

A laboratory setting with several scientists in white coats and safety glasses. One scientist in the foreground is looking at a computer screen displaying a chromatogram with multiple peaks. Another scientist to the right is holding a smartphone and a pen, possibly taking notes. The background shows various pieces of laboratory equipment, including a large ICP-MS machine and shelves filled with test tubes and glassware.

Toxic Heavy Metals in Food: Why Awareness Is Rising

A Comprehensive Literature Review

Executive Summary

Toxic heavy metals in food—including lead, cadmium, arsenic, and mercury—represent an escalating public health concern that has transitioned from a primarily academic and regulatory issue to a matter of significant consumer awareness and market consequence. This comprehensive literature review examines the rising awareness of heavy metal contamination in food systems through multiple dimensions: the scientific documentation of contamination risks, the evolution of regulatory frameworks as awareness indicators, media coverage and testing feedback loops, litigation patterns, and the emergence of consumer expectations for certification and standards.

Drawing from 50+ peer-reviewed studies spanning scientific assessments, risk evaluations, regulatory analyses, consumer perception research, and food safety governance frameworks, this review demonstrates that heavy metal awareness represents a structural shift in food system expectations rather than a transient concern. The evidence indicates that regulation precedes public awareness, testing technologies amplify concern through media coverage, and litigation serves as a visible manifestation of salience. The transition to consumer expectations represents a critical juncture where food standards must evolve to reflect both scientific evidence and market demands for heavy metal certification.

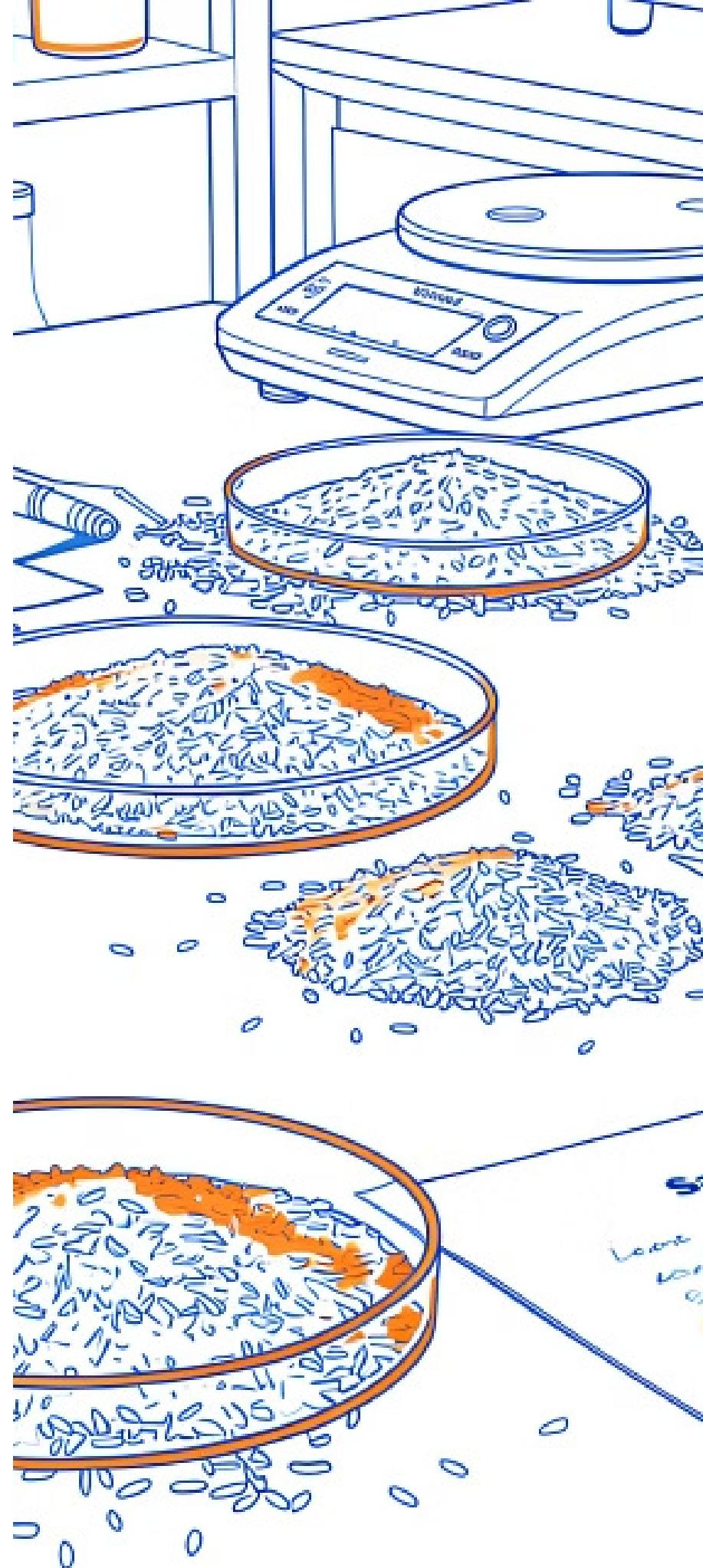
- Keywords:** Heavy metal contamination, food safety, regulatory framework, consumer awareness, risk assessment, certification standards, market expectations

