27). These approaches are more effective when supported by reference databases and confidence criteria, which help distinguish preliminary signals from findings that warrant confirmation (28–29). More broadly, the effective management of emerging hazards depends on linking analytical detection with interpretation and public health follow-up (30). In this process, the primary challenge is not only to detect a broader range

of chemicals but also to determine which signals are relevant to public health outcomes. For the assessment of animal-derived foods, subsequent consideration should be given to signals that repeatedly appear in the monitoring data or those related to common food categories that present reasonable toxicological concerns. When quantitative data are available, dietary exposure should be estimated by combining the occurrence levels with food consumption information. For compounds lacking established health-based guidance values, the threshold of toxicological concern approach can be used cautiously as a screening tool to support early prioritization, especially for substances present at low concentrations with known or tentatively assigned structures. This can help identify findings that warrant targeted confirmation, toxicological testing, and possible inclusion in future monitoring programs.

In animal-derived foods, where a limited number of widely consumed products may contribute disproportionately to dietary exposure, such integration is particularly important for translating analytical findings into meaningful risk-based decisions (31). Within a food safety risk analysis framework, prioritized signals can guide public health actions, including targeted confirmation, expanded surveillance in relevant food categories, development of routine monitoring methods, and risk communication that distinguishes preliminary screening findings from confirmed hazards. However, analytical detectability does not necessarily imply public health relevance.

In this sense, moving from burden to solutions does not require replacing conventional monitoring; rather, it requires making monitoring more adaptive, interpretable, and closely linked to public health actions.

CONCLUSION

Emerging chemical hazards in animal-derived foods originate not only from what is present in the food but also from our limited ability to detect and interpret them. As contamination sources diversify and transformation processes within animals generate structurally complex derivatives, the boundary between known and unknown hazards becomes increasingly blurred, thereby challenging traditional monitoring frameworks that rely on predefined target lists.

To address this problem, monitoring should not be limited to predefined compounds. High-resolution mass spectrometry and non-targeted screening enable

the detection of a wider range of chemicals, including substances that may be overlooked by routine targeted methods. However, their true value depends on advances in data interpretation, prioritization, and confirmation. Without effective strategies to distinguish meaningful signals from background complexity, expanded detection alone cannot translate into improved risk assessment.

From a public health perspective, the central task is not only to identify a broader range of compounds but also to prioritize those with public health significance. This necessitates the integration of analytical capabilities with the exposure relevance, toxicological significance, and actual food production conditions. Future work should focus on enhancing monitoring frameworks to more effectively link detection with risk assessment and public health responses to emerging chemical hazards in animal-derived foods.

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