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Cinnamomum Adulteration: Scope, Detection Methodologies, Health Implications, and Regulatory Challenges A Global Review

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Abstract

Cinnamon is among the world's most economically significant spices, yet the genus Cinnamomum is one of the most frequently adulterated food commodity groups due to price differentials between premium Ceylon cinnamon and Cassia varieties, compounded by the visual indistinguishability of powdered products. This review—Cinnamomum Adulteration: Scope, Detection Methodologies, Health Implications, and Regulatory Challenges A Global Review—provides a comprehensive analysis of Cinnamomum adulteration encompassing botanical differentiation, adulteration typology, detection methodologies, health implications, and global regulatory architecture, with special attention to C. burmannii's ambiguous regulatory status. It synthesizes peer-reviewed literature, regulatory documents, and international standards from 2004 to 2025, systematically analyzing detection platforms spanning classical, spectroscopic, chromatographic, and molecular DNA-based methods. The 2025 EU JRC study analyzing 104 commercial samples found that over 66% failed quality standards or exceeded coumarin limits, with species substitution confirmed in 9% of Ceylon-labeled products. Advanced detection methods include Bar-HRM, qPCR, NIR, EDXRF, and HPLC-DAD, enabling comprehensive authentication across multiple adulteration types. Health risks center on coumarin hepatotoxicity (Cassia: up to 12.18 mg/g; C. verum: 0.005–0.090 mg/g), heavy metal toxicity, and allergen mislabeling. Cinnamomum adulteration requires a species-specific, risk-based authentication framework supported by regulatory harmonization among ISO, Codex Alimentarius, and national agencies. The Codex Alimentarius Commission's 2024 decision to initiate cinnamon standard development creates a policy window for action. Future priorities include harmonized coumarin limits, mandatory species labeling, heavy metal surveillance, and capacity building for molecular authentication in producing countries.

INTRODUCTION

Cinnamon is one of the oldest documented spices in human civilization, with records of its use in ancient Egypt, China, and the Mediterranean world predating the Common Era. In contemporary trade, the genus Cinnamomum encompasses approximately 250 species, of which a handful dominate international commerce: C. verum (Ceylon or true cinnamon), C. aromaticum (Chinese cassia), C. burmannii (Indonesian cassia), C. loureiroi (Vietnamese cassia), and C. tamala (Indian bay leaf cinnamon). The dried inner bark of these trees—consumed as quills, chips, or powder—constitutes the traded commodity.

The economic stakes are substantial. Ceylon cinnamon commands a market price roughly double that of Cassia varieties, driven by its more delicate flavor profile, lower coumarin content, and favored status in pharmaceutical and nutraceutical applications. Vietnam has emerged as the EU's leading cinnamon supplier by volume in 2023, while Sri

Lanka remains the defining origin for Ceylon cinnamon. The combination of rising global demand, interspecies price differentials, and the visual indistinguishability of powdered products creates a structural incentive for fraud that regulators and analytical scientists continue to struggle to contain.

The problem is not trivial in scale. A landmark 2025 study by the European Commission's Joint Research Centre (JRC), analyzing 104 commercially available cinnamon samples from ten EU countries, found that over 66% failed to meet international quality standards, were non-compliant with EU food safety legislation, were suspected of fraud, or exceeded legal coumarin limits. Substitution of Ceylon cinnamon with Cassia was confirmed in approximately 9% of Ceylon-labeled samples; however, this species substitution was not the most frequently encountered issue. More pervasive problems included quality non-compliance, coumarin overexposure, root-bark substitution, and contamination with extraneous botanical material.

Cinnamon authentication is further shaped by an asymmetrical global supply chain. Ceylon cinnamon is primarily associated with Sri Lanka, while Chinese, Indonesian, and Vietnamese Cassia species dominate different commodity channels depending on trade routes and price points. Importing regions—particularly the EU and North America—increasingly bear the regulatory burden of detecting identity fraud after products have already entered complex distribution networks, often with insufficient documentation of botanical origin. The consequence is that authentication failures are identified downstream, at substantial cost to consumers, enforcement agencies, and legitimate producers alike.

Among the major commercial species, C. burmannii occupies a particularly important position as the highest-volume cinnamon commodity in global trade. Its dual regulatory status—legitimate Cassia-type cinnamon in many markets, but a potential adulterant when substituted for products labeled as Ceylon cinnamon—makes it central to the authentication challenge. It is also pharmacologically significant in its own right, which complicates overly simplistic framings of Cassia species as inherently inferior or fraudulent.