From Academic Risk to Public Issue

The Evolution of Heavy Metal Contamination Recognition

The recognition of toxic heavy metals in food has evolved from a specialized scientific concern into a mainstream public health issue. Early research documenting contamination levels across diverse food categories established the epidemiological foundation for current awareness. Studies measuring toxic elements in commonly consumed foods revealed pervasive contamination that frequently exceeds international safety thresholds. Research on heavy metal accumulation in aquaculture products demonstrated that farmed fish and seafood from Bangladesh, Thailand, and other aquaculture-producing regions often contained arsenic, cadmium, and lead concentrations surpassing FAO permissible levels [1]. Similarly, investigations into rice consumption—a dietary staple for billions globally—found that rice grain contamination with arsenic, cadmium, and lead represents a significant exposure pathway, particularly affecting children in rice-consuming populations [2] [3].

The transition from academic documentation to public awareness occurred as health risk assessments moved beyond merely quantifying contamination to calculating actual health impacts. Standardized methodologies employing Target Hazard Quotient (THQ), Hazard Index (HI), Estimated Daily Intake (EDI), and carcinogenic risk calculations quantified the non-carcinogenic and carcinogenic implications of consumption patterns [4] [5]. These assessments revealed that children face disproportionate risks due to their lower body weight and higher ingestion rates relative to adults, rendering heavy metal exposure a pediatric health concern [6].



Unexpected Contamination Vectors

Research on cassava from mining-affected regions demonstrated Target Hazard Quotient values exceeding 1 for children, with **lead posing health risks of 485.71** for young consumers [4]. The elevation of this issue from academic literature to clinical and public health discourse marked the beginning of broader awareness.

Food categories previously considered safe emerged as unexpected contamination vectors. Soft drinks, breakfast cereals, instant coffee, and dietary supplements—products marketed to all age groups but consumed extensively by vulnerable populations—were found to contain heavy metals requiring health risk assessment [7] [8] [9]. These findings appeared not in specialized toxicology journals alone but began appearing in food science, public health, and eventually mainstream medical literature, signaling the expanding scope of concern beyond agricultural experts and food scientists.

High-Risk Products

- Soft drinks and beverages
- Breakfast cereals
- Instant coffee
- Dietary supplements
- Children's snacks

Regulation as a Leading Indicator of Awareness

Standards Emergence and Tightening

Regulatory frameworks serve as institutional indicators of awareness and concern. The evolution of heavy metal standards in food regulation demonstrates how scientific evidence translates into policy, which then signals to broader stakeholders that contamination is recognized as a significant threat [10]. The European Union's regulatory landscape exemplifies this progression. The original Commission Regulation EC No. 1881/2006 established maximum permissible levels for lead, cadmium, and mercury in various food categories [11]. Subsequent amendments, culminating in the comprehensive Commission Regulation EU 2023/915, progressively lowered tolerance thresholds and expanded the scope of regulated metals and food categories, reflecting accumulated scientific evidence of health risks [11].

01

Scientific Documentation

Research establishes contamination evidence and health risk data

02

Regulatory Response

Agencies establish or tighten maximum permissible levels

03

Public Awareness

Regulations signal to stakeholders that contamination is significant

04

Market Adaptation

Industry implements testing and certification systems

The regulatory response to arsenic contamination illustrates awareness escalation. As research documented inorganic arsenic's carcinogenic properties and its bioavailability through food, regulatory agencies worldwide established—or tightened—arsenic limits. The European Commission set specific limits for arsenic in rice and rice products, and the United States Food and Drug Administration established action levels for arsenic in apple juice and rice cereal [12]. These regulatory decisions followed scientific documentation rather than preceding it, yet they serve as public-facing evidence that toxicity concerns warrant intervention [13].

National regulatory frameworks demonstrate comparable progression. The Russian Federation updated its standards based on harmonization with international requirements, specifically addressing lead and pesticide residue levels, indicating systemic awareness of evolving contamination patterns [13]. Regulatory expansion reflects institutional recognition that heavy metal contamination requires ongoing attention. The recognition that developing countries and marginalized communities face higher contamination exposure due to proximity to industrial sources, inadequate water treatment, and reliance on contaminated irrigation creates regulatory interest in environmental justice dimensions [5] [14].

Certification systems represent regulatory mechanisms that institutionalize awareness. GLOBALG.A.P., ISO 22000, HACCP systems, and organic certification schemes all include heavy metal monitoring and testing protocols, converting scientific evidence into mandatory practices. The proliferation of certification requirements across export markets and premium food segments indicates that regulation has expanded beyond traditional government oversight to encompass market-based quality assurance mechanisms.

Media, Testing, and the Feedback Loop

How Information Amplifies Concern

The relationship between testing technology, media coverage, and consumer awareness represents a feedback mechanism amplifying concern about heavy metals in food. Advances in analytical instrumentation—particularly inductively coupled plasma mass spectrometry (ICP-MS), graphite furnace atomic absorption spectrometry (GFAAS), and high-performance liquid chromatography (HPLC)—enabled detection of increasingly lower concentrations of heavy metals [12]. These technological advances created capacity for extensive testing of food products previously assumed safe. Systematic screening of markets revealed that contamination was more prevalent than previously documented, generating datasets suitable for media reporting and policy attention.



Comprehensive Testing

Researchers conduct systematic screening using advanced methods



Media Coverage

Outlets report findings as accessible consumer risk narratives



Public Demand

Awareness creates demand for further testing and transparency

The mechanism operates through several steps. First, researchers conduct comprehensive testing of food categories using standardized methods, often revealing contamination levels warranting public health attention. Studies measuring multiple heavy metals across diverse food products—cereals, seafood, vegetables, beverages, and infant foods—generated findings of sufficient concern to warrant publication in high-impact journals and media coverage [10] [12]. Second, media outlets report findings, transforming scientific results into accessible narratives emphasizing consumer risk. The particular vulnerability of children to heavy metal exposure—a theme appearing across numerous studies—provides compelling narratives for media coverage [8] [15].

Third, public awareness of testing results and contamination findings creates demand for further testing and transparency. Consumer pressure documented in perception studies demonstrates that awareness of contamination drives expectations for testing and certification [16]. Farmers and consumers in Ghana expressed strong concern about bioaccumulation, long-term health risks, and environmental pollution, influenced by education level and access to information [16]. The feedback amplifies institutional response, creating self-reinforcing awareness escalation that institutional actors cannot ignore [17].

Testing standards and methodologies themselves reflect and reinforce awareness. The development of advanced testing protocols demonstrates the institutionalization of testing in food safety systems and expansion from isolated research to routine monitoring.

Litigation as a Signal of Salience

Legal Accountability and Market Consequences

While direct litigation cases specifically targeting heavy metal contamination in food represent a smaller literature than general food safety litigation, the patterns of legal action in related food contamination domains provide instructive models for understanding how legal consequences amplify awareness and drive market responses. Litigation serves multiple functions in the awareness ecosystem: it translates abstract health risks into concrete economic consequences, creates visibility through public proceedings, and establishes precedent for liability.