This review is organized to address the problem at multiple analytical levels: botanical identity, chemical composition, adulteration typology, detection methodologies, health consequences, and regulatory architecture, including the evolving role of the Codex Alimentarius in global spice governance. The goal is to provide an integrated account useful to pharmaceutical scientists, food safety regulators, analytical chemists, and supply chain practitioners across producing and importing countries.

Several studies have significantly advanced Cinnamomum authentication, including Peiris et al. (2025), who used Bar-HRM analysis for species discrimination; Ghidotti et al. (2023) who employed EDXRF elemental profiling for detecting Ceylon cinnamon adulteration; and the EU JRC (2025) landmark study revealing over 66% non-compliance across 104 commercial samples. Additional research has demonstrated non-targeted HPLC-DAD fingerprinting with chemometrics for quantifying adulteration, NIR and MIR spectroscopy for detecting bulking agents, and comprehensive reviews of C. burmannii's pharmacological significance ("Ensuring Authenticity of Cinnamon Powder: Detection of Adulteration with Coffee Husk and Corn Meal Using NIR, MIR Spectroscopy and Chemometrics," 2024). The regulatory landscape has evolved with the Codex Alimentarius initiating cinnamon standard development, EFSA establishing a tolerable daily intake (TDI)

for coumarin, and ISO providing physicochemical specifications. Despite these contributions, a comprehensive review systematically integrating botanical differentiation, detection methodologies, health implications, and regulatory frameworks remains lacking, as previous studies have focused on isolated aspects rather than offering an integrated global perspective. The rapid evolution of detection technologies and concurrent regulatory developments create an urgent need for synthesis to inform policy and practice, particularly given the ambiguous regulatory status of C. burmannii and converging factors including the EU JRC findings, US FDA lead contamination alerts, and growing consumer demand for authentic products.

This review aims to provide an integrated analysis across five dimensions: botanical and chemical differentiation, adulteration typology, detection methodologies, health implications, and regulatory architecture. It offers theoretical contributions by synthesizing disparate research streams and advancing food fraud theory, as well as practical benefits for pharmaceutical scientists, food safety regulators, analytical chemists, supply chain practitioners, producer countries, international standard-setting bodies, and consumers by providing guidance on species selection, surveillance strategies, methodological selection, quality assurance, infrastructure development, standard harmonization, and informed decision-making.

Botanical Taxonomy and Commercial Species

1. The Cinnamomum Genus

The genus Cinnamomum belongs to the family Lauraceae, order Laurales. Members are predominantly evergreen trees and shrubs distributed across tropical and subtropical Asia, Australasia, and the Americas. The bark, leaves, flower buds, and roots all possess characteristic aromatic properties attributable to complex mixtures of phenylpropanoids, terpenoids, and phenolic compounds. The four species of primary commercial significance are morphologically similar — particularly in bark cross-section and powder form — yet differ substantially in phytochemical composition, sensory profile, coumarin content, and market value.

2. Cinnamomum verum (Ceylon Cinnamon)

C. verum J. Presl (synonymous with C. zeylanicum Blume) is indigenous to Sri Lanka and the Malabar Coast of India. It is characterized by thin, papery quills with multiple layers of inner bark that roll concentrically within one another, a light tan coloration, and a delicate, sweet-spicy aroma attributable to a high content of trans-cinnamaldehyde (typically 55–90% of essential oil) with minimal coumarin (0.005–0.090 mg/g). It is the cinnamon of preference in Western herbal traditions, pharmaceutical-grade preparations, and regulatory frameworks that set coumarin maximum limits in foodstuffs.

3. Cinnamomum aromaticum (Chinese Cassia)

C. aromaticum Nees (synonym C. cassia (Nees) ex Blume) is native to Myanmar and cultivated extensively in southern China. It produces harder, thicker, single-rolled quills of a reddish-brown hue. Its essential oil is dominated by cinnamaldehyde but contains markedly higher coumarin, with measured concentrations ranging from hundreds to over 7,000 mg/kg in some market samples. The coumarin content of this species constitutes the primary regulatory concern in importing jurisdictions.

4. Cinnamomum burmannii (Indonesian Cassia)

C. burmannii ("Standardization of Cinnamomum Burmannii Nees Ex Bl. Bark from Five Areas of Indonesia," 2020) Blume — also known as Batavia cassia, Padang cassia, or Korintje cinnamon — is the dominant Cinnamomum species by trade volume globally. Cultivated in tropical Southeast Asia, it constitutes the dominant cinnamon variety in the North American market. Its bark is characterized by thick, hard single rolls with a dark reddish-brown surface, a pungent sweet-spicy flavour, and an essential oil profile comprising cinnamaldehyde, eugenol, and coumarin. Its pharmacological properties — anti-inflammatory, antidiabetic, antimicrobial, and antioxidant activities — have been documented in the peer-reviewed literature. The species occupies an ambiguous regulatory position: legitimate Cassia-type cinnamon when correctly labelled; adulterant when substituted for products marketed as Ceylon cinnamon.

5. Cinnamomum loureiroi (Vietnamese Cassia)

C. loureiroi Nees is the Vietnamese species, prized for its intensely aromatic bark with high cinnamaldehyde content, and is increasingly prominent in EU import statistics. Like other Cassia types, it contains significant coumarin and shares the core authentication challenge of all Cassia species: correct labelling and prevention of species substitution fraud.

Table 1. Comparative Overview of Commercially Significant Cinnamomum Species

Species	Common Name	Primary Origin	Quill Type	Coumarin (mg/g)	Global Market Role
C. verum	Ceylon / True cinnamon	Sri Lanka	Thin, multi-layered, pale tan	0.005–0.090	Premium; ~2× price of Cassia
C. aromaticum	Chinese cassia	Myanmar / China	Thick, single-rolled, reddish-brown	1.0–12.18	Commodity; significant EU imports
C. burmannii	Indonesian cassia (Korintje)	Indonesia	Thick, hard, dark reddish-brown	~1.0–5.0	Highest volume globally; dominant in North America
C. loureiroi	Vietnamese cassia	Vietnam	Thick, rough-textured	~0.5–3.0	Largest EU supplier by volume (2023)

Source: Compiled from Peiris et al. (2025), Ghidotti et al. (2023, EU JRC (2025), and Handayani et al. (2024)

Patterns and Typology of Cinnamomum Adulteration

1. Species Substitution

The most recognized and economically motivated form of adulteration is the complete or partial substitution of C. verum with one or more Cassia species. In powdered form, morphological differentiation is effectively impossible by visual inspection, and Cassia cinnamon's stronger flavour may be perceived by consumers as an indicator of quality rather than species difference. The 2025 EU JRC study confirmed species substitution in 9 percent of Ceylon-labelled products — a figure that likely underestimates true prevalence given the diversity of labelling conventions across jurisdictions.

2. Intra-Species Part Substitution

A less visible but more prevalent form of fraud involves substitution of cortex bark (the commercially valorized inner bark) with root bark, stem bark, or leaf material from the same

species. Root bark contains significantly higher camphor concentrations and lower cinnamaldehyde content, reducing product quality while maintaining species identity. The 2025 EU study identified six samples with elevated camphor and inorganic elements (Al, Si, Ti, Cr, Fe, Zr) consistent with root material or processing contamination. This fraud is particularly difficult to detect by species-specific molecular assays, which will return a correct species match regardless of which plant part was used.

3. Extraneous Bulking Agents

Market surveys have documented adulteration of cinnamon powder with a wide range of extraneous botanical and non-botanical materials: coffee husk, cornmeal, wheat flour, sawdust, starch, and other low-cost plant powders. Detection of allergenic species — onion, fenugreek, white mustard — by quantitative PCR in commercial cinnamon samples has been reported in recent studies. These adulterants may be present in small quantities that escape organoleptic detection but can cause allergic reactions in sensitized individuals and constitute clear violations of food labelling law in jurisdictions that mandate declaration of allergens (Behr, 2024).

4. Heavy Metal Contamination

An emerging concern, distinct from botanical adulteration but often co-occurring in substandard supply chains, is heavy metal contamination. The U.S. FDA issued public health alerts in 2024 regarding elevated lead levels in commercially available ground cinnamon, with some samples posing acute risk to children. The 2023–2024 U.S. apple puree baby food recall was directly linked to cinnamon adulterated with lead chromate. Chromium levels up to 20 mg/kg have been detected in European market samples. Unlike coumarin, chromium is not currently regulated in the EU, representing a regulatory gap. Such contamination may arise from soil geochemistry, processing equipment, or intentional addition of chromate compounds to enhance coloration (Muhammad & Dewettinck, 2017).