Direct Legal Impacts

- Business closure and income loss for affected producers
- Property value destruction from contaminated farmland
- Corporate accountability through litigation seeking damages
- Regulatory intervention triggered by legal proceedings

Preventive Corporate Responses

- Stricter testing and monitoring protocols
- Third-party verification programs
- Supply chain traceability systems
- Enhanced quality assurance measures

The experience with contamination affecting farmland and crops illustrates litigation's role in escalating concern. When farmers discover devastating levels of contamination from agricultural inputs, business closure, income loss, and property value destruction can result—consequences that generate litigation seeking corporate accountability and regulatory intervention. While specific heavy metal cases may be limited in number, the mechanism demonstrates how contamination translating to economic loss creates legal action that forces regulatory agencies and corporate actors to acknowledge systemic problems.

More significantly, the threat of litigation shapes corporate behavior and regulatory response before cases proceed to trial. Manufacturers and suppliers implement stricter heavy metal testing and monitoring protocols to reduce liability exposure. Quality assurance programs emphasizing third-party testing and verification represent defensive legal strategies. The development of supply chain traceability systems and certification verification reflect institutional responses to reduce litigation risk and manage reputational exposure [17].

The psychological effect of litigation patterns amplifies salience beyond actual case frequency. When companies settle product liability cases or face regulatory penalties, media coverage of these consequences reaches consumers and reinforces perception that contamination represents genuine hazard warranting concern. The visibility of legal consequences—financial penalties, product recalls, market access restrictions—demonstrates institutional accountability that elevates public confidence in risk assessment.

Why This Is Not a Passing Trend

Scientific Persistence and Structural Factors

The persistence of heavy metal contamination as a concern reflects underlying structural factors that prevent the issue from resolving through temporary attention cycles. First, the problem exhibits geographic ubiquity and temporal persistence. **Heavy metals are non-biodegradable; once deposited in soil and water systems, they persist indefinitely**, continuing to contaminate food chains [18]. Mining activities, industrial emissions, agricultural practices using contaminated water and fertilizers, and inadequate waste management create ongoing contamination sources [19]. Research on food chains extending from water contamination through soil to maize to cow milk documented persistent transfer mechanisms that reproduce contamination across food systems [20].

Geographic Ubiquity

Non-biodegradable metals persist indefinitely in soil and water systems [18]

Vulnerable Populations

Children face disproportionate exposure risks across multiple studies [21] [5]

Expanding Evidence

New research continually identifies contamination in untested product categories

Regulatory Evolution

Frameworks expand rather than stabilize, addressing multiple metals and populations [12]

Market Mechanisms

Premium segments create sustained consumer interest independent of media cycles

Second, vulnerability populations face disproportionate exposure that generates sustained concern. Children's higher exposure risk—documented across multiple studies demonstrating that estimated daily intake and health risks exceed those for adults [21] [5]—ensures that pediatric health advocates maintain attention to the issue. The recognition that developing countries and marginalized communities face higher contamination exposure due to proximity to industrial sources, inadequate water treatment, and reliance on contaminated irrigation creates ongoing concerns about environmental justice that sustains activism and policy attention.

Third, the scientific evidence base continues expanding rather than reaching closure. New research documenting contamination in previously untested product categories, new evidence of health effects at lower exposure levels, and identification of vulnerable subpopulations maintains scientific attention. The recognition that bioaccumulation and biomagnification affect some metals preferentially, concentrating contamination in certain tissues or at certain trophic levels, ensures that emerging data continually expands understanding [22] [23].

Fourth, regulatory frameworks expand rather than stabilize, indicating institutional recognition that the problem requires intensifying attention. The progression from basic maximum permissible levels to comprehensive regulations addressing multiple metals, multiple food categories, vulnerable populations, and cumulative risk reflects the understanding that simple threshold-based regulation proves insufficient [12]. The development of more sophisticated risk assessment methodologies incorporating uncertainty analysis, Monte Carlo simulation, and probabilistic approaches demonstrates that the field moves toward greater precision rather than closure [3] [15].

Fifth, market-driven mechanisms create incentives for sustained attention. The emergence of organic certification, heavy-metal-tested products, and premium food segments demonstrating lower contamination levels creates market niches that sustain consumer interest regardless of regulatory attention. Businesses implementing advanced testing and offering transparency about heavy metal results differentiate themselves in competitive markets. This market mechanism ensures that heavy metal awareness persists as a consumer preference that influences purchasing decisions independent of media cycles.