5. Fungal Contamination

A further category of adulteration-adjacent concern is mycological contamination, particularly by Aspergillus flavus, which produces aflatoxins with hepatotoxic and carcinogenic potential. This has been documented in cinnamon export products and presents a serious public health and trade compliance risk. A 2025 molecular study using Barcode High-Resolution Melting (Bar-HRM) analysis successfully detected spiked-in A. flavus DNA in cinnamon admixtures, demonstrating that modern molecular platforms can simultaneously authenticate species identity and flag mycological contamination — a significant advantage over sequential single-purpose assays (Administration, 2024).

METHOD

Classical and Organoleptic Methods

Traditional quality assessment of cinnamon relied primarily on sensory evaluation, including visual inspection of color, quill morphology, texture, and olfactory and taste characteristics. While accessible, these approaches lacked the sensitivity and specificity required for detecting adulteration in powdered products or partial substitutions. Microscopic examination of cellular structures provided additional discriminatory value in less processed samples, but its effectiveness declined significantly as particle size decreased, particularly in finely ground powders where diagnostic features became difficult to distinguish.

International standards such as ISO 6539 for Ceylon cinnamon and ISO 6538 for Cassia species established physico-chemical benchmarks, including moisture content, essential oil content, and ash levels. However, these parameters were insufficient for reliably detecting interspecies substitution or the broader range of adulterants reported in contemporary surveillance studies.

Chromatographic Methods

1. Gas Chromatography – Mass Spectrometry (GC-MS)

GC-MS of cinnamon essential oils and volatile fractions provides a rich chemotypic fingerprint enabling discrimination of Cinnamomum species. Key markers include: cinnamaldehyde (dominant in all commercial species), eugenol (higher in C. verum), coumarin (elevated in Cassia species), and camphor (indicative of root bark substitution). Head Space-GC-MS is particularly valuable for volatile profiling without extensive sample preparation. The 2025 EU JRC study employed HS-GC-MS as one of four orthogonal methods in its multi-analyte authentication framework.

2. HPLC-DAD and HPLC-MS

High-performance liquid chromatography with diode array detection (HPLC-DAD) enables targeted quantification of marker compounds and, when combined with chemometric modelling, non-targeted fingerprinting. A 2024 study demonstrated that non-targeted HPLC-DAD fingerprints combined with partial least squares (PLS) regression could identify and quantify Ceylon cinnamon adulteration across multiple fraud scenarios, with R^2 exceeding 0.988 and RMSEV below 13 percent. Coumarin, eugenol, cinnamaldehyde, and cinnamic acid function as complementary biomarkers whose relative ratios differentiate species reliably when assessed in combination.

Spectroscopic Methods

1. Near-Infrared (NIR) Spectroscopy

NIR spectroscopy has emerged as one of the most promising tools for routine cinnamon authentication due to its rapidity, non-destructive character, minimal sample preparation, and compatibility with field deployment. Multivariate chemometric algorithms — PLS regression, DD-SIMCA, MCR-ALS — applied to NIR spectra can authenticate species identity, identify adulterants (Cassia species, clove, black pepper, coffee husk, cornmeal), and quantify adulterant concentrations. NIR is particularly well-suited as a screening tool in supply chain contexts, where speed and deployability take priority over absolute quantification accuracy.

2. Mid-Infrared (FT-IR) Spectroscopy

Fourier-transform infrared spectroscopy in the mid-infrared range (400–4000 cm^{-1}) provides complementary structural information to NIR. FT-IR fingerprinting with orthogonal signal correction (OSC) combined with detrending preprocessing has achieved prediction coefficients (R^2p) between 0.900 and 0.981 for quantifying adulteration levels. FT-IR is suitable as an in-supply-chain screening method providing accurate, rapid results without extensive sample preparation, and has been validated across multiple independent studies.

3. Energy-Dispersive X-Ray Fluorescence (EDXRF)

EDXRF provides elemental profiles (macro- and microelements) that serve as geographical and species indicators. A 2023 study demonstrated that EDXRF elemental profiling for 36 elements in 52 commercial cinnamon samples, combined with multivariate

analyses, effectively screened for Ceylon cinnamon adulteration. EDXRF is particularly relevant for detecting root bark substitution via elevated Al, Si, Ti, Cr, Fe, and Zr signatures, and for heavy metal surveillance.