Implications for Food Standards and Heavy Metal Certification

Emerging Market Requirements

The rising awareness of heavy metal contamination generates pressure for evolved food standards and certification systems that explicitly address these contaminants. Current regulatory frameworks, while increasingly comprehensive, remain insufficient for emerging market expectations. The European Union's regulatory approach, considered among the world's most stringent, establishes maximum levels for lead, cadmium, arsenic, and mercury in specific food categories, yet gaps remain [11]. Products consumed extensively by children—breakfast cereals, infant formula, and ready-to-eat foods—face regulatory pressure for even lower thresholds as awareness of pediatric vulnerability increases.

Certification systems are evolving to incorporate heavy metal testing as standard requirements rather than exceptional measures. For food producers seeking access to premium markets and export channels, heavy metal certification becomes a prerequisite rather than a value-added distinction. The emergence of third-party testing and verification programs reflects market demand for independent assurance.

Regulatory Gaps

Current frameworks insufficient for emerging market expectations despite EU stringency [11]

Certification Evolution

Heavy metal testing becoming standard requirement for premium market access

Harmonization Challenges

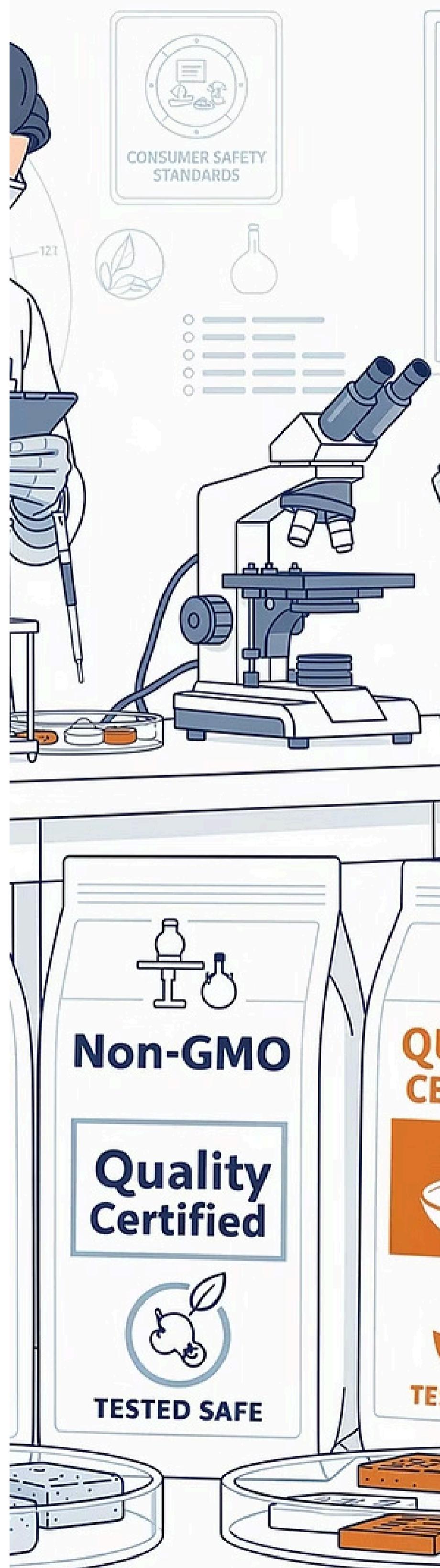
Variation between EU, US, and national frameworks creates complexity [24]

Database Integration

Heavy metal data needed in standard food composition databases for routine access

Standardization challenges emerge as different regulatory jurisdictions maintain varying thresholds and testing methodologies. The variation between EU, US, and national regulatory frameworks for heavy metals creates complexity for multinational food companies and exporters [24]. Harmonization efforts attempt to reconcile these differences, yet resistance from countries with less stringent standards, agricultural sectors facing compliance challenges, and industries seeking regulatory stability delays full harmonization. This regulatory fragmentation itself becomes a market signal that standards continue evolving, sustaining awareness that current practices may not represent endpoints.

The role of food composition databases and dietary guidance in standardizing heavy metal awareness represents an emerging consideration. The integration of heavy metal data into standard food composition databases used by nutritionists, public health professionals, and consumers would institutionalize awareness by making contamination information routinely accessible.



A Transitional Moment from Awareness to Consumer Expectation

Market Transformation

The current moment represents a transition from awareness as information to awareness as market expectation and consumer preference. Initial stages of awareness involve information dissemination—learning that contamination exists and poses health risks. The current stage involves the transformation of awareness into purchasing criteria and market demand that influences product selection, price premiums, and supply chain requirements.