Molecular DNA-Based Methods

1. DNA Barcoding and Bar-HRM

DNA barcoding exploits species-specific sequence variation in standardized genomic regions to provide unambiguous botanical identity. Chloroplast gene regions (rbcL, trnH-psbA, matK, trnL, trnL-trnF) and the nuclear ITS2 region have been evaluated for Cinnamomum discrimination. A 2025 study by Peiris et al. identified trnH-psbA as the most discriminating locus for resolving all four major commercial species from one another. Barcode High-Resolution Melting (Bar-HRM) analysis — combining DNA barcoding with melting curve analysis of amplicons enabled simultaneous species authentication and detection of Aspergillus flavus fungal contamination in a single assay. This multiplexing capacity is a significant advance over sequential or single-purpose approaches.

2. Quantitative Real-Time PCR (qPCR)

Quantitative PCR using species-specific primers enables both qualitative detection and proportional quantification of adulteration. Robust validated qPCR panels for major spice adulteration scenarios are now available in the literature. The EU JRC employed q-PCR as one of four orthogonal methods, successfully detecting rice DNA in one sample and flagging six others for extraneous species (onion, fenugreek, white mustard). Mini-barcoding combined with qPCR reduces amplicon size to improve performance on processed, degraded-DNA matrices typical of commercial powders.

Emerging Analytical Platforms

Machine learning-assisted chemometrics applied to NIR and FT-IR spectral data have shown classification accuracy that matches or exceeds conventional PLS-DA, with the additional advantage of detecting non-linear spectral patterns associated with novel adulterants not included in training sets. Hyperspectral imaging enables spatial mapping of adulterant distribution in powder matrices. Third-generation sequencing platforms (Oxford Nanopore) enable metagenomics-style profiling, identifying not only the dominant plant species but also fungal contaminants and trace botanical adulterants in a single sequencing run. Digital traceability systems blockchain-linked IoT are being explored for supply chain provenance recording. However, digital traceability cannot substitute for analytical verification; it can only preserve the integrity of data once reliable testing has been performed. The value of such systems depends entirely on the quality of the authentication data they record and the enforcement capacity that acts on them.

Table 2. Summary of Detection Methods for Cinnamomum Adulteration

Method	Target Analyte	Sensitivity	Deployability	Best Application
Organoleptic / Microscopy	Morphological markers	Low	Field; low cost	Initial screening (sticks only)
GC-MS / HS-GC-MS	Volatiles: coumarin, cinnamaldehyde, camphor	High	Lab-based	Volatile profiling; coumarin quantification

Method	Target Analyte	Sensitivity	Deployability	Best Application
HPLC-DAD / HPLC-MS	Marker compound fingerprints	High	Lab-based	Targeted and non-targeted fingerprinting
NIR Spectroscopy	Molecular functional groups	Moderate–High	Field deployable	Rapid screening; adulterant quantification
FT-IR Spectroscopy	Mid-IR functional groups	Moderate–High	Lab / near-field	Rapid screening; quantification
EDXRF	Elemental profiles (36 elements)	High	Lab-based	Geographical origin; root bark; heavy metals
DNA Barcoding / Bar-HRM	Species-specific DNA	Very high	Laboratory	Definitive species authentication
qPCR	Species / contaminant DNA	Very high	Laboratory	Quantitative multi-target screening
Nanopore Sequencing	Metagenomics: all species + fungi	Very high	Lab (emerging)	Research; comprehensive profiling

Source: Compiled from Peiris et al. (2025), Ghidotti et al. (2023), EU JRC (2025), and literature review

RESULTS AND DISCUSSION

Health Implications

From a global food safety perspective, Cinnamomum adulteration sits at the intersection of economically motivated fraud, chemical contaminant exposure, allergen mislabelling, and botanical identity deception. Each dimension carries a distinct risk profile, demands different analytical responses, and falls under different regulatory authorities — a fragmentation that itself constitutes a governance challenge.

1. Coumarin Hepatotoxicity

The primary and best-documented health risk associated with Cinnamomum adulteration is hepatotoxicity from coumarin exposure. Coumarin (2H-chromen-2-one) is present at trace levels in C. verum (0.005–0.090 mg/g) but at substantially higher concentrations in all Cassia species, with C. aromaticum and C. burmannii reaching up to 12.18 mg/g. The European Food Safety Authority (EFSA) has established a Tolerable Daily Intake (TDI) of 0.1 mg per kilogram of body weight per day. For a 10 kg child, this translates to a TDI of 1 mg/day — a threshold easily exceeded by regular consumption of cassia-rich foods. The 2025 EU JRC study found that 29.8 percent of cassia samples posed potential coumarin risk to children under 10 (European Parliament Resolution of 14 January 2024 on the Food Crises, Fraud in the Food Chain and Control Thereof (2023/2008(INI)), 2024).