This streamlined progression demonstrates how awareness evolves from passive knowledge to active market force.

Evidence of this transition appears in multiple domains. Consumers express willingness to pay premiums for products certified as low in heavy metals or grown without contaminated inputs [16]. Farmers encounter market pressure to adopt practices reducing heavy metal accumulation—investing in alternative water sources for irrigation, avoiding contaminated fertilizers, and implementing testing protocols that verify product safety [19]. Retailers increasingly position heavy metal safety as a competitive advantage, with some specialty retailers explicitly highlighting low-heavy-metal produce and seafood.

Consumer Behaviors

- Willingness to pay premiums for certified products [16]
- Demand for labeling specifying heavy metal testing
- Preference for transparency and traceability
- Selection based on certification information

Market Responses

- Premium segments emphasizing heavy metal certification
- Organic products positioning as lower-risk alternatives
- Direct-to-consumer sales offering traceability
- Retailers using safety as competitive advantage

The transition manifests in labeling demands. Understanding of packaging information and ingredient transparency influences purchasing choices. As awareness of heavy metal risks increases, consumers demand labeling that specifies heavy metal testing or certifies absence of contamination above specific thresholds. This demand creates market incentives for producers to obtain testing and place results on labels or marketing materials.

Market segmentation accelerates during this transitional phase. Premium food segments emphasizing health and safety differentiate through heavy metal certification. Organic products, by claiming to avoid synthetic inputs associated with contamination, position themselves as lower-risk alternatives. Direct-to-consumer sales, local food systems, and supply chain transparency initiatives capitalize on consumer concerns by offering traceability and testing information unavailable through conventional retail channels.

The geographic variation in market development reflects differential awareness levels. Developed nations with higher consumer health consciousness and purchasing power exhibit a more rapid transition to market expectations. Developing regions demonstrate emerging but accelerating market segments among affluent consumers, while mass market products maintain conventional standards. This geographic variation suggests market transformation will progress gradually but persistently across global food systems.

Conclusion

Institutionalization of Heavy Metal Awareness as Durable System Change

The rising awareness of toxic heavy metals in food represents more than a temporary public health concern or media-driven panic. Rather, it reflects institutionalization of awareness across multiple systems—scientific research communities, regulatory agencies, certification organizations, food industry actors, litigation processes, and consumer markets—that creates self-reinforcing mechanisms sustaining attention regardless of transient factors. The academic documentation of contamination established the evidential foundation. Regulatory frameworks translated science into institutional requirements. Media coverage and testing created feedback mechanisms amplifying concern. Market mechanisms converted awareness into consumer preference. **These systems interact synergistically, preventing the issue from fading despite competing demands for attention.**



The transition toward consumer expectation represents the consolidation phase in which awareness becomes embedded in purchasing criteria, product development, and supply chain requirements. This phase promises to be more durable than awareness based solely on information, as market mechanisms create permanent incentives for attention to heavy metal contamination. Producers maintaining awareness through quality assurance systems, consumers exercising preference through purchasing choices, and retailers using market differentiation through heavy metal certification create structural reasons for sustained focus.

Food standards and certification systems must evolve to accommodate emerging market expectations while maintaining scientific rigor in establishing safety thresholds. The current moment offers an opportunity to harmonize global standards, integrate heavy metal data into routine food composition databases, and develop transparent testing and labeling systems that empower consumers while protecting vulnerable populations. The evidence suggests that failure to meet these emerging expectations will not eliminate the issue but rather cede market leadership to producers offering greater transparency and safety assurance.

The trajectory from academic documentation through regulatory evolution to consumer expectation suggests that awareness of heavy metals in food will intensify rather than diminish in coming decades. The persistence of contamination sources, the disproportionate vulnerability of developing regions and pediatric populations, the expansion of scientific evidence identifying new contamination pathways and health effects, and the market mechanisms now converting awareness into purchasing behavior all point toward sustained and deepening focus on this issue. Food safety systems, corporate strategies, and consumer choices will increasingly reflect integration of heavy metal contamination concerns into routine decision-making rather than treating the issue as exceptional or temporary.

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