The risk is compounded by consumer misperception that all cinnamon is pharmacologically equivalent. Individuals deliberately consuming cinnamon for documented glycaemic and anti-inflammatory properties — a growing nutraceutical practice globally — are at particular risk if their product is unlabelled Cassia or adulterated Ceylon. Hepatotoxicity case reports linked to cinnamon supplement consumption have been published across several clinical jurisdictions.

2. Heavy Metal Toxicity

The 2023–2024 US baby food scandal, in which cinnamon adulterated with lead chromate contaminated millions of units of apple puree, demonstrated that heavy metal risks in cinnamon can reach acute and population-level severity. Lead toxicity in children causes

irreversible neurodevelopmental impairment; there is no established safe threshold. Chromium, detected at up to 20 mg/kg in European market samples, is not currently regulated in the EU under a specific maximum level for spices, representing a gap in global food safety governance that remains unresolved.

3. Allergen Mislabelling

Detection of undeclared allergenic species — mustard, fenugreek, onion — in commercial cinnamon by qPCR constitutes both a safety risk and a regulatory violation. Mustard is a declared allergen under EU food labelling regulation; its undeclared presence in cinnamon is a legal infringement in addition to a health concern. The low-level nature of such contamination means that allergen risk may not be reliably captured by chemical methods alone, reinforcing the necessity of molecular surveillance as a routine element of spice quality control.

4. Pharmacological Complexity of C. burmannii

C. burmannii should not be reduced analytically to the status of adulterant. Its bark contains cinnamaldehyde, eugenol, coumarin, 2-hydroxy-cinnamaldehyde, and cinnamon polyphenols. Documented pharmacological activities include anti-inflammatory activity via soybean lipoxygenase and hyaluronidase inhibition, insulin-sensitizing effects through modulation of insulin receptor and GLUT4 expression, and antimicrobial, antioxidant, and antitumor properties. The species is the subject of pharmacological patents and clinical investigations. Its coumarin content, while higher than C. verum, requires dose-specific risk assessment rather than categorical exclusion — the same logic applied in the risk-based regulatory frameworks now being developed for Cassia spices globally.

Regulatory Framework and Governance Gaps

1. ISO Standards

The primary international standards governing cinnamon quality are ISO 6539:2014 (Cinnamomum zeylanicum / Ceylon cinnamon specification) and ISO 6538:1997 (Cassia, Chinese, Indonesian, and Vietnamese types). These standards specify physico-chemical parameters — moisture, ash, acid-insoluble ash, essential oil content — but do not address coumarin limits, species-level authentication requirements, or molecular identity testing. The gap between what ISO standards currently certify and what analytical methods can now detect is substantial, and revision is overdue.

2. Codex Alimentarius and Global Spice Governance

The Codex Alimentarius Commission, a joint FAO/WHO body responsible for harmonized international food standards, serves as the primary reference framework for national food safety systems, particularly in countries with limited domestic regulatory infrastructure. National and regional standards for herbs and spices are frequently modelled on or benchmarked against Codex provisions. At its 7th session of the Committee on Spices and Culinary Herbs (Commission, 2024a), the Codex Alimentarius Commission agreed to initiate new standard development work specifically on cinnamon, with the support of electronic working groups. This is a significant development: for the first time, cinnamon is the subject of a dedicated Codex commodity standard process.

The broader Codex architecture relevant to cinnamon adulteration includes: the General Standard for the Labelling of Prepackaged Foods (CODEX STAN 1-1985, revised), which requires accurate species identification; the Codex General Standard for Contaminants and

Toxins in Food and Feed (CODEX STAN 193-1995), which governs maximum levels for heavy metals and mycotoxins; and the Guidelines for the Control of Food Fraud (CAC/GL 101-2023), which provide the normative framework for fraud prevention across the food chain. The 47th session of the Codex Alimentarius Commission (CAC47) advanced maximum levels for lead in dried bark and dried culinary herbs — a provision directly relevant to the cinnamon lead contamination issue that triggered US FDA alerts ("Low-Cost Analytic Method for the Identification of Cinnamon Adulteration," 2020).

The absence of a species-specific Codex standard for cinnamon prior to 2024 has allowed importing jurisdictions and producing countries to operate under divergent frameworks, creating regulatory arbitrage conditions that facilitate fraud. The CCSCH7 decision to initiate cinnamon standard development should be understood as an acknowledgment that the current governance gap is no longer tenable.

3. European Union

The EU has set maximum limits for coumarin in food products under Regulation (EC) No 1334/2008 on food flavourings: 2 mg/kg in most foods, 50 mg/kg in traditional and seasonal baked goods, and 10 mg/kg in breakfast cereals and chewing gum. These limits are calibrated to prevent exceedance of the EFSA TDI of 0.1 mg/kg body weight. The European Parliament resolution of 14 January 2024 on food crises and fraud in the food chain explicitly identified spices as one of the most frequently adulterated food commodity categories, signalling legislative intent for stronger controls. The EU JRC study's findings are expected to inform threshold-setting for Cassia authentication markers and potentially drive revision of coumarin limits applicable to cinnamon as a spice rather than solely as a flavouring (Regulation (EC) No 1334/2008 of the European Parliament and of the Council on Flavourings and Certain Food Ingredients with Flavouring Properties, n.d.).

4. United States

The US FDA does not maintain a specific authentication standard distinguishing Ceylon from Cassia cinnamon. The 2024 public health alert regarding lead contamination in ground cinnamon, and the associated baby food recall, prompted voluntary industry responses but exposed the absence of routine heavy metal surveillance for the spice sector. The GRAS status of cinnamon does not address species-specific coumarin risk, and mandatory species labelling is not currently required. These gaps position the US as a jurisdiction where regulatory reform is most needed.

5. Producer-Country Standards and Export-Oriented Quality Systems

Producer-country standards remain critical because authentication failures often originate upstream, before products enter importing jurisdictions. Export-oriented quality systems should integrate species verification, contaminant surveillance, and batch-level documentation before cinnamon enters global trade networks. Sri Lanka's certification system for Ceylon cinnamon, administered under the Sri Lanka Standards Institution (SLSI), represents a model for geographical indication-linked authentication. Vietnam's rapid growth as an EU supplier has prompted renewed focus on GMP compliance and coumarin measurement at the point of export.

The Indonesian National Standard (SNI) for cinnamon bark addresses physico-chemical specifications for C. burmannii but does not yet incorporate molecular authentication requirements (*Pharmaceutical Applications and Phytochemical Profile of*

Cinnamomum Burmannii, 2012). The Farmakope Herbal Indonesia provides pharmacopoeial quality parameters for pharmaceutical applications of cinnamon. Both instruments serve as examples of producer-country quality infrastructure that, when upgraded to include species-level molecular authentication and contaminant surveillance, can provide the upstream documentation that importing regulators require (Tjandrawinata et al., 2011).

A common structural challenge across producer countries is capacity: robust molecular authentication requires laboratory infrastructure, trained personnel, and validated reference standards that are not uniformly available in major cinnamon-producing regions. International technical cooperation through FAO, WHO, ISO, and regional food safety bodies — is therefore a precondition for the upstream quality verification that global harmonization demands.

A Proposed Risk-Based Global Authentication Framework

The diversity of adulteration types documented in the literature — each with distinct analytical signatures, health risks, and regulatory implications — argues for a structured, risk-stratified approach to cinnamon authentication rather than reliance on any single marker or method. Cinnamon adulteration is most usefully categorized into five problem types, each requiring a specific combination of screening and confirmatory methods, and each pointing toward distinct regulatory interventions.

Table 3. Proposed Risk-Based Global Framework for Cinnamomum Authentication

Problem Type	Illustrative Example	Primary Risk	Recommended Screening	Confirmatory Method	Regulatory Need
Identity substitution	Cassia in Ceylon-labelled product	Consumer deception; coumarin overexposure	NIR / FT-IR chemometrics	DNA barcoding / Bar-HRM / qPCR	Mandatory species labelling; coumarin limits for spice category
Intra-species part substitution	Root bark / stem bark in cortex product	Quality degradation; elevated camphor	EDXRF elemental profile; HS-GC-MS	GC-MS camphor/cinnamaldehyde ratio; HPLC	Bark-part specification in Codex/ISO standards
Extraneous bulking agents	Coffee husk, cornmeal, starch	Fraud; allergen exposure (mustard, fenugreek)	NIR / MIR spectroscopy	Microscopy; allergen-specific qPCR	Adulterant maximum limits; allergen declaration
Heavy metal contamination	Lead chromate; elevated chromium	Acute/chronic toxicity; neurotoxicity in children	EDXRF screening	ICP-MS quantification	Maximum residue levels (lead, chromium) for dried bark and spice powders
Fungal contamination	Aspergillus flavus; aflatoxins	Hepatotoxic and carcinogenic risk	Bar-HRM (multiplex); metabarcoding	Mycotoxin quantification assay	Codex mycotoxin surveillance for spice category

Problem Type	Illustrative Example	Primary Risk	Recommended Screening	Confirmatory Method	Regulatory Need
Regulatory misclassification	Cassia correctly labelled but coumarin exceeds limits	Coumarin overexposure without fraud intent	Coumarin quantification (HPLC/GC-MS)	Regulatory threshold compliance review	Harmonized species-specific coumarin limits globally

Source: Compiled from EU JRC (2025), Codex Alimentarius (2024), EFSA (2004), and literature review

This framework is not exhaustive; novel adulterants will continue to emerge as detection technology improves and economic incentives shift. Its value lies in moving regulatory discussion from reactive problem-identification toward prospective risk stratification. Each problem type can be addressed with existing validated methods; what is lacking is the institutional mandate to apply them systematically at both the producer-country and importing-jurisdiction levels.

Emerging Approaches and Future Directions

Multi-platform orthogonal approaches — combining EDXRF for elemental profiling, HS-GC-MS for volatile markers, qPCR for species identity, and thermogravimetric analysis for adulterant quantification — have already demonstrated superior fraud detection rates relative to any single-method approach. The EU JRC 2025 study required four independent analytical methods to characterize the full range of irregularities present in commercial cinnamon; no single method was adequate. This finding should inform the design of regulatory surveillance protocols globally.

Machine learning-assisted chemometrics represents a second major frontier. Convolutional neural networks and other deep learning architectures applied to NIR or FT-IR spectral data have achieved classification accuracy matching or exceeding conventional PLS-DA, with the additional advantage of learning complex non-linear patterns that correspond to adulterants not represented in training sets. Transfer learning approaches enable models trained on laboratory instruments to be adapted to portable field devices — a critical capability for deployment in supply chain contexts in producing countries.

Third-generation sequencing (Oxford Nanopore) enables metagenomics-style profiling of cinnamon powder samples, identifying not only the dominant plant species but also fungal communities, bacterial populations, and trace botanical adulterants in a single run. While currently laboratory-bound and computationally intensive, the trajectory of sequencing cost reduction suggests that amplicon-free molecular authentication will become routine within a decade.

The pharmaceutical valorization of authenticated Cinnamomum species — particularly the development of standardized extract specifications and clinical evidence for therapeutic applications — provides a commercial rationale for rigorous authentication that extends beyond regulatory compliance. For C. burmannii, this means investing in quality infrastructure that serves both the spice trade and the growing market for botanical pharmaceutical ingredients, creating aligned incentives across regulatory and commercial domains.

CONCLUSION

Cinnamomum adulteration was not a peripheral food safety concern but a structural feature of the global spice market, where taxonomic complexity, supply chain asymmetries, and persistent price differentials created enduring incentives for fraud across multiple dimensions, including species substitution, intra-species part substitution, extraneous bulking agents, heavy metal contamination, and fungal contamination—each requiring different analytical approaches and presenting distinct risk profiles, with no single method or regulatory instrument proving sufficient.

The global cinnamon trade required a species-specific and risk-based authentication framework, as exemplified by C. burmannii's ambiguous status as a legitimate commodity, substituted ingredient, or pharmacologically valuable resource depending on labeling and regulatory context, necessitating authentication systems designed to navigate rather than oversimplify this complexity. The advancement of detection science—Bar-HRM, qPCR, NIR chemometric modeling, EDXRF, and non-targeted HPLC-DAD fingerprinting—provided a robust analytical toolkit for comprehensive authentication. Meanwhile, the Codex Alimentarius Commission's 2024 decision to initiate cinnamon standard development, combined with the EU JRC's empirical demonstration of widespread non-compliance, created a policy window for regulatory action that should not have been left unaddressed.

The principal remaining challenge was institutional: embedding validated analytical methods within regulatory frameworks spanning the full supply chain, from producing-country certification to importing-jurisdiction surveillance. This required sustained coordination among ISO, Codex, national food safety agencies, and the scientific community to develop standards that were both technically robust and operationally implementable across all cinnamon-producing and consuming jurisdictions. Future efforts should prioritize harmonized coumarin limits for spice categories, mandatory species labeling requirements, routine heavy metal surveillance protocols, and capacity building for molecular authentication in producer countries, ensuring that regulatory frameworks keep pace with both advancing analytical capabilities and evolving fraud patterns.

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